METHANOL PRODUCTION FROM EUCALYPTUS WOOD CHIPS

Attachment I

The Florida Eucalyptus Energy Farm Silvicultural Methods and Considerations

April 1982

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METHANOL PRODUCTION FROM
EUCALYPTUS WOOD CHIPS

Working Document 1

The Florida Eucalyptus Energy Farm -
Silvicultural Methods and Considerations

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April 1982

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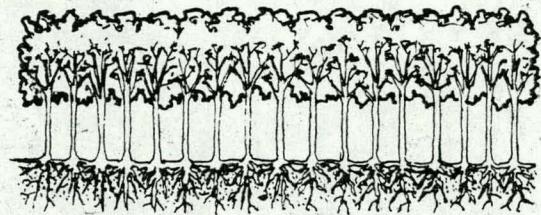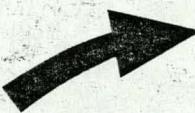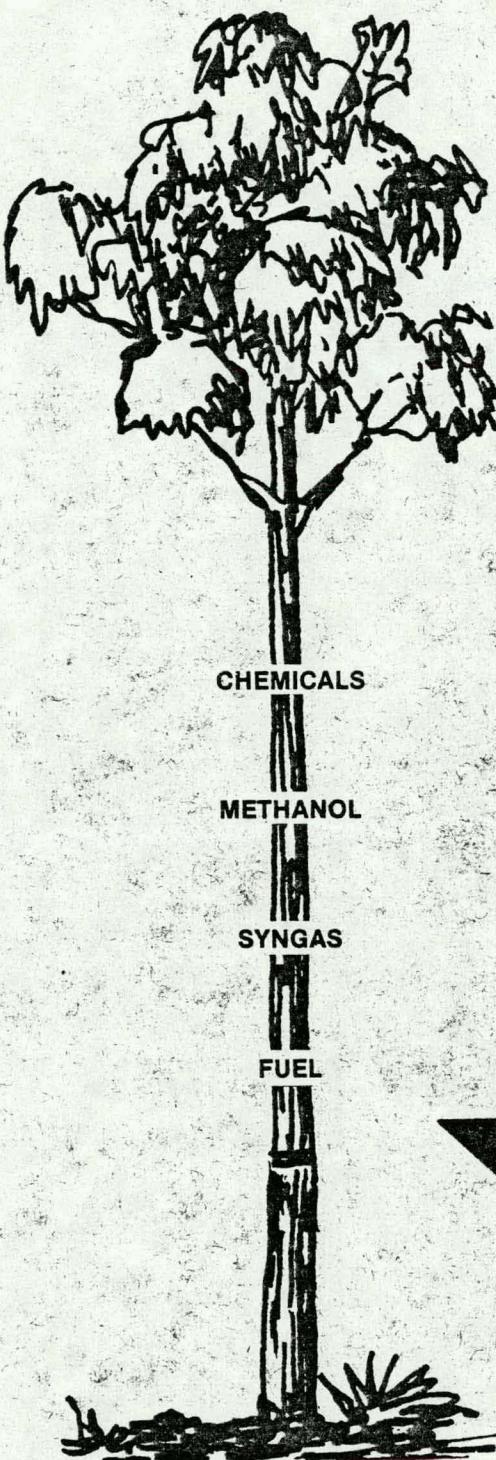
THE FLORIDA EUCALYPTUS ENERGY FARM--

SILVICULTURAL

METHODS AND CONSIDERATIONS

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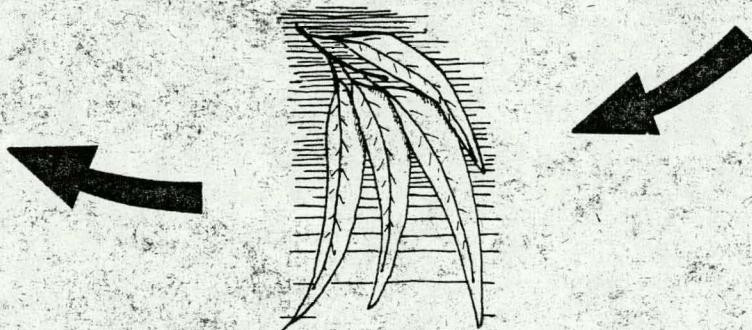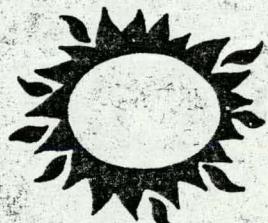
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THE FLORIDA EUCALYPT SILVICULTURAL ENERGY PLANTATION

1.0   INTRODUCTION AND OVERVIEW

Biomass Energy Systems, Inc. (BESI) launched its wood-to-methanol project in 1980 on parallel tracks, assessing the feasibility of both a 100 MGY methanol refinery and a 100,000 acre eucalyptus energy plantation to provide an assured and constant feedstock for the methanol refinery. This document describes in considerable detail the silvicultural matrix within which the nation's first large scale wood energy plantation will be nurtured into reality.

Wood biomass is the oldest energy system employed by man, and wood remains the primary subsistence fuel for much of the world's population. Wood biomass energy is the most environmentally benign of all the large scale energy systems and has an ecological soundness absent from the fossil fuel systems. Fundamentally, it is a solar technology where the leaf is the collector of solar energy which it converts and stores in the form of cellulose via photosynthesis. Wood and its byproducts are converted into energy and conventional fuel equivalents by combustion, gasification, pyrolysis, methanol synthesis, fermentation, or a combination of these processes.

When the OPEC cartel embargoed petroleum shipments to the West in 1974, they triggered a severe change in energy supply and demand balances, intensified by a second crunch in 1979. These changes in the world energy matrix rather suddenly have made wood fuel technology economically competitive with fossil fuels, especially coal and foreign petroleum distillates. Thus, what is new about today's wood biomass technology is the scale of wood fuel production necessary to meet exploding market demands.

An unbiased reviewer of the literature on wood fuels and related topics would conclude there is an explosion of interest and activity which will impact heavily on the wood production industry and economy in the near term. The National Audubon Society projects the use of biomass as fuel to increase from 2.1 to 8.9 quads by the turn of the century, with more than half of the increase attributable to wood. Some 7 million wood stoves have been sold in

the United States over the past three years. The wood products industry
supplies most of its energy from wood, while many other industries are
converting rapidly their boilers from fossil fuels to wood whenever a nearby
wood source assures a dependable fuel supply. Electrical utilities are
converting to wood on a small scale, wood supply and delivery systems being
the primary retardant. The wide interest in methanol as a gasoline additive
and neat fuel has interested a number of companies other than BESI in wood-
to-methanol systems. Indeed, Evergreen Energy Corporation, a consultant to
BESI, is launching a pilot project to convert the Texaco coal gasification
system to a wood feedstock. International Harvester has entered the field
with smaller scale, skid-mounted, wood-to-methanol plants which move to the
wood source rather than transporting the wood to a larger plant. The foreign
market for wood chips has never been better in price or demand. This tip of
the iceberg sketch of expanding demand leaves little room for doubt that highly
productive silvicultural energy plantations have a bright economic future in
a market where demand will far exceed supply for the next several decades.

Bioenergy programs must be designed to exploit the unique regional resource
base. Because of the favorable climate and available lands, Florida south of
Orlando is perhaps the most ideal region within the United States for creating
a new, large scale wood energy system. Forest planting is a land use highly
compatible with the increasing human population which characterizes Florida's
growth. The "organic" appeal of a renewable energy source from trees should
result in public and political support, in contrast to the attitudes toward
strip-mining for example. Environmental protection fervor may reach its zenith
in the Central and South Florida region.

A *eucalyptus* energy plantation, with 871 trees to the acre, each a cloned
replicate of a proven superior parent tree, growing in the Florida sunshine and
rainfall, has a potential yield of hardwood fuel which far exceeds man's
experience with most other natural or planted forests. Some eucalypt species
have an astonishing ability to convert sunlight, water, and nutrients into
stored energy. Individual *E. camaldulensis*, the river redgum in Australia,
planted on mined lands in Polk County have grown to 90 feet in height and 14
inches in diameter in less than seven years! One measured tree added 10% in

volume during the winter months between December 1980 and March 1, 1981; a period of expected slow growth and cold temperatures. Our mensuration studies of this existing stand show a yield of 15 cubic meters per hectare per year, about one-sixth of the estimated potential production of intensively managed, cloned eucalypts planted on better sites under more favorable growing conditions. This ability of eucalypts to rapidly produce such a great volume of wood fuel with virtually no management costs between planting and harvest, makes them the outstanding candidate tree choice wherever the climate and environment permits.

Establishment of additional woodlands is an environmentally desirable alternative to pasture and row crops, particularly on soils marginally suitable for agriculture. The installation of commercial wood fuel plantations is the only economically viable means of increasing forest acreage in the region. Although wood fuel plantations cannot compare with undisturbed native forests in biological values, they are ecologically benign compared to other more intensive land uses in Central and South Florida. In fact, fuel production forests still provide many of the benefits attributable to natural forest ecosystems--soil and water conservation, air quality improvement, climatic control, wildlife habitat, and esthetic and visual enhancement. Furthermore, wood fuel systems offset the adverse environmental effects of alternative fossil fuel systems.

The regional abundance of available and suitable lands is crucial to the development of a large scale, wood fuel system. There are well over a million acres of suitable land that might be converted to an energy plantation use. A commitment by landowners must occur before plantations can be established. Educating landowners to the exploding demand for wood fuel is necessary before they will incur the cost of installing the energy plantation. Most of the present land-uses are of a low intensity/profitability and will be easily displaced by uses with higher economic returns. The dominant present use is for cattle grazing, primarily cow/calf operations, an industry under severe economic stress.

Wood energy plantations will provide their owners with a profitable land use, while generating extensive socio-economic benefits to both the region and the state. Energy plantations are a potentially large and profitable industry for Central and South Florida. They will create substantial employment, service and other income opportunities. Furthermore, biomass plantations are one of the few ways in which the region and Florida can produce extensive amounts of energy. By moving towards a national energy self sufficiency, a Florida wood energy system can make a substantial economic and strategic contribution.

The opportunity is great, the timing is right, and a vigorous wood fuel industry is aborning in Florida. The first large scale silvicultural energy plantation was started in 1982 with the deliberate planting of eucalypts in Polk County as an energy crop. That beginning will expand through the 1980's into hundreds of millions of eucalypts from which the first wood fuel can be harvested in 1988. There will be no halting of this idea whose time has come. From the genetic pool contained in the almost invisible *eucalyptus* seed will spring a massive energy crop that translates into millions of tons of coal not burned in Florida, and millions of barrels of foreign petroleum products not consumed by Floridians. Let the planting begin so the harvest may soon follow to the benefit of Florida and her peoples.

2.0 REVIEW OF PRESENT KNOWLEDGE AND THE LITERATURE

This section identifies and distills the relevent literature we have reviewed, as well as inserting key concepts and extant knowledge not necessarily documented in the literature. Rather than taking a bibliographic approach, we've concentrated on those ideas important to the evolution of our planned approach to the installation, management and harvest of the nation's first large scale *Eucalyptus* energy plantation. The work of others has contributed significantly to our project, for which we are grateful. Many of the ideas first presented here will be discussed more fully in later sections of the document.

2.1 <u>Biomass</u>. While the term biomass has an ecological origin as the total accumulation of biological material on a unit of area, the energy and fuels usage generally applies to agricultural and food wastes, animal wastes, organic municipal refuse, and crops specifically grown for energy uses. Biomass is a significant worldwide energy source and now supplies an estimated two percent of United States energy (Tillman, 1978).

The contribution of biomass to U.S. energy consumption in all its forms in 1979 was about 1.9 quads, the equivalent of about one million barrels of oil per day (Klass, 1981). Various projections for the year 2000 place the biomass share of total U.S. energy consumption at 10 to 20 percent, about one-half of which will be contributed by wood waste and fuelwood. Increasing activity in many countries document that the processing and use of biomass is in transition toward a much larger role in bioenergy (Abelson, 1980).

Triggered by the high cost of petroleum and uncertain supplies, the massive use of biomass as chemical feedstocks is on the near horizon and may prove to be even more practical than a direct energy use (Budiansky, 1980). Other woody biomass uses include raw material supplies for the pulp and paper industry, poles and pilings, plywood, furniture, construction, and a myriad of other applications. Additionally, biomass is widely perceived as an attractive thermoelectric energy source, especially as an alternative to coal and the atom for the production of power (Plotkin, 1980).

The potential for a new technology based on terrestrial biomass systems recently was assessed by the MITRE Corporation (Johnson, et al., 1980), including a comprehensive analysis of methanol production from feedstocks grown on silvicultural farms. A 1979 symposium sponsored by the Division of Petroleum

Chemistry of the American Chemical Society (1981), entitled *Biomass as a Nonfossil Fuel Source*, is a must beginning point for all students of biomass fuels.

2.2 **The Wood Energy Plantation.** Wood fuel is the biomass technology with the greatest near-term capability to displace significant amounts of petroleum consumption. Market forces now favor increased residential heating, electrical generation, and industrial uses of wood fuel systems. The U.S. Forest Service estimates that wood could supply 9.3 quads of energy for the nation annually, or about 12 percent of total consumption (Berger, 1981). With the widespread application of agroforestry technology, we consider this a conservative estimate.

The characteristics and value of wood as an energy resource has been reviewed by Tillman (1978). While there is a great diversity among wood fuels, the better hardwoods have a Btu value comparable to lignite coal ($\pm$ 8500 Btu/lb), with the advantages of low ash, very low sulfur content, and a generally significant reduction in the combined environmental impact of combustion when compared to coal and petroleum. Disadvantages in the use of wood as a fuel are related to the high moisture content of green wood requiring drying or combusting in a mix with fossil fuels, larger volumes required for equivalent heating values, transportation and handling costs, localized supplies, and competition for the wood resource resulting in supply-side shortfalls.

Clearly, expansion of the woody biomass resource base is necessary before substantial increases in wood energy uses can occur without disrupting the existing forest product industry (Berger, 1981). Only in a few localized areas of the United States are waste wood supplies and non-commercial forest stands available in sufficient quantity to sustain major increases in energy uses.

Trees can be successfully grown on marginally productive agricultural lands. Federal and state assistance programs encourage and support tree farming. Recently enacted tax incentive programs benefit tree farmers whose trees provide not only woody biomass, but a number of environmentally beneficial services.

A new agroforestry technology is evolving to mass produce wood fuel at greatly increased rates and yields (Inman, 1977; Mariani, et al., 1978; Yang, et al., 1977; Howlett and Gamache, 1977; Sajdak, et al., 1981 and Ledig, 1981). While showing great promise, these high rate and yield wood energy production systems have been limited to research and development scale projects rather than becoming operational in the private sector.

Wood fuel use in the Third World countries has been highly destructive to natural forest communities due to the lack of silvicultural management practices and natural limitations, such as the infertile, highly leached soils of the tropics or the thin soil of mountain areas. These lands are being deforested for a variety of reasons, including logging, slash and burn agriculture, cattle grazing, cultural expansion, and wood harvesting for fuel. Consequently, extensive research on *fast-growing exotic trees* has progressed considerably in countries like Brazil and the Congo. The major impetus to develop intensive forestry has been to reduce cutting pressure on less accessible native forests and improve energy and timber resources (Barney, 1980). In a drive to reduce the national trade deficit, Brazil has planted large industrial *Eucalyptus* plantations on deforested lands; consequently, wood pulp exports have increased five-fold in three years (Cameron, 1980).

Indeed, agroforestry programs in the Third World have far outstripped efforts in the United States (Spurgeon, 1980). For over three decades, large scale *Eucalyptus* energy plantations have operated in Argentina and Brazil to provide charcoal for steel mills (Mariani, et al., 1978). More recently, Brazil has committed other *Eucalyptus* plantations to gasification and methanol production in pilot plants.

A stable supply of woody biomass is essential for any planned, large-scale commercial use of wood fuel. Silvicultural energy plantations can out-produce conventional forests many fold in their annual yield of wood feedstocks. Over most of the country, these woody biomass production systems must be installed if wood fuel is to realize its potential as an energy resource. For this to happen, the private sector must be convinced that high yield silvicultural plantations are profitable and economically sound investments before a significant installation of plantations can occur.

Sajdak, et al. (1981: 30-31) and Howlett and Gamache (1977:5) have identified a number of advantages of high yield, short rotation silvicultural plantations over conventional managed forests:

1. Higher yields per unit of land area; therefore, less land needed to produce a given amount of biomass.

2. Early amortization of plantation establishment costs.

3. Increased efficiency of most cultural and harvesting operations because of complete mechanization.

4. Reduced plantation regeneration costs after the first rotation.

5. Genetically improved trees can be utilized quickly.

6. The biomass produced will be of more uniform quality.

The use of fast growing hardwoods for maximum biomass production continues to receive major emphasis. Several biomass candidate hardwoods have been tested in the United States, including red alder (DeBell, et al., 1978), cottonwood (Baker and Blackman, 1977), poplar (Zavitkovski, 1979), sycamore (Steinbeck, et al., 1972) and eucalypts (Conde and Rockwood, 1979). Tree improvement programs are producing genetically improved plant materials, with strains being developed for specific soil and site conditions. Gains in yield from advances in genetics and vegetative propagation are being matched by gains from more intensive plantation management.

"Intensive culture", as defined by Dawson (1976), is the "application of several cultural practices to the establishment and management of plantations with the objectives of increasing the quantity and quality of wood produced." This includes the practices of silviculture, pathology, genetics, and economics, collectively. To be economically viable, the *Eucalyptus* energy plantation concept requires a high level of biomass productivity. This argues for a closely spaced, short-rotation silvicultural regimen. However, the degree of silvicultural intensity used in cultivation will have a marked effect on economic feasibility as well as productivity.

Biomass productivity potential under close-spaced, short-rotation conditions is estimated to range from 5-13 dry ton equivalents (DTE) per acre per year with current technology (Inman, 1977; Bungay and Ward, 1977; Fege, et.al., 1979). Berger (1981) reports preliminary yields from optimum research sites of 12 to 30 dry tons per hectare per year, while sites not subject to improved management conditions have shown yields of 5 to 8 dry tons per hectare per year. Other DOE test sites have shown 25 to 90 percent production improvements from first generation genetic selections.

Rapidly growing trees, like those in the *Eucalyptus* stands we have studied, allow for lower establishment costs per acre becase of the lower stocking densities typical of conventional forest plantations, while achieving high yields, short rotations, and regeneration by coppicing. This combination of the above listed advantages of silvicultural energy plantations, the unusual potential of eucalypts to rapidly produce biomass, the favorable Florida climate, and the availability of large acreages of suitable land hold the promise of economical and feasible large scale wood fuel plantations.

2.3 Eucalypts as Candidate Biomass Trees. *Eucalyptus* is one of
the fastest growing tree genera, and is used extensively in reforestation
around the world (Food and Agricultural Organization of the U.N., 1975).
The genus includes between 450 to over 700 species, sub-species and/or
varieties, depending upon the taxonomic source (Krugman, 1974; Mariani, et al.,
1978; Blakely, 1955; and Johnston and Marryatt, 1965). The eucalypts are
broad-leaved evergreen trees within the myrtle family (Myrtaceae) that range
from tall trees bigger than the redwoods to low growing shrubs. While
eucalypts are mainly native to Australia, where they dominate about 95 percent
of the forest areas, they also are native to the Philippines, New Guinea,
Timor, and Indonesia (Hall, Johnston, and Marryatt, 1963; Hall, Johnston, and
Chippendale, 1975).

The adaptability of many species of eucalypts to a wide range of
environmental conditions is well documented (Mariani, et al., 1978; Chippendale,
1973; Hillis and Brown, 1978). In Australia, they occupy deserts and rain
forests, snowy mountain slopes to infertile sands, salt flats to rich loams,
swamps, and virtually all habitat types between the extremes. Members of the
same species often grow under very different environmental conditions (Boden,
1964.

This extreme adaptability and genetic plasticity, as well as the
rapid growth of medium denisty hardwood with excellent fiber characteristics
(Penford and Willis, 1961), has led to their introduction and cultivation over
much of the world with favorable temperatures, including southern Europe, the
Middle East, Africa, India, Pakistan, South America, and North America. World-
wide plantings of *Eucalyptus*, over the past two centuries, probably exceed a
million acres. This is a tree crop with which man has had a great deal of
cumulative silvicultural experience reported in a vast technical literature.
Probably, only the tree genus *Pinus* has been more studied.

Eucalypts were first introduced into California and Hawaii around
1853 (LeBarron, 1962; Penford and Willis, 1961) and Florida about 1878 (Zon
and Briscoe, 1911). Other states with eucalypt plantings include Arizona,
Georgia, Mississippi, Texas, and Washington (Mariani, et al., 1978). About

200 species of eucalypts have been introduced into the United States, mostly as ornamentals (Krugman, 1974). Most recent large scale plantings by commercial interests have been in Florida, where pulp and paper companies have sought a suitable low cost hardwood fiber crop. Since 1977, consideration of eucalypts for biomass plantations has focused on programs in Hawaii, California and Florida.

A compreshensive feasibility study was completed in 1977 which analyzed the biomass potential for candidate tree species under short-rotation plantation regimes in different geographical locations. This study, entitled Silvicultural Biomass Farms, was prepared for the United States Energy Research and Development Administration (now the Department of Energy) to assess the potential of wood biomass as a feedstock for producing energy products (Inman, 1977). Eucalyptus was identified as the primary biomass candidate for Florida (Howlett and Gamache, 1977). Mariani, et al. (1978) expanded on the potential of eucalypts for silvicultural energy plantations. Even in Australia, there has been a gradual evolution from management of the natural eucalypt forest to eucalypt plantations in which productivity has increased enormously through the application of agroforestry techniques developed in Spain, Portugal, and South America (Cromer, 1974). Clearly, the worldwide trend is toward highly productive plantations of eucalypts; mechanized; intensively managed; planted with either genetically select, or cloned trees; all within a reasonable transportation distance of an industrial facility that makes full utilization of the harvested trees.

The most important single criterion for selecting tree candidates is simply the ability to grow rapidly in total biomass (Howlett and Gamache, 1977). This includes characteristics such as: (1) rapid juvenile growth; (2) adaptability to varying site conditions; (3) ease of establishment and regeneration; and (4) freedom from major insect and fungal pests.

A number of eucalypt species are adapted to relatively frost-free locations in the continental U.S. Attacks of insects or disease are uncommon, and no significant amount of damage has been observed in this country (Schory, 1960; Uhr, 1976; Mariani, et al., 1978). In addition, Inman (1977) predicts that a biomass production of 12 dry ton equivalents per acre per year is feasible with existing technology utilizing the close-spacing, short-rotation philosophy.

Bevege (1976) has suggested a practical upper limit dry weight yield of 50 tons/ha/yr for woody crops. Silvicultural expectations of normal yields from well-managed eucalypt plantations of superior trees exceeding 20 dry tons/ha/yr appear reasonable for warm temperate and tropical regions. Yields of clonally propagated *Eucalyptus* at Aracruz Cellulose, S.A. in Brazil currently average 65 m^3/ha/yr, which is equivalent to about 11 dry tons/acre/year. Their best clonal plantations have reached maximum yields of almost 14 dry tons/acre/year. Small, sample plots of eucalypts in certain favorable sites in East Africa and Brazil have grown at a rate of 90 m^3/ha/year, or 15.5 tons/acre/year (Eldridge, 1978). Conversely, an excellent slash pine Florida plantation might accrue wood at a rate of 16.1 m^3/ha/year, or only 2.3 tons/acre/year. Maximum biomass yield from eucalypts in Florida is undeterminable at present, although the preliminary evidence from existing stands in Polk and Glades Counties suggest a potential range in production consistent with eucalypt plantations elsewhere in the world.

Yang, et al. (1977) evaluated the *Eucalyptus* energy plantation scenario and concluded that *Eucalyptus* was a particularly desirable biomass crop for Hawaii. They concluded that eucalypts had about the same solar energy conversion efficiency as grasses, and that a sustained growth of 10 feet in height and one inch diameter each year had been demonstrated in existing stands. Sizeable acres of mature (65+ years) eucalypt stands are cut and chipped annually for export to Japan for paper pulping. These mature trees exceed 200 feet in height and 40 inches d.b.h. The nature of Hawaii's eucalypt forests have been described by Picford and LeBarron, 1960; LeBarron, 1962; Walters, 1980; and Fujii, 1976. Yang, et al. (1977:6-87) identified the following advantages and disadvantages of *Eucalyptus* biomass plantations in Hawaii:

- rapid growth and good yields are attainable on non-agricultural land with little or no cultivation

- extensive plantings are present in Hawaii indicating adaptability to soil and climate conditions

- no problems concerning insect or fungal pests have arisen in the 70 years *Eucalyptus* has been planted in Hawaii

- cut stumps coppice repeatedly and regenerate very rapidly--coppices several feet high at six months after cutting and 20 to 50 feet tall after two years were observed at Paauilo Mauka, Hawaii, on Capitol Chip operating sites*

- harvest technology is quite well developed and exemplified in Hawaii by the Capitol Chip operation; most costs are readily available

- chips produced could be marketed for pulp or for energy, if economic conditions so indicate

- mechanized planting technology exists and is feasible for Hawaii

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*On-site observation by task force member.

Vail (1979) conducted an interesting study screening woody plant candidates for biomass plantations within the United States, resulting in 24 likely candidates, of which *Eucalyptus* was one. Vail considers woody biomass as one of the most promising alternative energy sources, but cautions that its renewability must be preserved by optimizing the productive utilization of natural resources (sunlight, water, and nutrients) to maximize biomass supplies.

The ideotype technique (Donald, 1968) is applied to describing the following biomass crop ideotype (Vail, 1979:8):

(1) Processes Solar Energy

- <u>Upright</u>, <u>excurrent growth</u> and <u>multilayered crowns</u> to efficiently capture sunlight on any given spot

- <u>Indeterminate growth</u>, <u>early growth initiation</u>, and <u>long leaf retention</u> to collect sunlight over as much of growing season as possible

- <u>Perennial above-ground stems</u> to provide easily accessible storage of biomass

- <u>High Specific Gravity</u> - for maximum storage of energy per volume of biomass

(2) Responds to Man's Manipulation

- Narrow, compact crown and steep branch angle to allow close spacing

- Coppicing habit to allow multiple harvests from a single planting

- Rapid juvenile growth to allow short harvest cycles

- Early successional stage to allow maximum use of inorganic nutrients and sunlight

The *Eucalyptus spp.* with the greatest potential for biomass crops score extremely well on all of the above eight characteristics. As a cropping system, eucalypt biomass plantations combine high productivity with greater stability than agricultural systems of similar yields. Management maintenance requirements between harvests are likewise minimal. This is why BESI has selected eucalypts as their plants for woody biomass production. The established quality of *Eucalyptus* fiber for pulping is a strong secondary factor assuring a non-energy secondary market.

2.4 *Eucalyptus camaldulensis*--Our Species of Choice. In the fall of 1980, BESI by necessity selected a single species to work with initially in its Central Florida plantings. We decided on *E. camaldulensis*, the river red gum, for the following reasons:

1. It is the most widely distributed eucalypt in Australia, naturally occuring along streams and in floodplains (Hillis and Brown, 1978).

2. It is known for rapid growth on poor sites with low rainfall.

3. The ability to tolerate periodic waterlogging of soils and high soil salinity, as well as drought.

4. It coppices readily, with plantations in Israel already in the seventh cutting cycle.

5. The usefulness of the wood for fuel, including a high density.

6. One of the most widely planted exotic species, especially in the Mediterranean area, with about 500,000 ha of commercial plantations established.

7. Achieves its best stem form under dense stocking conditions; and normally does not require intensive management (fertilization, irrigation, and pest control).

8. A dozen or more studies from around the world, like Siddiqui, et al. (1979) for Pakistan, spoke of *E. camaldulensis* being physiologically more adaptable to a variety of environmental and managed conditions than the other species of *Eucalyptus*.

9. California screening of 36 species by King and Krugman (1980) placed E. *camaldulensis* among the seven highest rated species for survival and growth, especially after the record-breaking 1972 freeze. Resistance to freeze damage is an extremely important characteristic for Central Florida plantings.

10. Historically, circa 1910, the largest eucalypt in Florida was a river red gum growing near Fruitville, and there were larger numbers of this species in more places in Florida (Zon and Briscoe, 1911) than any other. These authors also considered the species resistant to temperatures as low as 18-19°F after the first yer of growth.

11. Emphasis elsewhere in Florida on research with E. *robusta* and E. *grandis* and their hybrids, suggesting the value of prioritizing research on a third species.

12. Data availability from seven year old stands of E. *camaldulensis* already established in Polk County on mined and reclaimed soils, including the knowledge they had survived the local climate prevalent during that period.

13. The existence of "superior" trees in these Polk County stands from which we could obtain juvenile sprouts for tissue culture experimentation and production-scale propagation.

14. The apparent inability of this species to produce an abundant and viable seed crop in South Florida helps to address environmental concerns about escape and natural system invasion, neither of which was evident for this species in our field studies.

15. Demonstrated resistance to disease, insect pests, and catasrophic fire.

2.5   The *Eucalyptus* Experience in Florida. Several species of eucalypts
were planted on Merritt Island, Florida, as early as 1878 (Zon and Brisco,
1911). Important experimental plantings are reported as early as 1942 by
Claude Devane, Tropical Forestry Project, Florida Forest Service. Additional
experimental plantings were made in 1954, and the results were so encouraging
that *Eucalyptus* research was given a higher priority (Schory, 1960). During
this early period, The Tropical Forestry Project began to coordinate activities
with the U.S. Forest Service, the Florida Forest Foundation, the Plant
Introduction Gardens, the Fairchild Tropical Gardens, and the Subtropical
Experiment Station (Metcalf, 1961). Also during the mid-1950's, several pulp
and paper companies such as the Buckeye Cellulose Corporation, the St. Regis
Pulp and Paper Company, and the Collier Corporation initiated experimental
plantings of *Eucalyptus* on their Florida owned lands (Mariani, et al., 1978).
A cooperative research and development program involving the U.S. Forest
Service, the Florida Division of Forestry, and several commercial firms was
established in 1971. The Southeastern Forest Experiment Station of the U.S.
Forest Service has a continuing research program to improve eucalypts. Species
selection, site conditions, and cultural practices for pulpwood production have
been the major thrust of the research. Recent efforts by the Forest Service and
the University of Florida have begun to explore the potential of eucalypts as a
biomass resource.

2.5.1   Existing Plantings. The generalized locations of the major
eucalypt plantings in Florida are shown in Figure 2-1. The Florida planting
program was described in considerable depth by Uhr (1976). The Florida
commercial eucalypt acreage has increased from nearly 3,000 acres in 1976 to
almost 18,000 acres in 1982, mostly Georgia-Pacific Corporation and Lykes
Brothers, Inc. plantings in Glades County. These stands of E. *grandis* and
E. *robusta* have been severely stressed by two extreme droughts in 1980-81, fol-
lowed by a hard freeze in January of 1982. The extent of recovery from these
combined stresses will be monitored closely in the summer and fall of 1982.
The emphasis on the Florida eucalypt program thus far has been fiber production,
rather than as an energy crop. There is a growing interest in the energy
potential of the Florida eucalypts, as well as the possibility of launching
a Florida eucalypt chip export industry and researching the pulp
properties of Florida grown eucalypt wood (Franklin, 1977).

FIGURE 2-1

Important Eucalypt Plantings in Florida

LEGEND

1. E. camaldulensis seed orchard
2. IFAS close spacing experiment
3. Lykes Bros., Inc. and Georgia-Pacific
4. IFAS range experiment station (Ona)
5. Gardinier (Horse Creek)
6. Gardinier (Bowling Green)
7. Agrico (Overburden)
8. Grace (Sand Tailings)
9. Grace (Duette)
10. Grace (Ft. Lonesome)
11. E. tereticornis seed orchard (St. Leo)
12. Withlacoochee State Forest (Experimental)
13. St. Regis (Experimental ST-76)
14. Disney World
15. USFS (Experimental-rooted cuttings)

source: Guide to Fun in FL Atlas--Florida Wildlife Federation

The production potential of Florida eucalypts has been considered by Conde and Rockwood (1979), relying on E. *grandis* data from Meskimen and Franklin (1978). The pulpwood plantings are seriously understocked at about 300 trees per acre, resulting in a low production level of less than 3 DTE/A/yr (Conde and Rockwood, 1979). We believe estimates of production levels presented in this document more closely approximate the probable yield from a Florida eucalypt energy plantation.

Much of the Florida research consists of unpublished data not available to us at this time; and, of course, the research is ongoing. Meskimen (1979:2. revised 1980) summarized growth and yield data from Lykes Bros., Inc.'s Ferguson Forest:

- An 8-year seedling rotation

- Trees averaging 18+ m (60 feet) tall at age 8 years

- Perhaps a 7 year coppice rotation

- Two, perhaps three, coppice rotations

- Yields in the range of:
  Pessimistic = 13 m^3/ha/yr (2.2 dry tons/acre/year)
  Realistic target = 16 m^3/ha/yr (2.5 dry tons/acre/year)
  Optimistic = 19 m^3/ha/yr (3.0 dry tons/acre/year)

Meskimen cautions that gross understocking was the overriding characteristic of these three stands. Freeze dieback has been the primary condition defect in the Ferguson Forest, affecting 22 percent of the trees.

Meskimen and Franklin (1978) recommend a spacing for E. *grandis* plantations of 6 feet by 12 feet, with a density of 605 trees per acre. This planting, at age 5 months, froze back to the ground with a minimum temperature of 23°F five feet above the ground. Despite the freeze, survival was 92 percent at 4 years and 85 percent at 7.4 years. Genetically improved seedlings were used from second and third generation seed orchards. The authors predict a rotation of 8-10 years and at least two coppice rotations before the need to replant.

Geary (1975) experimented with December and February winter plantings in Collier County, Florida. The obvious efficiencies of winter planting are an important consideration in establishing large acreages. The four species tested were E. *camaldulensis*, E. *tereicornis*, E. *grandis*, and E. *robusta*. Almost 100 percent of the seedlings of all species survived the December planting (dry conditions). In the February planting (exceedingly dry), 86 percent of E. *camaldulensis* and E. *tereticornis* seedlings survived contrasted to 38 percent of the E. *grandis* and E. *robusta*. This is consistent with E. *camaldulensis* being more drought resistant as well as more cold hardy than E. *grandis* or E. *robusta*.

There has been extensive unpublished experimentation with the application of rock phosphate, resulting in the current Glades County practice of applying 0.5 tons per acre to the beds after site preparation. A trend has been observed of moderate improvement in cold hardiness with the application of rock phosphate on some sites.

A major emphasis in the Florida eucalypt program has been on achieving genetic gains (Franklin and Meskimen, 1973; 1975). A very promising line of *E. grandis* x *E. robusta* F_1 hybrids has resulted from this work (Franklin, 1978). Rockwood and Squillace (1981) have reviewed the potential of utilizing genetic differences in woody feedstocks to increase yields of methanol and ethanol. Rockwood and Conde (1975) are conducting research on genetic variation in *E. grandis* as it relates to biomass production, particularly the response to competition effects at denser spacings.

The most recent review of genetic selection of eucalypts, largely in Florida, has been provided by Franklin (1978). Franklin emphasizes the need for genetic adaptation of virtually any eucalypt seed lot to the Florida environment, by selection and breeding, before the species or provenance can be adopted to form commercial stands. This poses severe constraints on the planting of large acreages with high yield *E. grandis* and *E. robusta* seedlings in the colder areas of Central Florida. Vegetative propagation by cloning of high quality parent trees of *E. camaldulensis* growing in Polk County remains the most viable near term alternative source of plants in large numbers until other cold hardy, fast growing species and provenances become available on the long term after undergoing the genetic selection procedures described by Franklin (1978).

2.5.2 Land Suitability and Availability. Numerous authors
have stressed the need for available land acreages before a sufficiently
large wood energy system can be installed (Inman, 1977; Howlett and Gamache,
1977; Mariani, et al., 1978; Johnson, 1980). The available lands and their
current uses have been described in our Background Environment Document,
relying heavily on data provided by the Environmental Protection Agency in
their areawide impact assessment of the Central Florida phosphate industry
(EPA, Vol IV and Vol X, 1978). This Silvicultural
Document also addresses the available land questions. The Economics Document
contains a comprehensive evaluation of available land from a real estate
perspective. A regional land suitability analysis by BESI shows over 320,000
hectares (nearly 800,000 acres) of prime eucalypt lands in the region. Over
550,000 acres (nearly 225,000 ha) are owned by a handful of phosphate companies
alone, largely committed to a ranching use. The total acreage available for
energy plantations in Central and South Florida probably approaches two million
(more than 800,000 ha).

Salo, et al. (1977) evaluated the land potential for silvicultural
energy plantations for four land scenarios, using the USDA Soil Conservation
Services' land classes, with the most available lands being noncroplands in
Scenarios 1, 2 and 3. Available lands ranged from a low of almost 7 million
acres (nearly 3 million ha) in Scenario 1 to 15 million acres (over 6 million
ha) in Scenario 3 (Table 2-1).

Clearly, an abundance of land is available in uses that have a low
economic return to the owners and to local governmental taxing authorities.
The projected productivity of *Eucalyptus* plantations will make them economically
competitive with most other agricultural uses of the land resource.

TABLE 2-1

Potentially Available Biomass Production Lands
For Five-County Area of Central Florida

<u>Land Quality in Acres (Hectares)</u>

County	Fair		Moderately Good		Good		Excellent	
DeSoto	268,889	(108,816)	306,364	(123,981)	312,938	(126,642)	338,847	(137,127)
Hardee	201,438	(81,519)	246,812	(99,881)	247,032	(99,970)	300,656	(121,671)
Hillsborough	218,639	(88,480)	316,099	(127,921)	322,438	(130,486)	414,407	(167,705)
Manatee	226,565	(91,688)	281,700	(114,000)	284,634	(115,187)	309,370	(125,198)
Polk	321,502	(130,107)	510,375	(206,542)	519,826	(210,366)	693,015	(280,454)
TOTALS	1,237,033	(500,610)	1,661,350	(672,325)	1,686,868	(682,651)	2,056,295	(832,155)

2.5.3 <u>Climatic Suitability</u>. A complete evaluation of
regional climate is provided in the Background Environmental Document. The
climatic suitability of the region for growing eucalypts is discussed in
Section 5.1 of this document. Salo, et al. (1977) identified *Eucalyptus spp.*
as a possible biomass candidate for their North Florida site in Levy County,
expressing the view that cold tolerant species could survive the winter
freezes. The major problem with growing eucalypts anywhere in the Southeast
is the problem of damage or death caused by cold weather. Genetic selection
of cold hardy species and tissue culture propagation of individuals surviving
hard freezes eventually will provide eucalypts for plantations in North
Florida. At this time, BESI does not recommend commercial plantings of
eucalypts north of Polk County. The damage caused by the 1982 freeze to the
Glades County plantations reinforces this opinion.

Using the methodology of Papadkis (1970) and the world climatic
diagrams of Landsberg, et al. (1965), climatic comparisons are possible between
the Florida study area and Australia. Over half of the weather stations in
Australia record minimum temperatures comparable to peninsular Florida (Mariani,
et al., 1978). Prevailing temperature conditions are suitable for eucalypt
plantations in the study area, as is visibly demonstratable by the eucalypts
growing throughout the region. However, cold hardiness differences in yields
and survivability between species, provenances, and even clonal lines can be
of major economic importance for the commercial planting. All eucalypts are
most vulnerable to freeze damage during the first few months after planting.
A hard freeze of long duration could devastate a newly installed, or even two
year old plantation, especially if the plants are not from a cold-hardy line.

Moisture is an equally important limiting factor, especially during
the first few months after planting. Only drought tolerant varieties should
be planted between February and June in the winter drought/summer rainfall
cycle common to the study area. The winter planting experiment of Geary (1975),

in which February was extremely dry, resulted in over 60 percent mortality of the
E. *grandis* and E. *robusta*. Generally, the study area is in the moist,
sub-humid climatic type of Watts' (1971); and the 55-60 inches of annual rain-
fall is sufficient for high yield eucalypt production, probably with a
preference for drought-resistant lines.

The Australian towns of Atherton, Bowen, and Rockhampton in
northeastern Australia have climates (Landsberg, et.al., 1965) similar to
Tampa, Florida. This is the natural range of E. *camaldulensis* from which
additional provenances will be selected for Florida test plantings.

Ultimately, field performance is the only positive verification
of a eucalypt's suitability for a particular climate. This is the primary
reason why BESI has relied on a Spanish provenance (unknown) of E. *camaldu-
lensis* that has performed well in the Polk County climatic matrix. As a
species, E. *camaldulensis* is considered to be more drought tolerant and cold
hardy than most other eucalypt biomass candidates.

2.6 **Plantation Installation.** Vast acreages of presently non-productive or underproductive Central and South Florida marginal lands can become Nature's storehouses of solar energy through photosynthesis and woody biomass growth. They are available and awaiting the installation of eucalypt energy plantations. The scarcity of available, suitable land has been considered by many to be a limiting factor for large-scale wood production (Tillman, 1977; Zavitkovski, 1976, Inman, 1977). Typically, the land resources of a region are committed to other, often more economically productive land uses. In some areas, large landowners have the option of directing future land utilization. The presence of the Phosphate Industry in West-central Florida has resulted in a relatively few ownerships, each with large acreages of available lands suitable for eucalypt plantations. Cattle grazing is the predominant pre-mining and post-reclamation land use. Beef production potentially is vulnerable to displacement by a more productive land use, such as eucalypt biomass plantations.

The establishment of wood producing plantations in Florida historically has been in areas immediately adjacent to industries with a large and continuing consumptive appetite for wood. Most plantation production is targetted for an identifiable market at the time of establishment. The wood producing capabilities of Central and South Florida have been under-utilized because of the long distance from an established market and associated high transportation costs. Productivity generally has been lower, also, because of poorer site quality and climate for the traditional southern timber species. Most of the land was in open range until the 1950's, lacked statewide fire protection until the 1970's, and continues to lack a ready local market for the wood produced. High land values, low yields and prices, and long distances from markets continues to discouage all land-owners except for the most foresighted. The eucalypt energy plantation concept merges new marketing opportunities within the region with a tree crop that can produce high yields on marginal land at a profit.

Because the direct cash cost of initially installing the planta-
tion is high (±$500/acre), few landowners will make the investment on
large acreages until the uncertainties of the market place are lowered.
There are no silvicultural limitations or technological obstacles to
installing eucalypt plantations on a scale of 20,000-30,000 acres per year.
The economic uncertainties and up-front cash requirements are the actual
limitations we encounter in each conceptual presentation to landowners.
As the establishment of eucalypt plantations moves forward, experimental
observations and new data will contribute to the methodology reported in
the literature and in this document.

2.6.1 <u>Site Preparation</u>. Site preparation is the treatment of land to place it in a condition to grow most abundantly the woody biomass crop. Complete site preparation is essential to the control of competition in the first year (Schory, 1960). Seedlings, once suppressed, never fully recover from the effects of competition even if they survive. Conversely, initial growth increases obtained during the early establishment phase as a result of intensive and complete preparation are maintained during the entire rotation (Schonau, 1977; Schonau, et al., 1980). Virtually all authors agree on the overriding importance of complete site preparation and we are convinced of its necessity. Sites with prohibitive preparation costs should not be committed to a eucalypt plantation. Once the established seedlings achieve canopy closure or site dominance, in Florida between 12-18 months post planting, control of competition is no longer a problem (Carter, 1974).

To achieve complete preparation most sites must be deep plowed and cultivated. Thorough cultivation results in spectacular initial growth rates (Luckoff, 1955). Groulez (1970) had similar results in Mediterranean plantations. Obviously, methods and costs vary significantly between a pasture site and a well-stocked woodland (Yang, et al., 1977).

Site preparation overlaps with planting since the type of planting machine employed may require modifications in the preparation technique (Cameron and Riley, 1981). Relationships with fertilization have also been demonstrated (Meskimen, 1971), where fertilizer treatment partially compensated for grass competition. A relationship with fire risk is evident in that the highly vulnerable eucalypt plantlets are at little risk on new sites where the ground cover fuel accumulation is minimal as a result of complete site preparation and/or the use of herbicides. The length of time to canopy closure or site dominance by the planted eucalypts also is a function of the density of the stocking; a spacing interaction. High soil moisture is important to establishment

during the first days following planting, and the elimination of competing plants helps to retain soil moisture for the eucalypts, as well as nutrients, minerals and trace elements.

Generalized approaches to site preparation have been considered by most planners of silvicultural biomass plantations (Salo, et al., 1979). These generally consist of clearing, chopping, disking, the application of such soil amenities as ash and fertilizers, the installation of roads, irrigation and drainage systems, etc. Decisions as to which treatments to use are highly site and crop specific. For example, bedding is a common and necessary treatment in the South Florida eucalypt plantations on the palmetto prairie sites (Cowan, in ms); but, it is not needed for the most well-drained, sandy sites of Central Florida. Large plantations will need to be sub-divided into forest management modules dependent on differences in soil, hydrology, and topography. Planning of the biomass energy forest is a necessary first step before the onset of site preparation.

2.6.2 <u>Planting Stock</u>. There is temendous variability in *Eucalyptus* growth due to genetic differentiation (Uhr, 1976). Although there are many outstanding trees in eucalypt stands, there is little consistency in height and diameter at breast height (dbh) among the individuals in a stand. Knowledge of the breeding systems of various eucalypts has been well reviewed by Eldridge (1978) with suggestions for genetic improvement. Many, probably most, plantations originate from a few seed trees, resulting in an inadequate genetic base for the establishment of large plantations. This problem is particularly acute in terms of the Florida seed source for the *E. camaldulensis* used in our program. Jackson and Oio (1973) have shown that the Petford and Katherine provenances (S.6953 and S.6860) from northern Australia gave excellent results in Nigerian field trials. To improve the genetic base for *E. camaldulensis* requires provenance trials in Florida. BESI places a high priority on obtaining seed lots from northern Australia collected from a large number of widely separated, select trees. Trees from these collections, grown in Central Florida, will then be selected for tissue culture propagation to produce the many millions of plantlets needed for a 100,000 acre energy forest. We recognize the necessity to seek a continuous improvement in biomass tree characteristics by the deliberate broadening of the genetic base. The best provenances of any *Eucalyptus* species must be screened for those natural qualities that best fit the man-dominated environment of the Florida energy plantation.

The initial source of our *E. camaldulensis* clonal plantlets for the first plantations must be from select trees in the existing Polk County stands. Preliminary experience has shown that the plantlets propagated from the highest quality trees in the stands reflect the vigor and dominance of the parents.

Hartney (1980) offers a comprehensive discussion of vegetative propagation of eucalypts, including tissue and organ culture. Krugman (1974) reviews the North American experience with the production of eucalypts from the seed. We agree with his observation that vegetative propagation from cuttings and grafting does not appear to be practical in the United States. Low labor costs are essential for a cutting system to be economically feasible. Likewise, there has been only limited success with bare-root *Eucalyptus* plantings. Consequently, nearly all commercial Florida plantings involve small, containerized seedlings

adaptable to machine and hand planting. With the acceptance of a standardized container, automated or semi-automated planting equipment will be perfected. Plantings in Florida usually occur from mid-June to mid-September, although winter planting has been tried with variable success (Geary, 1975).

The Florida Division of Forestry is the primary supplier of commercial *Eucalyptus* seedlings in Florida. The seedlings are propagated at the Division's Herren Nursery from available quantities of select and unimproved seedlots. According to Herren Nursery staff, production has concentrated more on *Eucalyptus grandis* and *E. robusta* than other species. These two species exhibit exceptional growth, although they are sensitive to freezing temperatures. Other species that have been utilized include *E. camaldulensis, E. tereticornis,* and *E. viminalis*, which are considered candidates for colder climes. *Eucalyptus camaldulensis* seems particularly promising in Central Florida.

Seed progeny testing for South Florida continues to improve seed stock (Franklin and Meskimen, 1975), although it takes many years to develop superior strains from seed. During 12+ years, Florida eucalypt seed sources consistently have been improved. However, open, uncontrolled pollination continues to result in a wide range of genetic variation in seedlings, and thereby restricts potential improvement. Seeds from the current progeny testing have been producing more uniform stands and currently are in commercial use (B. Swendsen, pers. comm.). Selection has concentrated on fast juvenile growth, as well as form and volume of harvestable logs.

The first select seed from Florida orchards became available for nursery production in 1972. Even today, procuring large quantities of select nursery stock requires lead times of eighteen months and longer depending on the quantity required. The further improvement of genetic strains, selection for adaptability to Central Florida, selection for productivity on mined soils, and large scale production of superior planting stock are of paramount concern for the accuation of a commercial wood energy system in the study area.

BESI has elected to concentrate on the establishment of
plantations with cloned plantlets for the following reasons:

- Reduce Genetic Variability. Most Florida eucalypts
originate with containerized seedlings, nursery grown, from select seed
orchards. Even when the seeds are from select mother trees subjected to
several generations of genetic improvments, plantations show dramatic
variability, particularly in wood volume. In a six year old plantation,
two inch dbh trees commonly are found growing next to twelve inch dbh
trees from the same seed lot. Cloned plantlets replicate the form of
the original parent tree, resulting in a more uniform stand with much
greater productivity. We project a minimal doubling of woody biomass
yield if cloned plantlets are installed rather than seedlings.

- Improve Growth and Form. The efficient growth, harvest
and transport of fuel wood to market requires uniformity and optimization
of such traits as diameter, height, straightness of stem, crown size,
branching, etc. By selecting carefully for these characteristics the
donor trees to take into tissue culture, plantlets are produced that mirror
the outstanding qualities of the parents.

- Adaptation to Site Specific Conditions. Plantlets can be
grown in a controlled environment and subjected to stressful ambient
conditions or soils modeled after the plantation site. Plantlets surviv-
ing such exposures are more likely to survive when outplanted to the site.
Tolerance to high salinity, high or low soil moisture levels, and low
temperatures can be established rapidly through the use of tissue culture
technology.

- Numbers. The rapid multiplication rate achievable in the
tissue culture laboratory is the only technology available for producing
the large numbers of select eucalypt plantlets needed for a 10,000 acre
plantation without delaying the planting for two or more years.

● When weighed against the increased yield and the one-time planting cost for multiple harvests, the substantially higher cost of plantlets in contrast to seedlings is economically sound.

2.6.3 <u>Planting Considerations</u>. The experience in planting eucalypts of other workers relevant to our concept is limited, because no one has planted large numbers of clonal plantlets produced by tissue culture, in Florida or elsewhere. Since these clonal plantlets are much more expensive than nursery seedlings, $300/1,000 versus $80/1,000, the cost alone demands that each plantlet be given an optimum opportunity to survive and produce a high yield of woody biomass. Thus, extreme care must be taken at each stage of the planting process.

A low soil moisture coupled with high evapo-transpiration conditions (hot, sunny, and windy) would be life threatening to recently installed plantlets, as would a hard freeze. Therefore, until there is more experience in Central Florida, plantings should take place in the six months between June 1 and October 31. Watering-in of the plantlets normally would not be economically feasible, nor would irrigation. The selection of eucalypts resistant to drought and freeze effects is, the most practical approach, while acknowledging the risks of weather and climate inherent in most cropping systems.

The large areas to be planted and the high costs of labor compel the use of mechanical planting machines. Because of the emphasis on complete site preparation on favorable topography, we intend to use the continuous furrow concept (USDA-Forest Service, 1967), probably with manual feeding at the first stage of operations. The factors relating to mechanical planting systems have been reviewed recently by Lawyer and Fridley (1979). Our automated nursery production system in Todd Planter Trays (Speedling, Inc.) is compatible with a continuous furrow planter. The 10 foot spacing between rows prohibits the multiple row mechanical planters now on the market. Again, because of the high cost of the plant-lets, the biological factors affecting survival and vigor override the speed and efficiency of the planter.

Cowan(in ms) recommends a planting depth 2-4 centimeters below the soil line of the container. Deep planting is especially important under low soil moisture conditions (Schory, 1960). Root placement, shoot orientation, and soil compaction around the root mass are parameters crucial to survival and vigor, as well as the depth of planting. A mechanical planting system will have to be fine-tuned to handle our plantlets and containers (Lawyer and Fridley, 1979). However, most of the commercial Florida eucalypt acreage has been planted by machines designed for planting bare-root pine seedlings. We do not believe the selection or development of a suitable planting system will be limiting in any way.

As emphasized by Cowan(in ms), at least two weeks should pass between site preparation and planting; but, site prepared land should not go unplanted indefinitely because of the speed at which competing plants invade the site.

The transportation and handling of the plantlets between the nursery and the site must be well organized and done in such a way as to not disturb and stress the plantlets. Soil moisture, controlled temperatures, proper ventilation, and minimal time for planting after removal from the nursery are controlling factors (Cowan, in ms). The Todd Planter Trays provide a nearly ideal system for maintaining a high quality of plants during transition.

Plantlets must be protected from cattle grazing and fire during the first year following installation (Schory, 1960). Density and spacing considerations are addressed in the following section.

2.6.4 <u>Planting Density and Spacing</u>. Numerous studies in
the U.S. have documented spacing and rotation experiments of various
short-rotation candidates including poplar, red alder, and sycamore
(Steinbeck and McAlpine, 1972; Ek and Dawson, 1977; DeBell, et al.,
1978; and Kennedy, 1975). The data can be correlated directly to
Eucalyptus cultivation only in general terms. Extremely dense plantings
(1'x4', 2'x4', etc.), once considered optimum for energy plantations,
are not considered economical for northern hardwoods (Rose and DeBell,
1978). Recent dense plantings of *Eucalyptus grandis* in California have
produced yields of 10 dry tons/acre/year and may prove economical to
cultivate (Sachs, et al., 1980). Data from high density eucalypt plant-
ings in South Florida by the University of Florida and the U.S. Forest
Service are currently being collected. High volumetric yields are reported
by most authors when spacing is reduced and the number of plants per acre
is increased. In nearly every case, high density plantings suffer a higher
plant mortality. Harms and Langdon (1976) report various densities for
Loblolly pine (*Pinus taeda* L.) ranging from 1,012/acre (2,500/ha) to
16,187/acre (40,000/ha) with plant mortality at age 14 ranging from less
than 20% for the lowest density to more than 75% for the highest density.
Sachs, et al., (1980) reports high yields from *Eucalyptus grandis* planted
in Southern California at a spacing of about 2.5 feet by 2.5 feet
(75 cm x 75 cm), a density of 6970 trees/acre (17,222/ha). Wardle (1967:
47) concludes that "the spacing giving the best financial results depends
on the precise objective of the enterprise: and that "on the expectations
considered most likely to come about, spacing of 8 feet gives the best
financial result."

A study of *Eucalyptus saligna* for saw timber in Hawaii compared
results of 15 year-old plots planted on 14x14, 12x12, 10x10, and 8x8 foot
spacings (Walters, 1980). A striking result was that the mean annual
volume increment peaked at 5 years for all spacings. Total stem volume
at 15 years ranged from 9759 cubic feet per acre (i.e., 7.8 dry tons/acre/
year) for the 8x8 ft. (2.4x2.4 m) spacings to 7096 cubic feet/acre (i.e. 5.5 dry tons,

acre/year) for the 14x14 ft. (4.3x4.3 m) spacing. Other spacing trials with *Eucalypti*
in South Florida have suggested that if merchantability limits on tree
size were circumvented, yields 16-68 percent greater could be achieved
at close spacings (Meskimen and Franklin, 1978a). However, it is apparent
that doubling the stocking, from 577 to 1147 trees per acre, does not
double the volume production after 7.4 years. Neither optimum rotation
age or spacing have been evaluated for eucalypt energy plantations in
Florida (Conde and Rockwood, 1979). Wang, et al. (1981) reported on
experimental *Eucalyptus* energy plantation at LaBelle, Florida installed on a 1x1 m
spacing that required 10,000 plants/ha. They assumed a planting cost for
10,000 eucalypts of $50/ha ($20.23/acre).

Several coppice harvests are anticipated with some stool mortal-
ity with each harvest. Since interplanting following establishment is not
a recommended practice, the initial stocking rate needs to be high enough
to compensate for both mortality of plantlets or seedlings and the loss
of stools. Biomass Energy Systems, Inc. intends to stock its plantations
with tissue cultured plantlets at 871 trees/acre on 5x10 foot centers
(1.5x3.0 m), thereby allocating 50 square feet (4.5 m²) to each tree with-
out compensating for mortality.

Meskimen and Franklin (1978) concluded that *Eucalyptus grandis*
in Florida planted at a spacing of 4 feet by 8 feet (1.2x2.4 m), a density
of 1361 trees/acre (3354/ha), yielded a volume about 1.7 times greater than
a planting 8 feet by 12 feet (2.4x3.7 m), a density of 454 trees/acre (1122/
ha). These authors recommended a 6x12 foot spacing, or 605 trees/acre
(1495/ha) until more data becomes available. Higher density plantings of
almost any woody biomass species produce higher volumes at harvest. In
most cases diameters are smaller and, at a species dependent age, stem height
levels off. Most high density plantings have been done on very small
acreages, usually hand planted, and many have not considered the economic
return when compared to the initial establishment cost. Costs must include
not only the plants, but also planting, and maintenance to the point of
harvest. Harvesting efficiency is very much a function of density and yield.

Harvest yields below 40 tons/acre (90 tonne/ha) are not likely to be cost effective (JPR Assoc., 1981). Can we plant high density stands of 43,560 trees/acre (110,000/ha) on 1 foot centers by machine? Is proven harvesting equipment available? In today's money market, can the grower afford plant costs of more than $3,000 per acre (almost $9,000 per hectare) at start-up? Where plantlets produced in tissue culture cost several times the price of seedlings, the number of trees planted per acre becomes the dominant cost in establishing the plantation.

2.6.5 **Fertilization.** The use of commercial fertilizer
on forest land as a management practice has been limited in scope and
largely experimental (Motley, et al., 1980). Whole tree biomass
production with higher densities and shorter rotations results in higher
attendant requirements for nutrients (Riekerk, et al., 1981). One reason
for fertilization of biomass energy plantations, other than increasing
yields, is to offset possible drastic reductions in nutrient availability
and recycling efficiency which may accompany the frequent harvest of
biomass and export from the site of nutrients and minerals (Lugo, 1970;
Barnett, 1981). Applications of coal and wood ash industrial wastes,
usually with single rotation applications following harvests, as well as
forest land disposal of treated waste waters, sludge and solid waste
mulches, are possible soil treatments.

Yearly fertilization of the LaBelle *Eucalyptus* Site has been at the
rate of 50 kg/ha/year of nitrogen and phosphorus on a 10,000 trees/hectare
stand (Smith and Conde, 1980). Cowan (in ms) has recommended even applica-
tions of ½ to 1 tonne/hectare of ground rock phosphate on the site-prepared
land, followed by passing a bedding plow with an hourglass roller to firm
beds. This one nutrient treatment per rotation has become the standard
management practice for eucalypt planting in Glades County, Florida, with
visually obvious favorable results when contrasted to untreated control areas.
The use of phosphate fertilizer on poorly drained flatwood soils in North-
west Florida sometimes resulted in increases in wood accumulation of 700%
(Laird, 1972).

The relationship between eucalypt growth performance and applications
of nitrogen and phosphorus are complex and defy generalization as reviewed
by Cromer, et al. (1980). As might be expected, research results are highly
variable, depending largely on the species, treatments, soil and moisture
conditions, and climate.

Eucalypts have produced phenomenal amounts of biomass with the application of more intensive silvicultural practices. Under the proper conditions, _fertilization_ can increase productivity 3- to 5-fold (Cromer, et al., 1975; Cromer et al, 1980). Hartley (1977) had good results with fertilization trials of E. _tereticornis_ in Papua New Guinea, as did Krohn (1981) in Guam. Until more research is available, BESI intends to rely on site specific soil analyses before deciding on nutrient supplements, other than the standard provision of ½-1 ton/acre of ground rock phosphate on all but mined soils which may require a nitrogenous treatment to offset atypically high phosphate levels. Fertilization is an expensive, energy intensive subsidy that should be utilized only when research and experience demonstrates its necessity and cost-effectiveness.

Weed control during the early establishment phase is considered one of the main restrictions to initial growth (Schonau and Boden, 1980) which overrides fertilization effects. Meskimen (1971) reported on the value of inhibiting effects on E. _camaldulensis_ of competition with turf grasses. Mycorrhizae can be important to eucalypt nutrition (Pryor, 1956; Malajczuk, et al., 1975); but, we know of no study of this relationship in the Florida eucalypt plantations.

2.6.6 <u>Weed Control and Herbicides.</u> The need for control of competing plants in the early life of the plantation has been well established in the literature and discussed in this document. Thorough site preparation and extensive cultivation have been the primary approach in eucalypt plantations rather than the application of herbicides. A long acting, postemergent herbicide that was effective, safe and inexpensive would be enormously helpful (Martin, in press). Wang, et al. (1981) report that the use of herbicides to control weeds in *Eucalyptus* plantations is unknown. Apparently, none was used in the LaBelle planting (Smith and Conde, 1980). Sachs, et al. (1980) used a preemergence herbicide in their very dense plantings of E. *grandis* but thought it may have been unnecessary because of the near total domination of the site by the foliage of the biomass crop. Wattle crop growers in South Africa are enthusiastic over the use of glyphosate at the rate of 300 ml per sprayed kilometer to control inter-row weeds. Because of damage to the eucalypt crop, a spray rig dubbed the C. D. Wricksha was developed to prevent spray drift onto the wattle rows (Wattle Research Institute, 1981).

As with fertilization, the effectiveness and methodology for chemical control of weeds in eucalypt plantations are highly site and species specific, including selection of the best herbicide for the specific situation. Until we have experimented with a variety of materials in field trials, BESI does not intend to routinely use herbicides for plantation establishment. Herbicides have not been a standard management practice in the Glades County plantings. We estimate the cost of a single herbicide application to be $40/acre ($100/ha).

2.7 <u>Plantation Management</u>. The foremost eucalypt plantation management questions address irrigation, rotation cycles, fire hazards, and pest damage. No soil amenity treatment or fertilizer applications are anticipated except at site preparation and possibly following harvest.

2.7.1 <u>Irrigation and Water Relationships</u>. Under normal eucalypt plantation management regimes, BESI considers irrigation an unnecessary economic cost and a needless consumptive use of water. It is neither practical or feasible to install a system. Rarely, cropland with existing irrigation systems may go into eucalypt production. This would allow dry season planting free of plantlet mortality from water deficit stress. Existing irrigation systems also would provide the opportunity for experimentation to determine if appreciable growth increases can be realized by irrigating during periods of inadequate rainfall. Wilting of established eucalypts has not been observed by us in Central Florida, even during the severe droughts of 1980 and 1981.

Eucalyptus species vary in their transpiration rates, as shown by Kaul and Negi (1979) where *E. saligna* had 1.5 to 2.0 times the water loss of *E. tereticornis*. *E. tereticornis* demonstrated an effective stomatal closure mechanism lacking in the other species tested which resulted in a dramatic decrease in transpiration when challenged by a water deficit stress. Since *E. camaldulensis* is known to be drought hardy, it probably has a similar mechanism to maintain a favorable water balance. *E. tereticornis* also had a lower stomatal frequency, an adaptation that permits a higher level of hydration under water deficit stress conditions. This type of research needs to be done on Florida grown *E. camaldulensis*. Because of genetic determinants, differences in drought resistance can be expected between provenances of the same species. A low energy management strategy dictates selecting eucalypts that are drought resistant rather than practicing irrigation.

Karschon and Heth (1967) studied for 4 successive years
the water balance of an *E. camaldulensis* plantation in Israel on a semi-
arid site with a mean rainfall of 640 mm/year. They determined the ratio
of actual evapotranspiration by the trees to open water evaporation as
0.06:0.11 for the average over the dry season. Thus, the leaf was practic-
ing a significant conservation of water when compared to free water evapora-
tion. Often, Florida's hardwoods have evapotranspiration losses greater
than pan evaporation. Soil moisture depletion by a grove of *E. occidentalis*
growing on a desert site in Israel was reported by Stibbe (1975). As soil
moisture declined, the quantity of water lost by evapotranspiration was
sharply decreased. The actual evapotranspiration of the grove was 48 percent
of pan evaporation, with an average rate of 8.6 mm/day over a period of 5
months.

Riekerk, et al. (1981) have measured a consistently lower soil
moisture content under the "high density plantations" of eucalypts in South
Florida when compared to adjacent palmetto prairie. They estimate that
transpiring forest vegetation in Central Florida consumes 15 cm/yr of soil
moisture, and, that eucalypts may exceed that rate. Frank Cowan (pers. comm.)
has indicated that irrigation is not necessary for the eucalypt plantations
in Glades County. However, these stands apparently were stressed by the
record droughts of 1980 and 1981. The intensive planting of eucalypts at
the LaBelle site was assumed to require 25 cm of irrigation water per year
in excess of rainfall (Wang, et al., 1981). Salo, et al. (1979) estimated
irrigation system installation costs of over $1,000/acre. Even if drought
periods result in a reduced rate of biomass production, it is doubtful that
irrigation could be cost effective.

There are many complex interactions between irrigation, rainfall,
and climate (Stidd, et al., 1975; Shukla & Mintz, 1982). Massive replace-
ment of semi-arid grasslands and deserts with forests can be expected to
increase rainfall on a regional basis. There are equally complex interactions
between the water table, forests, and nutrients, as discussed by White and
Pritchett (1970); and, there are substantial hydrologic benefits from forests

in controlling erosion and stabilizing sediments (Ursic and Duffy, 1972).
Such interactions as they relate to eucalypt plantations are unstudied
subjects for future research programs.

Irrigation of energy crops has been proposed as a means of
creating optimum conditions for maximum yield. Some research indicates
a tentative conclusion that energy invested in producing biomass will
bring commensurate increased returns (Zavitkovski, 1979). However, this
probably is not a judicious alternative in Central Florida considering the
high cost and relatively ample water budget, unless high nutrient waste
water from phosphate operations or sewage treatment plants is utilized.
Rose and Kallstrom (1976), in their analysis of the economic feasibility
of intensive cultures, suggest that irrigation costs might be charged to
the cost of cleaning up polluted effluent. We believe this to be the only
way in which irrigation systems could be affordable for eucalypt plantations.
In locations where mining companies are required to operate under a zero-
discharge regulatory dictum, as in the watershed of Lake Manatee, the waters
normally discharged could be used to irrigate biomass crops grown on both
reclaimed and unmined land.

2.7.2 <u>Rotation Cycle</u>. Several studies in the U.S. have documented spacing and rotation experiments of various short-rotation biomass candidates including *Populus spp.*, red alder and sycamore (Steinbeck and McAlpine, 1972; Ek & Dawson, 1977; DeBell, et al., 1978; and Kennedy, 1975). The data cannot be correlated directly to *Eucalyptus* cultivation, except perhaps in general terms. The optimum rotation age has not been evaluated for eucalypt energy plantations in Florida (Conde and Rockwood, 1979). With no economic constraints imposed, the optimum rotation age would be reached when mean annual biomass growth rate truncates or levels out (Zavitkovski, 1976). However, fiscal considerations, especially land costs and high interest rates, could reduce the optimum economic rotation, possibly to a lesser age than that set by the growth rate of the trees.

Harvests need to occur when the rate of biomass accumulation declines, and/or when the trees reach the upper limit diameter near ground level for efficient mechanical harvesting, about 12 inches (30 cm). Our studies of Polk County *E. camaldulensis* stands show substantial increases in biomass through the 6th year, with growth occuring in all seasons. Basal diameter of some select trees exceed the limits of conventional harvesters at year 7. Stems need to be cut (sheared) near the ground to favor coppicing. Therefore, BESI has selected for planning purposes, 7 years as the optimum growth interval to first harvest. Subsequent intervals between coppice cuts might drop to as low as 5 years, depending on mensurational data which will be gathered in the plantations as on-going research.

Meskimen and Franklin (1978) anticipated a rotation of 8 to 10 years for Glades County *E. grandis* plantings. Franklin (1979) observed that *E. grandis* and *E. robusta* may have a potential for a 1 to 3 year rotation on the phosphate strip-mined lands north of the Glades County plantings. In South Florida's oldest eucalypt plantation, stand volume continued to

increase through year 10; but, there was a substantial decline in the rate of volume increase after year 8 and height increases leveled out sharply at year 8 (Meskimen, 1979). The author's best guess projection for the Ferguson Plantation was an 8 year seedling rotation and a 7 year coppice rotation.

The choice of rotation is varied according to the planned use of the stand. Opie, et al. (1978) considers a short rotation as one less than 40 years! But Sachs, et al. (1980) were cutting their E. *grandis* biomass planting twice annually. Ethiopians cut their E. *camaldulensis* forest every 2 to 3 years (Horvath, 1968). Siddiqui, et al. (1979) note that E. *camaldulensis* provenances in Pakistan that were fast growing at age 6 were still fast growing at age 10, with no loss in specific gravity. Cromer, et al.(1975) found no drop in productivity over a 10 year rotation in an Australian intensive culture fertilization experiment. In a report from Portugal (Goes, 1967), rotations of 10 to 12 years were used for a variety of eucalypt species. The Hawaii terrestrial biomass plantation study group (Yang, et al., 1977) recommended 5 to 8 year rotations of eucalypts as the primary biomass crop. A 40,000 hectare eucalypt plantation in Brazil is harvested on a 7 year rotation cycle (Abelson, 1982). A study of E. *saligna* for saw timber in Hawaii compared results of 15 year-old plots planted on 14x14, 12x12, 10x10, and 8x8 foot spacings (Walters, 1980). A striking result was that the mean annual volume increment peaked at 5 years for all spacings.

The above cited literature supports selection of a 7 year first harvest rotation interval in an optimum regimen. There will be sufficient flexibility to cut at 6 years if economic factors dictate; or, to wait until year 8 if there is no need for harvesting in year 7. At this point, we would not recommend a rotation beyond year 8 for a biomass use of the trees.

2.7.3 <u>Fire Hazard</u>. The threat of catastrophic loss to
wildlife is an uncertainty faced by most forest managers and woodland
owners. Schory (1960) believed that all Florida eucalypt plantations
must be managed to exclude fires. He noted that young plants are parti-
cularly vulnerable, and that a few species like *E. robusta* developed a
thick protective bark as they mature. The coppicing trait of eucalypts
permits revegetation of the stand, even when most of the trees are killed
or severely damaged.

As *Eucalyptus* ecosystems mature, litter fuel accumulates to
an equilibrium level of 10-15 tons per acre (Crane, 1972). With such
fuel accumulations, fires usually are uncontrollable. Eucalypt barks act
as fire brands, and their ribbony distribution along the trunk allows for
the rapid spread of fire into the crown (Mariani, et al., 1978).

Allelopathic effects in eucalypt ecosystems have received a
great deal of research attention (Ashton, 1962; DeBell, 1970; DelMoral and
Muller, 1970; and Mount, 1968). Where such effects are well pronounced,
the density of understory vegetation is reduced, with a lowered accumulation
of fuel. Fire behaviour in eucalypt forests was the subject of a mono-
graph by McArthur (1967). McArthur (1968) notes that the eucalypts in
general have a high tolerance to fire with adaptations that allow them to
survive fires of high intensity. LeBarron (1962) stated that forest fires
present no serious problem to eucalypt plantations in Hawaii. Cremer, et al.
(1978) observe that fire vulnerability differs with the individual plant,
the site conditions, the species, and the stand. Fire damage is not readily
predictable ahead of the fire event.

We believe that the density of 871 trees per acre, the short
rotation period of 7 years, and the intensive site preparation planned
for the BESI eucalypt plantations will minimize the risk of catastrophic
wildfire. The high moisture content of young trees likewise mitigates against
mortality from a burn. Nonetheless, prevention by exclusion will be our
first line of defense. The primary management expenditure between plant-
ing and harvesting will be the annual maintenance of a system of firebreaks.
Suppression of nearby conflagrations in cooperation with the Florida
Division of Forestry will be a constant management function of the BESI
forestry staff. We do not intend to practice prescribed burns at this
time. Possibly, fuel accumulation on a stand by stand basis may support
experimental controlled burns. Fire may be an effective management tool
for use between rotations, following the harvest. Mineralization of the
litter and slash well might enhance the coppice growth. This will be a
subject of future research.

Spontaneous combustion in a hardwood chip storage pile of
50,000 tons was reported by Boggan (1977). Temperatures increase in whole-
tree chip piles to $140^{\circ}F$ ($60^{\circ}C$), which drives off moisture and improves
fuel value (Motley, et al., 1980). Because of the uncertainty surrounding
the fire hazard of whole tree eucalypt chips, which may produce more volatile
gases than native hardwoods, chip storage piles should not be larger than
10,000 tons (the larger the pile, the higher the internal temperature), and
their internal temperature should be monitored closely. At the plant site
chip storage area, a water sprinkling system should be available to lower
internal pile temperatures if the heat buildup becomes hazardous. Ideally,
eucalypt wood chip storage at the plant will be minimized until we have
gained experience and better defined the problem.

2.7.4   Potential Damage from Disease and Insects.   Mono-
specific plantings of many species of *Eucalyptus* have produced high-yield-
ing stands up to 40-50 m^3/ha/year in contrast to 10-25 m^3/ha/year in native
Australian stands (Florence and Shepherd, 1975).   A Brazilian plantation
of 40,000 hectares produced 40 tons/ha/year in the third rotation and a
target of 100 tons/ha/year appears reasonable (Abelson, 1982).   The major
difference between native and exotic stands is the relative absence of
foliage damage to introduced eucalypts by disease or insects when compared
with the same species in Australian forests (Heather and Griffin, 1978).
In fact, the depressed growth and productivity of subalpine *Eucalyptus*
in Australia has been attributed to continuous grazing by phytophagous
insects (Morrow and LaMarche, 1978).   In another example, Podger (1975)
reports 106 forest insects attacking *E. saligna* in Australia.   At present,
there have been no serious infestations of Florida eucalypts in forest
plantings.   However, plant pest impacts on *Eucalyptus spp.* may increase
as plantings are expanded in Central and South Florida.   If a severe problem
occurs, a pest control management strategy will have to be implemented.

Schory (1960) wrote that attacks by insects and disease in
Florida were uncommon, and that no significant damage had been observed
and reported in the United States.   LeBarron (1962) indicated there were
no serious pests present in Hawaii's eucalypt forests; but, that it was
an always present threat.   Beetles have been a serious problem for eucalypts
in North Africa (Brunck, 1975).   Termites in many tropical countries have
been known to kill large numbers of living trees (Pong, 1974; Greaves, et al.,
1967; Momoh and Gibson, 1975).   The extent of risk is difficult to assess.
Introduced trees on favorable sites with suitable soil, climatic,and mois-
ture conditions, often are suprisingly free of insect pests.   This appears
to be the case in Florida, California, and Hawaii.   South African eucalypts
are relatively free of insect and fungal attack except for two insects
imported by accident from Australia (Green Heritage Comm., 1978).

A wide variety of fungi can attack locally grown eucalypts, causing stem or root damage (Kuhlman and Barnard, in ms). Fungi of the genus *Cylindrocladium* are particularly widespread vectors of leaf blights, stem cankers or root rot in eucalytps. *Diaporthe cubensis* fungi is an important cause of stem cankers on eucalypts in Brazil and Surinam (Hodges, et al., 1979). Damage is most severe among trees less than 6 to 8 years old. Infections are commercially significant in Brazil, promoting research for tolerant genotypes. High rainfall in a tropical climate appears to be necessary for a severe outbreak. *Clitocybe tabescens*, commonly referred to as "mushroom root rot", has been reported to occur on several eucalypt species in Florida, although damage potential is undetermined. It is widespread in distribution and often associated with large, rotting stumps. Heat lesions commonly are found on Florida seedlings just above the groundline on sunny, hot sites.

Although widespread in Australia, eucalypt pest problems are uncommon in Florida. Young saplings are much more prone to damage than well-established trees. Cattle periodically graze and trample them, deer may browse them, and hogs root them up. There also may be occasional grazing by beetles on tender new growth. These problems when detected are local and have impact on productivity in large plantations. Rabbits have been a serious problem in eucalypt forests in Australia (Rolls, 1969; Crane, 1972). A variety of small rodent species have damaged newly planted seedlings in California, leading to recommendations for in soil, wire rodent barriers.. When subject to cattle use, all new plantations should be fenced to protect young trees from grazing, trampling, and rubbing (Schory, 1960).

The potential threat of disease outbreaks in large mono-
cultures is always present because of (1) monospecific composition--
the extensive use of one select species, (2) reduced genetic diversity--
characteristic of clonally propagated crops, and (3) low plant resistance--
exotic species not adapted to pathogens in a new environment (Heather and
Griffen, 1978). These points must be addressed more comprehensively
prior to widespread eucalypt cultivation. Genetic selection in concert
with clonal propagation can act as an effective check system for harmful
pathogens. Plantations consisting of one or a few clones lack genetic
diversity. This can be overcome by planting many clones, with the members
of each clone spatially separated (Hartney, 1980).

BESI foresters do not consider the risk of damage to Florida
eucalypts from insects, fungi, and other pests to be sufficient to impede
establishment of plantations or significantly impair productivity. A
high degree of managerial vigilence should detect damage early enough to
combat the pest agent in most cases. This is clearly an area of concern
that will require research and attention as more plantations are installed.

2.8 <u>Harvesting Issues</u>. Accurately estimating harvesting costs, about $1500/acre in 1981 dollars, is crucial to the economic feasibility analysis because they are the largest single expenditures in the eucalypt wood production system. Fortunately, these expenses are incurred just before sale of the wood crop, so they need be financed for a brief period of time, if at all. Mechanical harvesting requires very expensive heavy equipment and a skilled work force. With the rapid changes in the state-of-the-art technology, predicting the specific harvest system to be used in 1989-1990 is unnecessary; while estimating the capital, labor, and operating costs of that system is speculative at best. We have found very little information in the literature specific to our questions about harvesting systems and methods, timing of the harvest, coppicing, the relationships between harvest techniques and coppice yields, and site preparation for the coppice rotation.

2.8.1 <u>Harvest Systems</u>. The procurement of wood from
the forest for use as fuel, fiber, or food has evolved from harvesting
entirely by hand to nearly complete automation and mechanization.

In many cases hand labor has been displaced by machines
because of the increasing cost of labor, safety, the expense of workman's
compensation insurance, and industry requirements for increased productivity.

Changes in silvicultural recommendations and forest management
techniques have also dictated changes in wood harvesting systems. Closer
spacing, improved seed lots, and clonal plantlets have increased the
potential for per acre wood production. In Australia, a mechanized harvester
reduces labor requirements by two-thirds as opposed to normal billet.
operations (Cromer, 1975). Whole tree chipping provides a profitable use
for forest lands previously considered unproductive (Butts and Preston, 1979).
An extremely comprehensive discussion of whole tree chipping systems has
been provided by the FAO (1976) and JPR Assoc. (1981). Continually moving
harvesters are technically feasible (Kerruish, 1977) for harvesting short
rotation eucalypts. Howlett and Gamache (1977) observed that trees larger
than 4 inches (10 cm) in diameter at ground level would have to be harvested
using a conventional whole-tree harvesting system or some modification
thereof. Silage type harvesting systems may be applicable for stands less
than 3 years of age (Rose, 1976; DeBell and Harms, 1976). A short-rotation
harvester could sever, chip, and relocate chips via a blower into a trailing
van or wagon (Dutrow, 1971). Whole tree chipping, besides producing raw
material, can also dispose of slash as an alternative to burning (FAO, 1976).
Warren (1977) and Miyata (1980) offer guidelines for estimating fixed and
operating costs of logging equipment.

Among the highest harvesting costs using conventional systems that we encountered were $13.60/ton ($12.34/tonne) in 1977 and $16.32/ton ($14.81/tonne) in 1980 for whole-tree chips (Ga. Forestry Comm., 1980). A cost of $7.50/ton ($6.80/tonne) for whole tree chips, excluding stumpage or transportation, was quoted by Morbark (1980). A range of costs was reported by Motley, et.al. (1980) from $7.70/ton ($6.99/tonne) to $11.12/ton ($10.09/tonne) for various harvesting systems. Lee Timber Company (pers. comm.) reported harvesting costs of $14.29/ton ($12.96/tonne) for a pulpwood stick operation in South Florida. Another Florida logging contractor reported harvest costs of $10.00/ton ($9.07/tonne), plus transportation, for a whole tree logging operation (J.A. Martin, pers. comm.)

Because of the wide range in harvesting expenses, BESI has chosen to use a $10/ton ($9.07/tonne) cost. When equated against a projected harvest of 154 tons (140 tonnes) per acre, harvesting costs approximate $1500/acre ($3360/ha). We believe that when the harvests are needed beginning in 1990, systems will be available that offer the eucalypt grower a profitability factor equivalent to that resulting from a $10/ton ($9.07/tonne) present day cost.

For current planning purposes, harvesting systems utilized should be those of proven performance. As prototype systems are developed and ascertained feasible through field trials, consideration will be given to any equipment which increases productivity, lowers per unit production costs between the plantlet and the plant, and lends themselves to overall operational profitability.

2.8.2 <u>Coppice Growth</u>. The economic feasibility of short
rotation woody biomass cropping depends upon reliable coppice regeneration.
This is particularly so because of the high initial planting costs of
tissue culture plantlets. The use of plantlets would not be cost effective
if they were not contributing to several harvests. Coppice growth, the
ability of a species to produce shoots from cut stumps, eliminates the
need for replanting the subsequent rotation; thereby saving several
hundreds of dollars per acre. The ability to coppice differs among species
and provenances within species (Opie, et al., 1978). *E. camaldulensis*
is well known for its coppicing ability. Hillis and Brown (1978) show
a coppice growth stand of *E. camaldulensis* in Israel where the very
impressive 5 year old sprouts (about 60-70 feet tall and 10-12 inches dbh)
were the sixth crop from the original stump!

Only those eucalypt species with lignotubers, which carry
food reserves and an abundance of accessary bud tissue, coppice readily
(Cremer, et al., 1978) from the root. Epicormic coppicing from stems is
highly variable. Coppicing allows plantations to survive fire, freezes,
and floods, as well as harvesting. We observed that small, containerized
seedlings of *E. grandis* and *E. robusta*, planted just a few days before a
hard freeze in Polk County, Florida, coppiced rapidly from their base.
Coppice regeneration is known to be highly variable by the season of damage
and site characteristics, as well as by species, provenances, and individuals.
Tissue culture propagation from coppiced stands not presently available to
BESI will help us to optimize this exceedingly valuable adaptation.

Thinning of the original stands of coppicing species is generally
detrimental (Cremer, et al., 1978); and we doubt that thinning of coppiced
sprouts down to 2 or 3 per stump would be cost effective because of high
labor costs. The greatest volume of wood in coppice rotations of *E. saligna*

in Brazil resulted from leaving 2 or 3 sprouts to the stump (Couto, et al., 1973; Howland, 1969). Simoes, et al. (1972) showed no difference in coppicing between axe or chain saw felling, and stem diameter had no effect upon regrowth. Shearing, however, may adversely influence the coppicing of stumps (Kerruish, 1978).

Stump mortality resulting from harvesting must be kept to a minimum since interplanting of existing stands is not feasible. Damage to the stump and roots by the felling device, and the other harvesting equipment is to some extent unavoidable. Thus, some increase in disease and subsequent stump mortality is inevitable. Kerruish (1978) recommends a smooth surface on the stump, a slight sloping to shed moisture, and little disturbance of the cambium. He notes that saw cuts are more suitable than axe cuts, and that recutting the original stump does not adversely affect coppicing. This is extremely important since shear-type mechanical harvesters may have to cut the stem at undesirable heights above the ground. The harvester can be followed by a chainsaw creating the proper conditions for optimum resprouting.

A stump height of 5-10 cm above the ground is recommended (Kerruish, 1978). Low growing coppice stems are less vulnerable to wind damage. Slash should be piled or removed at the time of harvesting so the stumps are free of logging debris. If the detrital fuel accumulation is high, a controlled burn when the soil moisture is high may prove highly beneficial to coppice growth.

Carter (1974) recommends three coppice rotations following the initial harvest. An FAO (1955) study indicates coppice yields of pulpwood to be 120, 90, and 80 percent of the first rotations' yield. Myburgh (1967) found in South Africa that yields declined with every succesive cut; but, this parameter probably is highly variable. Little yield data are available from successive rotations. The number of possible coppice rotations is equally uncertain; but, for a species like *E. camaldulensis*, three coppice harvests appears to be a conservative estimate. Many more high yield coppice rotations are possible with the proper harvest techniques to protect the roots and stump, proper cutting of the stump, and the use of tissue culture plantlets selected for high coppice yields. Simoes, et al. (1972) showed that the most vigorous trees produced the most vigorous coppice, and that stump survival was independent of tree vigor.

In Florida, timing of the harvest could have an influence on stump survival and subsequent coppice success. Research underway in Glades County on the seasonality of coppicing by the U.S. Forest Service has shown a definite and strong decline in regeneration during the summer months (G. Meskimen, pers. comm.). There has been no identification of the causitive factors. Hopefully, this subject will be better understood before BESI undertakes its first harvests. If necessary, most cutting can be scheduled for those months that favor coppice regeneration. This would necessitate extensive stockpiling of stems in the forest, and could induce a seasonality factor for the work force involved in harvesting.

Optimum coppicing is sufficiently necessary and valuable to justify adjustments in the other aspects of the eucalypt energy forest's management that interface with regeneration.

2.8.3   Site Preparation for Optimizing Yields of Coppice
Rotations. The yield from coppice rotations can be enhanced by a number
of site preparation procedures following the harvest. Mechanized
harvesting should be done when soil moisture is low to avoid soil damage
by compaction (Hassan, 1977; King and Haines, 1979; Moehring and Rawls,
1970). Soil texture on most Florida eucalypt plantations will favor the
use of mechanization with little damage. If rutting is severe, a light
discing may be desirable before leaving the site. Harvesting crews must
be closely supervised to avoid damage to the soil, roots, and stumps.

Logging slash will be minimal because of the in-the-woods
chipping of branches and tops. We expect that a controlled burn of the
accumulated litter and debris will be desirable. Ash from the gasifier
will be returned to the forest after harvest and applied between rows.
Rock phosphate, and other minerals, nutrients, and trace elements will
be applied as indicated by a full-spectrum soil testing program to evaluate
soil depletion, if any, following a rotation cycle. The wood ash contains
all the essential elements for tree growth, except for those removed by
gasification (Motley, et al., 1980). The ash will improve soil texture
and raise the pH in the more acidic flatwoods soils. In the mining region,
gypsum applications also may improve yields.

After the harvest, a woods crew should dress-out the mechanically-
harvested stumps to favor coppicing. Stumps of select trees in the stand,
the top 2-5 percent, should be marked and mapped for future comparison
with the quality of the coppice regeneration.

Site preparation following a harvest will be minimal in comparison to the preparation before the initial planting.

The controlled burn may obviate the need of a post-harvest herbicide treatment. Coppice regneration will dominate the site quickly; and, the established root systems will not lose their dominance. Probably, herbicides will not be required.

The stumps should be watched carefully during the first year following harvest for a possible increase in pathogen activity. A fungicidal treatment may be effective if stump mortality from a number of possible disease agents is observed. This is not a significant problem in Florida at this time.

Experience and experimentation with eucalypt plantations in Florida will provide the basis for a better informed approach to between rotations site preparation.

Once coppice cut yields drop to 60-70 percent of the original harvest, the stumps can be removed by bulldozer and burned if the land is to be placed into another use. If eucalypts are to be replanted, the stumps can be killed with an appropriate herbicide and the new trees planted between the rows. If site preparation between rows to reduce competition by the interplanting technique allows competing vegetation to capture the site, full site preparation as done for the initial planting will be required. Such decisions are almost a decade away and a great deal more information will be available upon which to base management decisions.

2.9   Wood Markets for Florida *Eucalyptus*. At the present time,
we visualize four probable markets open in 1990 to *Eucalyptus* from
Florida plantations: (1) a methanol refinery; (2) pulp; (3) fuelwood;
and, (4) chemical feedstock.

2.9.1   Methanol Refinery. The BESI engineering working
document on the methanol refinery gasification loop establishes the
suitability of *Eucalyptus* wood for gasification and methanol synthesis.
Similiar unpublished tests have been run on Brazilian *Eucalyptus* by a
BESI consultant and support the same conclusion. Indeed, a *Eucalyptus*
wood to methanol plant is said to be under construction at this time in
Brazil. There is little of a specific nature in the literature on the
gasification of eucalypts for methanol synthesis (Filho and Zagatto, 1980);
but, wood is widely regarded as a suitable biomass feedstock for gasifica-
tion (Johnson, 1980; Kohan and Barkhordar, 1979; OTA, 1980; SERI, 1979;
Wan et al., 1980).

In the event a methanol refinery is constructed in the study
area, it will require 70,000 to 100,000 acres of feedstock harvested on a
7 year rotation. Because of the competing markets for the eucalypt wood,
the methanol producer should own or control at least 50% of the total
feedstock required for full operations.

The availability of wood will be a determining factor   when
a methanol plant might begin production. At least 20,000 acres of planta-
tion should be in the 6th year, with another 15,000 acres in the 5th year,
before the plant could open. This assures a three year supply at start-up.
It is unlikely that enough feedstock to sustain a methanol plant would be
available for harvest before 1990, even if planting moves forward as rapidly
as practical in 1983.

2.9.2 Pulp. The suitability of eucalypts as a pulpwood
has been well documented (FAO, 1975; Franklin, 1977; Franklin and
Meskimen, 1975; Uhr, et al., 1972). The species tested vary considerably in
their fiber characteristics, but E. camaldulensis fibers have good
characteristics which permit their use in a number of different processes
(FAO, 1975). Much of the Eucalyptus chips exported by Hawaii and Australia
are used for pulpwood in Japan and Korea (Yang, et al., 1977) (Anon.,
pers. comm.). Most of the eucalypts in Brazil originally were planted
for a pulpwood use, including the Jari plantations now being harvested
and milled. The eucalypts in Glades County, Florida likewise were planted
for the pulpwood market. Florida could become a major exporter of
Eucalyptus pulpwood with sufficient plantations and effective marketing.
World pulpwood stocks are inadequate and prices are likely to increase
substantially for the rest of this century.

2.9.3 Fuelwood. Fuel markets for Eucalyptus biomass
include residential stoves and fireplaces, industrial boilers, and
power plants. All three markets have a high potential for development
and expansion over the next decade before substantial acreages of the
new Florida plantations are ready for harvest. BESI trials with E.
camaldulensis cut in the summer of 1981 as a residential fireplace fuel
during the 1981-82 winter met with a high degree of consumer approval.
We are looking toward larger trials next winter. Many Florida industries
would like to achieve energy independence and fuel their own boilers,
as well as cogenerate electricity. Several phosphate companies that are
large consumers of electricity are studying the feasibility of building
and operating power plants. Most of them have enough land to grow their
own wood fuel. Existing coal-fired power plants can be expected to burn
Eucalyptus fuelwood when it beomces available to lower air emissions in

response to the acid rain problem. BESI is confident that the Central and South Florida fuelwood market of 1990 will compete to capture all of the supplies available from nearby eucalypt plantations.

2.9.4 Chemical Feedstocks. Two recent editorials in Science predict a major increase in the use of biomass and wood as chemical feedstocks (Abelson, 1981; Abelson, 1982). Conceivably the chemical potential of wood might exceed in value its use as an energy source. The processing of cellulose holds great promise in manufacturing food and pharmaceuticals, as well as a host of other synthetic materials that now originate from coal and petroleum.. Large stocks of wood feedstocks must be grown in close proximity to the processing industrial complex. Once the wood becomes available in sufficient quantitiy, some such new industry could displace the methanol refinery as the ultimate consumer of the eucalypt forests.

2.10 _Economic Feasibility_. Objectives of our wood-to-methanol silvicultural research include an economic assessment of :

(1) the feasibility of _Eucalyptus_ energy plantations as an alternative land use in the study region;

(2) the costs of establishing, managing, and harvesting these biomass plantations;

(3) the market potential and the probable price at harvest of _Eucalyptus_ wood in the Florida and world markets;

(4) revenue potential; and

(5) break-even returns and profitability.

These assessments are made and discussed in the economics working document.

There is great interest in the economics of intensively managed forest resources. Interest in woody-fuel systems springs from their potentially attractive economic returns compared to standard forest practices (Rose and Kallstrom, 1976), as well as direct competition in the market place with fossil fuels. Research is just beginning in this area, and our review turned up no articles examining specifically the economics of intensively planted _Eucalyptus_. Even so, the extant literature does provide guidance as to methodology and computer programming. It is interesting to note that much of this literature is in the vein of standard micro-economic theory, but recognition of this relation is lacking.

The literature does establish the viability of intensively managed forest resources. As early as 1966, McAlpine, et al. (1966) reported on yields of intensively planted sycamores. McAlpine and Brown (1967) related their success in expanding yields by allowing for coppicing

in short-term rotations. Cottonwoods received attention from McKnight (1970) and Heilman, et al. (1972) as an intensively planted species, and DeBell (1972) focused on alders. Poplar intensive cultures have been researched in the Lake States (Rose, et al., 1981). In the ensuing research more species were investigated and the research of economic methodology became more vigorous. Major reviews of the intensive culture literature were completed by Smith and DeBell (1973) and by Steinbeck (1973). It has become obvious from these studies that while copious amounts of biomass can be produced, this does not necessarily insure economic feasibility.

Economic factors received greater attention when Dutrow (1971) and Olawoye (1972) reexamined the sycamore. This emphasis on economics received a major boost with the work of Rose (1975; 1977). Rose developed a generalized economic framework for analyzing intensive cropping practices, and he developed a computer simulation model. This represented a breakthrough of sorts by allowing analysts to conduct vigorous economic examinations of intensive plantings under conditions of imperfect information. This computerized analysis serves as the basis for the computer modeling to be conducted in this study.

The economic computer-model building technique developed by Rose (1975) was refined by Rose and Kallstrom (1976) and applied to other hardwood crops by Rose and DeBell (1978). Filho and Zagatto (1980) address the economics of a methanol from wood project in Brazil. The emphasis on economic analysis is vital since it is technially possible to produce copious amounts of biomass in short rotation silvicultural farms, but it may not be economically feasible (Howlette and Gamach, 1977).

Intensive cultivation practices can be expensive. The additional costs must be realized in greater biomass yield.. There are diminishing returns as more energy is injected into the system. Some researchers propose that the energy efficiency ratio is not nearly as important as the net returns, i.e. the available energy which is the difference between energy input and energy output (Zavitkovski, 1979). The goal of intensive silviculture in wood energy systems should be to maximize output at a competitive price, yielding a reasonable profit. Such feasibility can be determined only through careful analysis which considers the best uses of the land and capital involved.

3.0 PLANTATION HISTORY

Many of the observations, comments, and conclusions in this document are derived from the intensive study of two eucalypt plantations on reclaimed, phosphate strip-mining sites in Polk County, Florida (Figure 3-1). One planting is on overburden and one is on sand tailings. Site preparation at both plantations consisted of discing with a heavy disc pulled by a Caterpillar D-4 crawler tractor and bedded using a Rome heavy duty bedding and rolling harrow. Beds, 6-12 inches (15-30 cm) in height, were constructed on 12 foot (3.7 m) centers. Application of 0.5 ton acre (1.12 tonne/ha) of ground rock phosphate was made prior to discing. According to Lee Draper (pers. comm.), Container Corporation of America (CCA) research forester, *E. camaldulensis* seed for these plantings was provided by the U.S. Forest Service, Lehigh Acres Laboratory, to the Florida Division of Forestry's Herron Nursery. The seed originated from the Glades County seed orchard maintained by the U.S. Forest Service which was initiated with seed from a Spanish source of unknown provenance (E.C. Franklin, pers. comm.).

3.1 Overburden Planting. The overburden plantation is approximately a 10 acre (4 ha) planting off Walker Road in Section 28, Township 32 South, Range 24 East (Figure 3-1). The land has long been owned and managed by Agrico Chemical Company and its predecessors. Original land acquisition was for the purpose of phosphate mining. There is no recorded evidence of land improvement prior to mining. The pre-mining plant community was native range dominated by wiregrass, broomsedge grass, palmetto, gallberry, slash and occasionally long-leaf pines, and various other plants typical of scrub flatwoods.

3.1.1 Mining. The property was mined from 1969 to 1971. Mining depth ranged from 20-40 feet (6-12 m), and 5,000-8,000 tons/acre (11,000-18,000 tonne/ha) of phosphate ore was recovered through Agrico's Payne Creek washer, which lies about 1.5 miles (2.5 km) to the west. Mining was done with a Bucyrcus-Erie 1260B dragline, assembled on-site in 1964 near the washer.

3.1.2 Reclamation. Reclamation of the area began in 1972 and was completed in 1974. The reclamation was a land and lakes type, where over-burden was relocated to lower areas by use of bulldozers and/or pans. Moderately

FIGURE 3-1

Polk County Location Map
Agrico and Grace Plantations

Source: 1980 Polk County Atlas
          Rockford Map Publishers
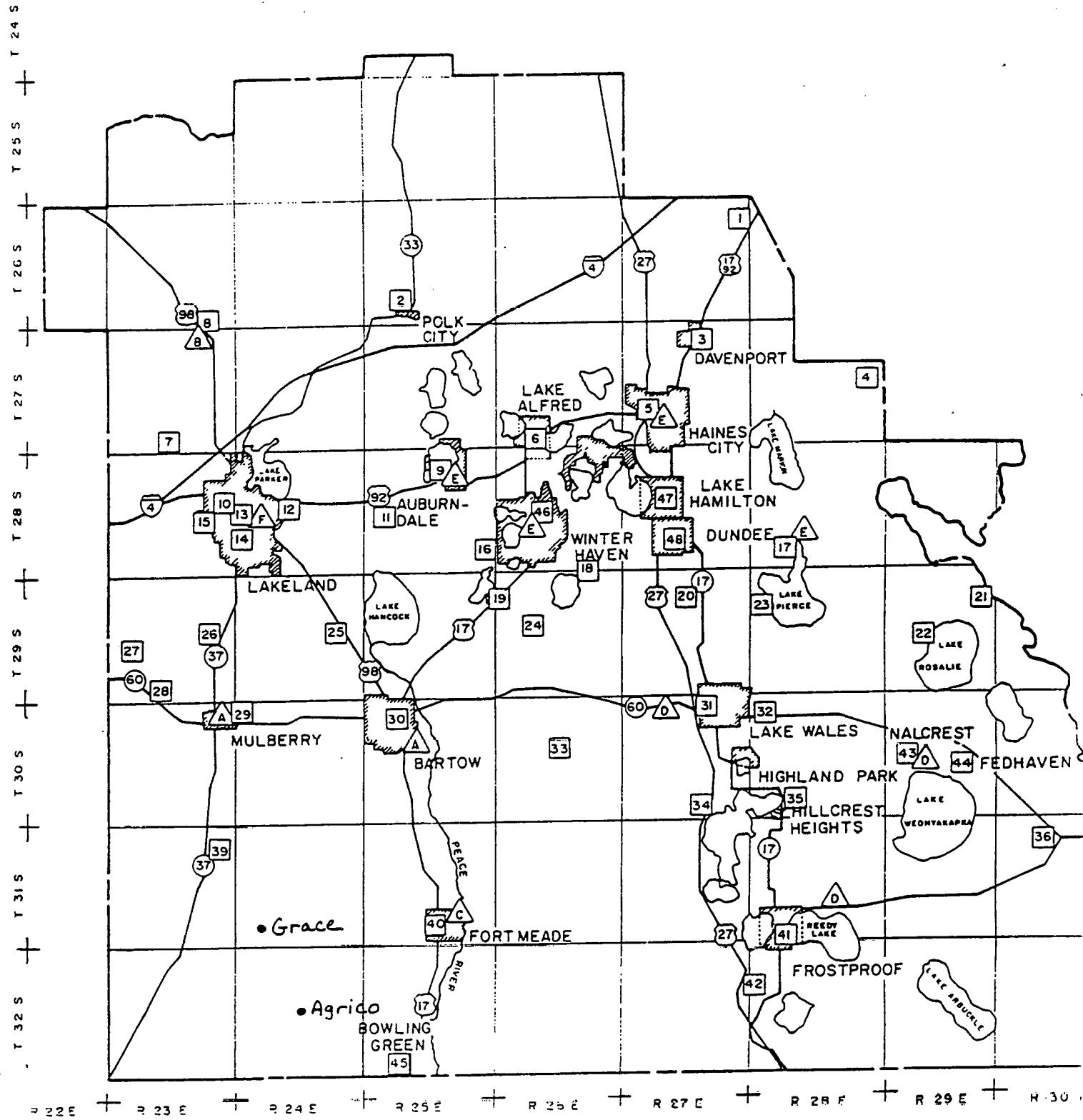
sized, interconnected water bodies were retained for cattle watering, wildlife and fish habitat, and esthetic value. Improved bahia grass (Argentine) and winter rye (Gator) was planted in the southeastern portions of the area, as well as along the periphery of water bodies for erosion and sediment control.

3.1.3 Planting. *Eucalyptus camaldulensis* and *E. tereticornis* were planted in July 1974 by CCA. Approximately 8 acres (3 ha) of *E. camaldulensis* were planted in the plot's southern portion and 2 acres (1 ha) of *E. tereticornis* on the north. Trees were planted 6 feet (2 m) apart within the rows, giving an original planting density of 605 seedlings per acre (1495/ha). Mean sea level elevations range from approximately 120-140 feet,(36.6-42.7 m) with Little Payne Creek in the northeast corner of Section 28 at approximately 110 feet(33.5 Other than the initial bedding, discing, and rock phosphate application of 0.5 tons per acre (1.12+/ha), no other silvicultural practices have been needed. Beds generally run east/west in order to intercept and otherwise impede rainfall runoff flowing down-gradient into the created water bodies. In some cases, old mine pipe was installed as "culverts" where large volumes of water were anticipated. Ground elevations generally fall from west to east and from south to north.

The planting procedure followed standard eucalypt forest establishment practices, using state-of-the-art recommendations from the U.S. Forest Service Laboratory at Lehigh Acres and the Florida Division of Forestry. As might be expected, residual phosphate levels, even seven years after planting, exceeded normally measured limits for P_2O_5 as provided by the University of Florida soil testing service. Presently, the trees show no obvious signs of phosphate degrade due to high phosphate levels. Preliminary soil testing and the determination of definitive soil nutrient needs is essential prior to planting large acreages. There should be no application of rock phosphate fertilizer to reclaimed mine soils unless a phosphate deficiency has been demonstrated by testing. Phosphate degrade may be correctible by additions of nitrogen and potassium, when necessary, to bring soils more nearly into the recommended nutritional balance for plant growth.

3.1.4 Growth. At approximately 6-1/3 years of age, the largest *Eucalyptus camaldulensis* was 14.1 inches (35.8 cm) in diameter at breast height (dbh; taken at 4.5 feet or 137 cm above ground), and the tallest was 97 feet

(29.6 m). Overall survival was 74 percent (450 stems/acre; 1,334 stems/ha). Less than 30 percent of the original planting had a dbh of 5.0 inches (12.7 cm) or more. Total per acre volume at 6-1/3 years was estimated at 1,527 cubic feet (106.85 m^3/ha). Mensurational data from remeasurements by BESI foresters indicated growth increases of up to 20 percent from November 1980 to July 1981, demonstrating an absence of winter dormancy. This recent growth increase during a period when growth was expected to decrease, supports a hypothesis that the stand may be recovering from phosphate toxicity, and that early potential growth was never realized. Examples of 2/3 year dbh increases covering all diameter classes are presented in Table 3-1 and 3-2.

3.2 Sand Tailings Planting. The sand tailings plantation is an approximately 12-acre (5 ha) planting lying north of State Road 630 and southwest of Agrico's South Pierce Chemical Works, in Section 30, Township 31 South, Range 24 East (Figure 3-1, see page 67). This plantation was recently acquired by the Agricultural Chemicals Division of W. R. Grace and Co. for possible use as a waste disposal area.

3.2.1 Mining. The area was mined as part of the Hooker Prairie mining operation of the American Agricultural Chemical Company (AAC) and was a waste disposal site for AAC washer #12. Thus, a greater mix of mined soils is aerated, with patches of overburden, sand tailings, clay, and debris intermingled. The property was mined during the 1940's and early 1950's. Information on mining depths and rock recovery is not available; however, the quality and quantity of the pebble fraction of the matrix was high, based on the relatively early mining date. Thus the levels of P_2O_5 in the plant root zone likewise will remain high over the long term.

3.2.2 Reclamation. In 1969, a successor company to AAC, Agrico Chemical Company, did some token reclamation in the area. Some low areas were filled and some peaks were eliminated. The area was planted with hairy indigo (a nitrogen-fixing legume and soil builder) and common Bermuda grass in 1970. Some indications of this initial planting are evidenced by the natural reseeding of indigo each year and the spread of common Bermuda grass where soil moisture is adequate. The indigo crop was never sufficient to warrant seed harvesting as intended.

TABLE 3-1

RECENT GROWTH INCREASE--OVERBURDEN

MEASUREMENT Nov. '80		MEASUREMENT July '81		% INCREASE		
DBH	HEIGHT	DBH	HEIGHT	DBH	HEIGHT	VOLUME
2.8"(7.1cm)	27'(8.2m)	3.6"(9.1cm)	30'(9.1m)	28.6	11.1	79.1
3.1"(7.9cm)	28'(8.5m)	3.8"(9.7cm)	30'(9.1m)	22.6	7.1	58.5
5.0"(12.6cm)	44'(13.4m)	5.5"(14.0cm)	52'(15.8m)	10.0	18.2	39.3
8.0"(20.3cm)	59'(18.0m)	9.1"(23.1cm)	63'(19.2m)	13.7	6.8	37.0
12.4"(31.5cm)	66'(20.1m)	13.3"(33.8cm)	72'(21.9m)	7.3	9.1	24.2

TABLE 3-2

RECENT GROWTH INCREASE--SAND TAILINGS

MEASUREMENT Nov. '80		MEASUREMENT July '81		% INCREASE		
DBH	HEIGHT	DBH	HEIGHT	DBH	HEIGHT	VOLUME
16.4"(41.7cm)	60'(18.3m)	16.7"(42.4cm)	68'(20.7m)	1.8	13.3	15.7
7.9"(20.1cm)	54'(16.5m)	8.7"(22.1cm)	58'(17.7m)	10.1	7.4	29.0
7.7"(19.6cm)	46'(14.0m)	8.3"(21.1cm)	60'(18.3m)	7.8	30.4	45.8
10.3"(26.2cm)	55'(16.8m)	10.8"(27.4cm)	65'(19.8m)	4.9	18.2	27.1
6.1"(15.5cm)	47'(14.3m)	6.5"(16.5cm)	57'(17.4m)	6.6	21.3	33.8
9.3"(23.6cm)	66'(20.1m)	9.9"(25.1cm)	73'(22.3m)	6.5	10.6	23.9
11.1"(28.2cm)	64'(19.5m)	11.8"(30.0cm)	70'(21.3m)	9.6	9.4	22.3

3.2.3 _Planting_. In the spring of 1974, CCA and Agrico decided
to plant a 10-acre block of eucalypts ranging from nearly the highest point
in elevation to the lowest. The depth of sand correspondingly ranges from
approximately 50 ft. (15m) on the west to about 4 ft. (1m) on the east. Underlying
the sand is a phosphatic clay residue of undetermined thickness. The site
was planted with _Eucalyptus camaldulensis_, except for the westernmost six rows
which are occupied by _E. tereticornis_. Mean sea level elevations range from
110-160 feet (33-49m). In 1975, an additional two acres were planted with
E. tereticornis at the south edge of the original planting.

Both plantings were accomplished using the same recommended eucalypt
forest establishment practices as at the Walker Road site. The planting density
of 605 trees per acre (1,495/ha) also was repeated. Beds generally run north/
south to intercept and impede rapid rainfall runoff. This is a technique of
erosion control not normally needed in the flat lands of peninsular Florida.
The need for erosion control on tailings sand areas is less critical than
erosion control measures on heavy soils. Because of rapid percolation and the
depth of sand at maximum elevations, plants at the higher elevations are usually
in a state of moisture deficit stress. Within one year after planting, both
the leaves and stems of many plants became very red, indicating stress. A
mineral deficiency was suspected initially; however, tests revealed the minerals
and nutrients necessary for growth to be within acceptable ranges. Gradual changes
from red to green beginning with heavier summer rainfall and gradual reversal
during droughty winter and spring months reinforced an interpretation of moisture
deficit stress. The plants in the deeper sands at the higher elevations showed
more evidence of moisture deficit stress, with poorer growth and survival.
Neither the overburden nor the tailings plantation was subjected to ground cover
and weed control practices; and, competition before canopy closure undoubtedly
inhibited growth and decreased survival.

3.2.4 _Growth_. Compiled data from the sand tailings planting
indicated that survival, height, diameter, overall volume and general plantation
appearance improved at lower elevations within the site. The mean dbh of dominant
and co-dominant stems in rows 1-20 (lower elevation) was one inch (2.54 cm)
greater than the mean for rows 21-40. Mean heights for the lower elevation was
nearly 7 feet (2.1 m) more than stems at the higher elevations. Survival at
lower elevations was 50 percent and 44 percent at higher elevations. The dominant
stems downslope held a 34 percent volume advantage over stems occuring at the

higher elevations. Soil tests to a 2 foot depth (0.6m) did not reveal any major soil nutrient differences. The history of the area and an examination of discarded cores from recent exploration drillings (fine phosphate particles) indicated a higher moisture content at the lower elevations with a higher than normal occurrence of montmorillonite clays within reach of the plant's root system during early tree establishment.

Generally, each new phosphate recovery plant is more efficient than the last. A plant processing ore thirty years ago was relatively inefficient and failed to recover many of the phosphatic particles now recovered by improved methodology. Phosphate in the pebble deposits of Florida is recovered through a screening process. Pebbles are sized from a greater than 14 mesh to a less than 150 mesh. Fines, which fall in the less than 150 mesh are recovered from the sand fraction of the ore body through a float and reverse float process using various chemical agents and processes upon which technology continues to improve. Thus, the older mined soils have higher P_2O_5 levels than the recently mined soils. As at the overburden site, current phosphate levels exceed the normally measured limits of P_2O_5 as provided by the University of Florida soil testing service (Table 3-3). Again, the trees showed no morphological signs of phosphate degrade stress due to high P_2O_5 levels in the soil.

At approximately 6-1/3 years of age the largest E. *camaldulensis* measured 16.4 inches (41.7 cm) dbh and the tallest E. *camaldulensis* was 73 feet (22.3 m). Overall survival was 59 percent (357 stems/acre; 882/ha); however, less than 30 percent of the original planting had a dbh of 5.0 inches (12.7 cm) or more. Total volume on a per acre basis at 6-1/3 years was estimated at 1,410 cubic feet (98.6 m^3/ha). Data based on remeasurements by BESI foresters indicated growth increases of up to 20 percent or more during November 1980 to July 1981. Again, this recent growth increase supports a theory that perhaps the stand is still in a state of recovery from early phosphate toxicity and that early growth potentiality was never realized. Other factors possibly contributing are reduced competition with understory plants and seasonally improved soil moisture conditions. Examples of 2/3 year dbh and height increases, which range through all diameter classes, are shown in Table 3-2 (see page 71).

TABLE 3-3

SOIL ANALYSIS AND RECOMMENDATIONS
SAND TAILINGS

LAB NUMBER	SAMPLE IDENTIFICATION	CROP TO BE GROWN	SOIL TEXTURE	ORGANIC MATTER	PH	PHOSPHORUS P2O5	POTASSIUM K2O	CALCIUM CaO	MAGNESIUM MgO	LIME TONS/A	N	P2O5	K2O
						LB/A AND RATING					LB/A		
11051	1	EUCALYPTUS(S. FLA.)	SAND	LO	5.6	916 VHI	19 VLO	5599	90 LO	0.0	200	0	50
11052	2	EUCALYPTUS(S. FLA.)	SAND	LO	5.9	916 VHI	19 VLO	5599	80 LO	0.0	200	0	50
11053	3	EUCALYPTUS(S. FLA.)	SAND	LO	5.7	916 VHI	19 VLO	5599	120 MED	0.0	200	0	50
11054	4	EUCALYPTUS(S. FLA.)	SAND	LO	5.9	916 VHI	28 VLO	5599	120 MED	0.0	200	0	50
11055	5	EUCALYPTUS(S. FLA.)	SAND	LO	5.4	916 VHI	19 VLO	5599	66 LO	0.0	200	0	50
11056	6	EUCALYPTUS(S. FLA.)	SAND	LO	5.8	916 VHI	19 VLO	5599	66 LO	0.0	200	0	50
11057	7	EUCALYPTUS(S. FLA.)	SAND	LO	5.4	916 VHI	19 VLO	5599	106 MED	0.0	200	0	50
11058	8	EUCALYPTUS(S. FLA.)	SAND	LO	5.3	916 VHI	19 VLO	5599	120 MED	0.0	200	0	50

4.0 SITE PREPARATION

4.1 <u>Background</u>. Experience in South Africa, South America, Israel, Hawaii, as well as Florida and the eucalypt plantation literature document that the optimum growth of eucalypts ultimately is determined by the quality of site preparation. Previous recommendations for the planting and establishment of eucalypt plantations in Central and South Florida have been: (1) disc and chop; (2) bed; (3) apply from 0.5 to 1.0 ton of ground rock phosphate per acre (1.12-2.24 tonne/ha); and (4) control native vegetation for at least one year after planting (Meskimen, 1971).

4.1.1 <u>South Florida</u>. The native palmetto prairie and flatwoods of South Florida, including Glades County, carry the only commercial plantings of eucalypts in the eastern United States. Site preparation, species selection, planting, and other silvicultural management recommendations from state and federal agencies generally have been directed towards this specific site. For example, there is no historic evidence of pine forests on the palmetto prairie. Therefore, there are no residual trees or stumps which would necessitate stump removal before the initial planting. Site preparation generally has not included the complete or long-term control of herbaceous and graminoid understory vegetation, although limiting competition in the first year is a recommended practice. Site preparation recommendations for South Florida have included chopping and/or double chopping as necessary to eliminate palmetto and other native ground cover competition. Typically, ground rock phosphate is applied at a rate of 0.5 to 1.0 ton per acre (1.12-2.24 tonne/ha). Single furrow planting beds, up to 2 feet (61 cm) in height and 4-6 (1.2-1.8 m) in width, are thrown-up on 12 foot (3.7 m) centers. Bedding is a standard treatment because inundation of all sites is probable during a normal rainy season. From Lake Okeechobee south to the tip of peninsular Florida, the slope of land is generally less than 2 inches per mile (3 cm/km) and soils are waterlogged for extended periods.

4.1.2 <u>Central Florida--Native</u>. Current site preparation practices for forest plantations in Central Florida vary according to two primary land types: (1) phosphate mined and reclaimed lands; and (2) native, unmined lands.

Recommended practices for the native, unmined lands include those treatments used in South Florida. As a minimum, land will be chopped and double-disced (i.e., disced in two directions). Chopping should be done with a double drum chopper or its equivalent, and discing with an offset harrow having cutting blades at least 24 inches (61 cm) in diameter. As required, the chopped and disced land may be cross-disced with a citrus grove type disc having a 12-18 inch (30-46 cm) diameter cutting blade, if leveling or breaking of large clods is necessary. Bedding is necessary only if drainage is poor or if low elevations cause prolonged inundation. Pine stumps must be removed. Dependent upon the quantity, pine stumps can be a saleable item to stump wood distillers like Hercules, Inc. in Brunswick, Georgia or Reichhold Chemicals in Pensacola, Florida. If not saleable, stumps must be uprooted from the ground with a bulldozer, piled, and burned prior to chopping and discing. Chopping, discing, stumping, and bedding (as required) should be completed at least 20 days in advance of planting. Ideally, at least one 1-inch (2.54 cm) rainfall should occur after preparation and prior to planting in order to settle the newly prepared soil substrate. In addition, a post-emergence type herbicide should be employed in order to keep the site clear of vegetative competition for at least 12 months. Herbicide recommendations will be discussed in the planting and maintenance sections.

4.1.3 <u>Central Florida--Reclaimed</u>. Phosphate mined and reclaimed lands can be among the most fertile soils in Florida. After mining and reclamation, these soils are characterized as sand tailings, overburden, sand-clay mix, or overburden cap over tailings, depending upon their respective roles in the mining process and the reclamation procedures. Since the native soils of peninsular Florida typically are Immokolee, St. Lucie, and other leached, infertile, and soil sandy types, the incorporation of kaolinite and montmorillonite

clays at or near the ground surface enhances the water-holding capacity of re-
claimed soils. Evidence indicates that mined soils show increasing pH values
as clay content increases. Consolidated clay settling areas, which tend to be
homogenous soil mixes (almost pure clay), have a pH of 7 or more.

4.1.3.1 <u>Site Quality</u>. The site quality for plant growth
on various phosphate mined and reclaimed soils increases as the amount of
incorporated sand tailings decreases. Our literature search has found no refer-
ence to site index tables for eucalypts like those available for the various
pine species. Based on our observations, at 6-1/3 years of age, the overburden
plantings offer an almost straight line curve height advantage of 10 feet (3 m)
for all diameter classes when compared to sand tailings. On both sites, annual
growth exceeded 10 feet (3 m) in height and 1 inch (2.54 cm) dbh for the better trees.

Site quality for *E. camaldulensis* appears related to the
availability of moisture, since empirical evidence suggests that it is influenced
by the clay content of the upper soil strata. Site preparation for phosphate
mined and created soils should include the incorporation of clays or a clay bear-
ing overburden stratum as an integral part of the reclamation and land reconstruction
process.

While soil suitability is important in maximizing productivity,
establishment of productive eucalypt plantations is possible on most natural and
reclaimed soil types.

4.1.3.2 <u>Site Preparation</u>. Preparation of reclaimed phos-
phate lands for eucalypt planting will require heavy discing, light discing and
soil testing to determine the pH and available plant nutrients. In mined areas,
stumping will not be a factor; but mining debris, such as rocks, pipes, cable,
and other trash, often require manual removal. Raking may be needed between
the initial and final discing in order to establish a smooth and level planting
site. Bedding normally will not be a necessary part of site preparation on

reclaimed land. Current state regulations dealing with reclamation of phosphate mined lands, except for wetlands reclamation, require adequate surface drainage and control of rainfall runoff.

Generally, pH should range between 6 and 7 in order that nutrients more readily may be taken up and utilized. If the pH is less than 5, lime or dolomite must be incorporated into the soil between discing operations. If soil testing reveals a need for dolomite or lime, applications probably would be in the range of 0.5 to 1.0 tons per acre (1.12 to 2.24 tonne/ ha). For the Central Florida phosphate district, dolomite generally provides the best soil conditioning because of its magnesium content; however, the amount of magnesium varies by mining location. Magnesium requirements may dictate the material source. When installing eucalypt plantations, soil testing should determine shortages, if any, of certain other trace elements, such as boron, zinc, and iron. A one-time soil treatment is relatively inexpensive compared to losses of production associated with shortages of necessary minerals and trace elements. Normally, soil treatments have not been necessary in Florida except for the application of rock phosphate on native soils. Where excessive amounts of phosphate are available in the soil, there is the possibility of a phosphate degrade problem. This toxic response possibly may be overcome by applications of nitrogen and potash in order to achieve a more normal balance with the phosphate concentration. Much more research is needed before the phosphate degrade problem, if it exists at all, can be put to rest. Table 4-1 includes a selection of locally available equipment which may be required for site preparation along with current list prices.

TABLE 4-1

Examples and Price of Locally Available
Site Preparation Equipment

4 wheel drive pickup for supervision and/or transportation to job
site. Includes automatic trans., ps, pb, air, step bumper, dealer
prep., destination charges.

Chevrolet K-10 $11,312 + tax
Toyota (5 speed trans.) $10,200 + tax
Dodge (318 engine) $ 9,400 + tax

Bottom Plow
$1500   3 disc

Bulldozer w/rake and blade

Komotsu D-85-E-18 (26" shoes) $193,900   Equiv. D-7
Caterpillar D-7-G $190,700

Komotsu D-155 (28" shoes) $255,500   Equiv. D-8
Caterpillar D-8-K $253,500

Wheel tractor 50-60 PTO Hp

John Deere 2240   50 Hp PTO $16,500
Ford 4110   48 Hp PTO $15,632
Ford 5610   62 Hp PTO $20,000
Massey Ferguson 255   60 Hp PTO $13,692
Deutz (air cooled)   60 Hp PTO $13,426

Heavy duty harrow TRH (Rome)

16 discs   30" dia $16,215
20 discs   30" dia $18,120

Bedding Harrow TRBR (Rome)

6 discs   30" dia $14,420

Chopper (Single drum - Fleco) (Double drum - Marden)

10' wide-Single $25,315   12' wide-Single $30,020
 7' double drum $26,325   8' double drum $34,625
10' double drum $38,425

5.0 PLANTING

Planting commences after proper site preparation, and when soil moisture conditions and freeze hazards have been considered. Success is measured by a survival rate greater than 80 percent. Climatic conditions are the most likely threat to high survival, if the plant lines are selected for drought resistance and frost hardiness; and, if the laboratory and greenhouse production is of a high quality. The procedures in each instance are those we intend to use in the establishment of BESI plantations.

5.1 **Climate.** Trees of the genus *Eucalyptus* primarily are native to Australia, with many species renowned for their rapid growth characteristics. The natural distribution of eucalypts covers a wide range of climatic conditions; however, most do not do well where temperatures rapidly drop below freezing. Consequently, eucalypts have been planted extensively and exclusively in the warmer regions of the world for timber, fiber and energy production. In the continental United States, fast-growing eucalypts are grown commercially in locations like Southern California and South and Central Florida where killing frosts are infrequent and of short duration. This good fortune puts Florida in a unique position to capitalize upon one of the most productive woody biomass crops.

5.1.1 **Freeze Probabilities Relative to Eucalypts Cultivation.** Central and South Florida's subtropical climate makes it the most suitable region with large acreages of land available for the cultivation of *Eucalyptus* within the continental United States. Over 50% of the reporting weather stations in Australia record minimum temperatures comparable to peninsular Florida (Mariani, et al., 1978). This permits the introduction of a variety of species/provenances that have promising biomass potential, many of which are thus far untested in Florida.

Freezing temperatures within the eucalypt region are primarily
restricted to the months of December, January, and February. In the
study area of West-central Florida, the mean date of the first freeze
ranges from December 20 to January 20 and the mean date of the last
freeze ranges between January 10 to February 10 (Table 5-1). Individual
trees are producing woody biomass throughout the year unless defoliated
by a freeze or fire.

Most of the more productive eucalypt biomass candidates also
tend to be the least cold tolerant. The most important criterion deter-
mining the extent of freeze damage is the age and size of the trees exposed
to a given freeze event. Young saplings are particularly susceptible to
cold damage, whereas older trees are more resistant. In addition, pre-
vailing temperatures during the period preceding a freeze event are critical
in determining damage to cold sensitive plants of all ages.

Even when planting a frost resistant *Eucalyptus* species recom-
mended for this area, like E. *camaldulensis*, freezing temperatures could
be sufficiently cold to devastate a newly installed plantation before the
trees have grown enough to optimize resistance. The damaged trees can be
expected to respond with coppice growth. The period between
mid-November and early March have freeze probabilities ranging from 10 to
100 percent in Polk County. Planting during this time span is a calculated
risk. However, for large scale commercial biomass operations, extension of
the planting period is essential to efficient operation of plantlet supply
systems. Reasonable estimates of loss potential can be made using the
University of Florida's Institute of Food and Agricultural Science freeze
probability charts (Bradley, 1975) and then applied to a risk-benefit analy-
sis. Freeze probabilities from the Lake Alfred station (Polk County) are
presented in Figure 5-1. Planting might reasonably be extended to include
October in the fall and February in the spring if moisture was not a critical
factor. With more experience and research, greater frost resistance can be
developed through genetic improvement and vegetative propagation.

TABLE 5-1

Probable Freeze Dates

PROBABLE DATE OF FIRST FREEZE	LAKE ALFRED				
	.10	.25	.50	.75	.90
$T \leq 32^{o}F$	Nov 24	Dec 10	Dec 27	Jan 14	Feb 1
$T \leq 28^{o}F$	Dec 10	Dec 26	Jan 20	*	*
$T \leq 24^{o}F$	Jan 13	*	*	*	*
$T \leq 20^{o}F$	**	**	**	**	**
$T \leq 16^{o}F$	**	**	**	**	**

PROBABLE DATE OF LAST FREEZE					
	.90	.75	.50	.25	.10
$T \leq 32^{o}F$	Dec 28	Jan 16	Feb 3	Feb 21	Mar 8
$T \leq 28^{o}F$	*	*	Jan 12	Feb 1	Feb 16
$T \leq 24^{o}F$	*	*	*	*	Jan 14
$T \leq 20^{o}F$	**	**	**	**	**
$T \leq 16^{o}F$	**	**	**	**	**

* Less than indicated probability
**Less than 5 occurrences

Source: Bradley, 1975

FIGURE 5-1

Freeze Probabilities
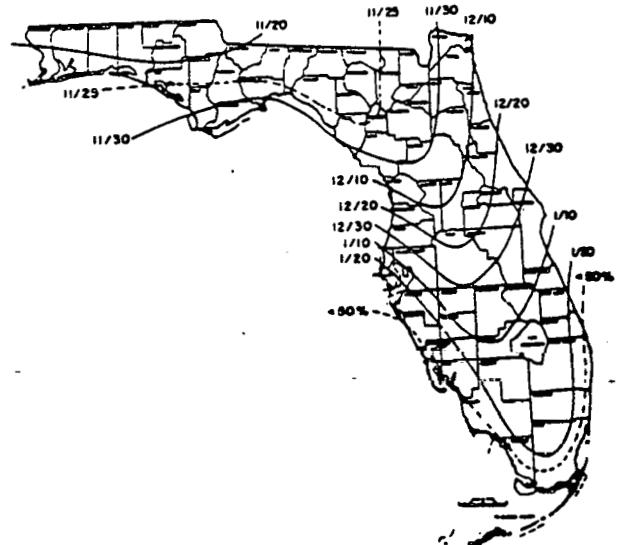
MEAN DATE (50% PROBABILITY) OF FIRST
(32°F) FREEZE OCCURRENCE.
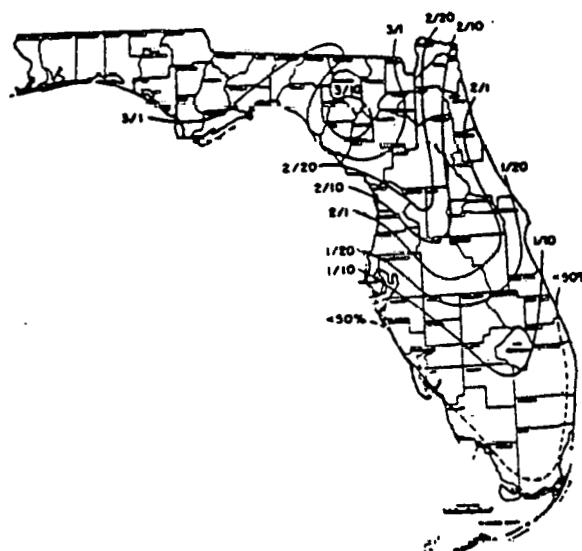
MEAN DATE (50% PROBABILITY) OF LAST
(32°F) FREEZE OCCURRENCE.

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In general, the prevailing temperature conditions in the region are suitable for high yield biomass production. Each species and particular site condition ideally should be matched to provide the most efficient achievement of this goal. Based on temperature conditions alone, Central Florida plantations should not perform significantly differently from existing Florida eucalypt plantations.

5.1.2   Moisture as a Limiting Factor to Eucalypt Survival and Growth. Eucalypt distribution can be classified according to rainfall in Australia: i.e., species from uniform rainfall zones, species from summer drought/winter rainfall zones and species from winter drought/ summer rainfall zones. Most forestlands in Australia correspond with winter drought/summer rainfall, or uniform rainfall zones, and are similar to Florida in this respect.

Water is perhaps the most important factor determining the success of vegetative establishment in Florida. Due to a predictable lack of adequate precipitation in the months of March, April, and May; eucalypt planting in Southwest Florida occurs mainly in the months of June and July, sometimes extending to August and September. This is necessary since newly-planted *Eucalyptus* trees of many species require some rainfall within the initial weeks of planting in order to survive.

Over most of the study area, there is a greater than 50 percent chance of at least 0.50 inches of rain per week during the mid May–September period (Butson and Prine, 1968). During the rest of the year there is a 20 to 40 percent chance of no rain during any given week (Table 5-2). Under these conditions, watering of trees could be initiated during no-rainfall planting periods as is done in some Brazilian plantations; however, the economics of a watering operation on large acreages does not appear feasible for Florida. Some sites may have an irrigation capability from prior cropping systems. For most sites, the most reasonable alternative to either irrigation or not planting would be to plant known drought-tolerant plantlets during the dry months.

TABLE 5-2

Percent chance of selected rainfall amounts per week
at Lake Alfred and Moore Haven

Based on weekly rainfall during the 41 year period 1925-1965.

Week Beginning		Percent chance for receiving rainfall of								Greatest amount weekly rainfall (inches)	
		None		.50 inch or more		1.00 inch or more		2.00 inches or more			
Jan	3	31	31	34	23	15	12	5	*	3.60	2.47
	10	35	32	33	22	15	10	7	*	3.55	1.94
	17	33	26	33	22	16	11	7	*	2.37	4.10
	24	31	24	34	22	18	13	7	5	3.20	2.60
	31	23	22	39	28	23	15	8	7	2.93	3.71
Feb	7	24	23	41	29	21	16	9	5	3.08	3.01
	14	24	25	41	31	25	17	11	*	3.60	2.20
	21	20	27	41	31	22	19	11	*	2.84	3.09
Mar	1	29	27	43	33	27	20	13	*	3.24	4.06
	8	28	22	43	37	28	20	11	5	2.99	1.81
	15	26	20	43	37	32	20	11	5	8.70	4.20
	22	25	20	44	38	34	22	12	8	3.74	3.34
	29	27	24	46	39	37	24	11	11	5.60	3.98
Apr	5	30	28	46	38	38	23	13	10	3.35	4.57
	12	34	28	42	37	31	26	11	11	5.08	5.56
	19	33	27	41	38	24	26	10	10	4.75	3.17
	26	31	24	37	41	20	31	7	10	4.96	2.33
May	3	30	24	39	43	21	28	7	10	6.30	4.25
	10	30	24	41	46	28	33	12	15	7.31	2.85
	17	23	21	52	51	37	34	20	24	3.99	3.83
	24	17	19	61	56	46	46	26	30	5.62	8.90
	31	10	14	69	63	47	46	29	30	6.27	7.08
June	7	9	10	72	69	48	54	28	33	5.82	6.24
	14	7	6	76	78	57	59	35	35	13.08	7.69
	21	7	5	74	77	60	62	37	36	16.19	5.25
	28	8	*	76	80	65	64	36	31	4.97	9.56
July	5	7	*	77	80	63	63	32	30	3.83	5.20
	12	6	*	83	84	66	67	34	35	6.12	3.81
	19	*	*	85	80	61	60	35	37	6.26	4.89
	26	*	*	85	78	56	59	33	36	5.26	5.28
Aug	2	*	*	82	75	55	55	29	31	3.57	4.84
	9	*	*	82	77	62	59	28	28	10.58	6.54
	16	*	*	81	76	64	56	29	30	4.73	5.34
	23	*	*	80	81	63	59	31	32	5.98	5.18
	30	*	*	78	79	59	59	30	36	10.42	5.89
Sept	6	*	*	77	77	58	58	30	33	13.15	7.46
	13	10	*	71	71	50	54	24	31	5.94	7.09
	20	11	5	63	69	46	49	23	26	4.77	10.26
	27	13	8	48	60	35	42	16	22	4.54	9.86

* Percent chance less than 5

Moore Haven
Lake Alfred

TABLE 5-2 (continued)

Week Beginning		None		.50 inch or more		1.00 inch or more		2.00 inches or more		Greatest amount weekly rainfall (inches)	
		\\multicolumn									
Oct	4	22	13	42	52	33	37	15	21	3.64	6.40
	11	33	23	34	44	26	34	12	21	5.09	4.06
	18	39	30	31	34	20	26	9	15	9.25	7.25
	25	44	33	23	26	12	19	*	10	1.46	1.75
Nov	1	43	32	23	18	10	12	*	5	2.05	3.55
	8	47	37	20	17	13	12	*	5	3.90	3.07
	15	45	42	22	17	12	10	*	*	5.40	1.52
	22	45	43	22	14	12	6	*	*	4.13	2.42
	29	43	41	23	15	11	*	*	*	2.17	0.81
Dec	6	40	37	27	16	13	*	*	*	2.24	2.61
	13	36	35	28	20	19	8	6	*	1.74	1.97
	20	31	29	33	23	20	13	6	*	2.82	5.56
	27	29	33	34	24	21	14	7	*	2.91	2.30

* Percent chance less than 5

Moore Haven
Lake Alfred

Normal drought conditions in the fall or spring should not be detrimental to established plantations. Damage has been observed from two consecutive extreme drought years in existing Glades County, Florida eucalypt plantations. Reduced growth is a probable result of prolonged drought. Drought tolerant eucalypt species may not experience a significant growth reduction on droughty sites. Again, moisture has its most crucial influence during the early establishment months. Provided eucalypt species are matched to appropriate site and climatic conditions, well-established plantations should weather the seasons quite well. Only the most extreme weather events appear to significantly impact on the existing stands, particularly the linking of a severe freeze with stress from prolonged drought.

5.1.3 Comparisons of Climatic Conditions in Southwest and West-central Florida.

The pioneering efforts in eucalypt cultivation in Central and South Florida by the U.S. Forest Service (Lehigh Acres) and their cooperators suggest that *Eucalyptus grandis*, *E. robusta*, *E. camaldulensis*, *E. tereticornis* and *E. viminalis* are the most promising candidates for near-term commercialization. In addition, species such as *E. macarthurii* and *E. nova-anglica* are candidates for more northern locations. Some 20,000 acres (8,000 hectares) in Southwest Florida's Glades County have been planted to *E. grandis*, *E. robusta*, and their hybrids.

It is presently unclear to what extent commerical plantations of *E. grandis* and *E. robusta* should be restricted to South Florida because of their cold-sensitivity. Both species are found growing in Central Florida. The extent to which they may be commercially grown north of Glades County remaines undetermined. In fact, these fast-growing species may outperform more cold tolerant species despite annual freezes. The apparently severe damage from the January 1982 freeze awaits evaluation.

Cooperative eucalypt plantings by the U.S. Forest Service and
St. Regis Paper Company in Sumter County, approximately 50 miles north
of the study area, have exhibited superior "freeze-coppice" growth for
these two species after seven years, despite a number of severe cold
spells. It has been suggested that "freeze-coppice" rotations are a viable
alternative to exclusive use of cold-tolerant species (E. C. Franklin,
pers. comm.).

Actual comparisons of Southwest Florida and West-central Florida
climates reveal slight differences in minimum temperature regimes (Figure
5-2). Annual average minimum temperatures within the study region range
from 25 to 28°F (-4 to -2°C). Average minimum temperature for Webster, near
the Sumter County eucalypt plantings (ST-76) was 23°F (-5°C); significantly
lower than temperatures found in the northern portions of the study area.
Conversely, the Labelle area in Southwest Florida appears only slightly
warmer than most of the study region.

A closer look at freeze intensity and duration suggests both
differences and similarities between the Central and South Florida regions
(Table 5-3). The largest difference lies in the occurence of temperatures
below 32°F (0°C). Freezing temperatures are longer and more frequent in
Bartow (representative of West-central Florida), with virtually no possibility
of a "frost-free" year. However, there is only a 20 percent chance of a
"frost-free" year in Labelle (representative of Southwest Florida). Thus,
freezing temperatures, however infrequent, must be expected in Florida
eucalypt plantations. Prolonged temperatures below 25°F (-4°C) are the
most threatening to Florida eucalypts.

Reviewing the occurence of temperature regimes of ≤28°F (-2°C) and ≤24°F
(-4°C) reveals decreasing differences between the two regions. Temperatures
≤24°F are almost equally infrequent in Labelle as in Bartow. Both regions
have less than a 20 percent chance in any winter of experiencing such low

FIGURE 5-2

Southwest and West-central Florida Climates
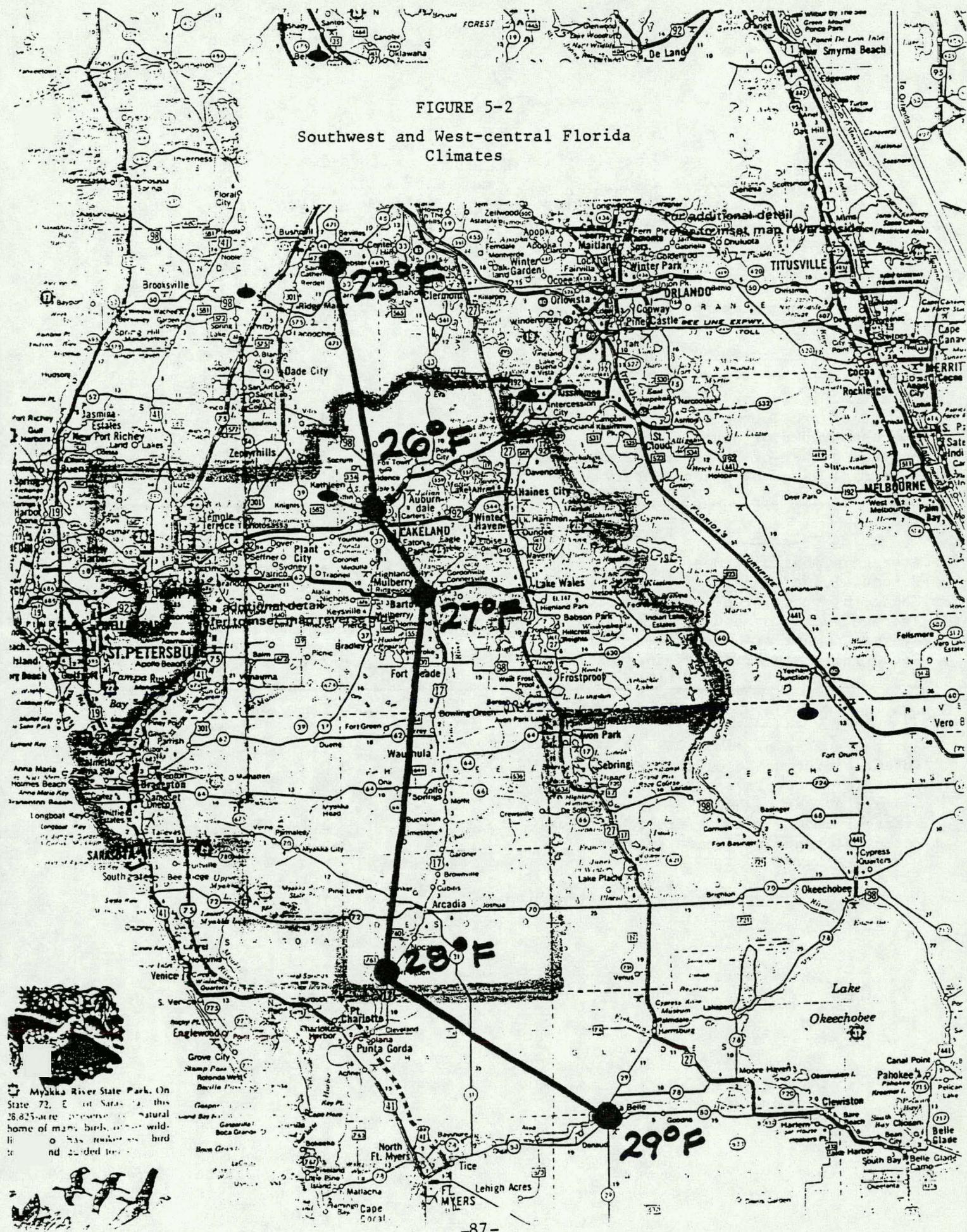
TABLE 5-3

Historic Temperatures at Bartow and LaBelle, Florida
(1937-67)

ANNUAL FREEZE DATA	BARTOW	LaBELLE
32°F		
Average number of times	7	3
Potential incidence of freezes	1-14	0-9
Chance of frost free year	<1%(0)	20%
Average number of hours	34.4	11.9
Average number of hours/freeze interval	5.1	3.7
Potential range of freeze interval	2-11.5	0-5.8
28°F		
Average number of times	2	<1(.83)
Potential incidence of freezes	0-7	0-3
Chance of frost free year	27%	43%
Average number of hours	9.0	2.3
Average number of hours/freeze interval	4.0	3.0
Potential range of freeze interval	0-7.7	0-7.5
24°F		
Average number of times	<1(.93)	<1(.1)
Potential incidence of freezes	0-3	0-2
Chance of frost free year	83%	94%
Average number of hours	0.9	0.3
Average number of hours/freeze interval	3.1	2.8
Potential range of freeze interval	0-5.0	0-3.0
AVERAGE ANNUAL MINIMUM TEMPERATURE	27°F	29°F

source: Johnson, Warren O., 1970.

temperatures. Extremely low temperature events tend to impact on a greater portion of the state with more uniformity; whereas, generally colder temperatures are more frequent in North and Central Florida due to the effect of stationary and dissipating cold fronts.

Consequently, a devastating freeze in a eucalypt plantation in West-central Florida is not a necessarily more likely event than in Southwest Florida. Indeed, the January 1982 freeze was more severe in LaBelle than in Lakeland. Experimental field plantings are necessary to determine the potential of E. *grandis*, E. *robusta* and their hybrids, as well as more cold-sensitive species, to perform well through West-central Florida's winter. Even with more data, climatic factors can be expected to influence major events in the management of the eucalypt plantation.

5.1.4 <u>Species Selection and Improvement Program</u>. Figure 5-3 compares areas of similar climate (homoclines) to peninsular Florida using the methodology developed by Papadkis (1970). These areas roughly correspond with the world maps of climatology which utilize climatic diagrams for stations around the world (Landsberg, et al., 1965). Unfortunately, these attempts at comparing sites for plant introduction suitability are limited, since soils are not considered. For example, in humid regions sandy soils are dry because they retain only small amounts of rainwater whereas moisture-binding clay soils remain wet; however, <u>the reverse is true in arid climates</u> where the infrequent downpours must be absorbed quickly for soil storage (Walter, 1973). Consequently, climate alone is not a predictor of plant performance in an exotic landscape. Ultimately, field performance is the only positive verification.

Since field trials screening species of eucalypts for those best adapted to South Florida have been limited, with virtually none in Central Florida, species/provenance trials are an essential research component of a large-scale, woody biomass program. A number of heretofor untried

FIGURE 5-3

MERCATOR PROJECTION
Capitals of Countries

source: Websters Unabridged Dictionary
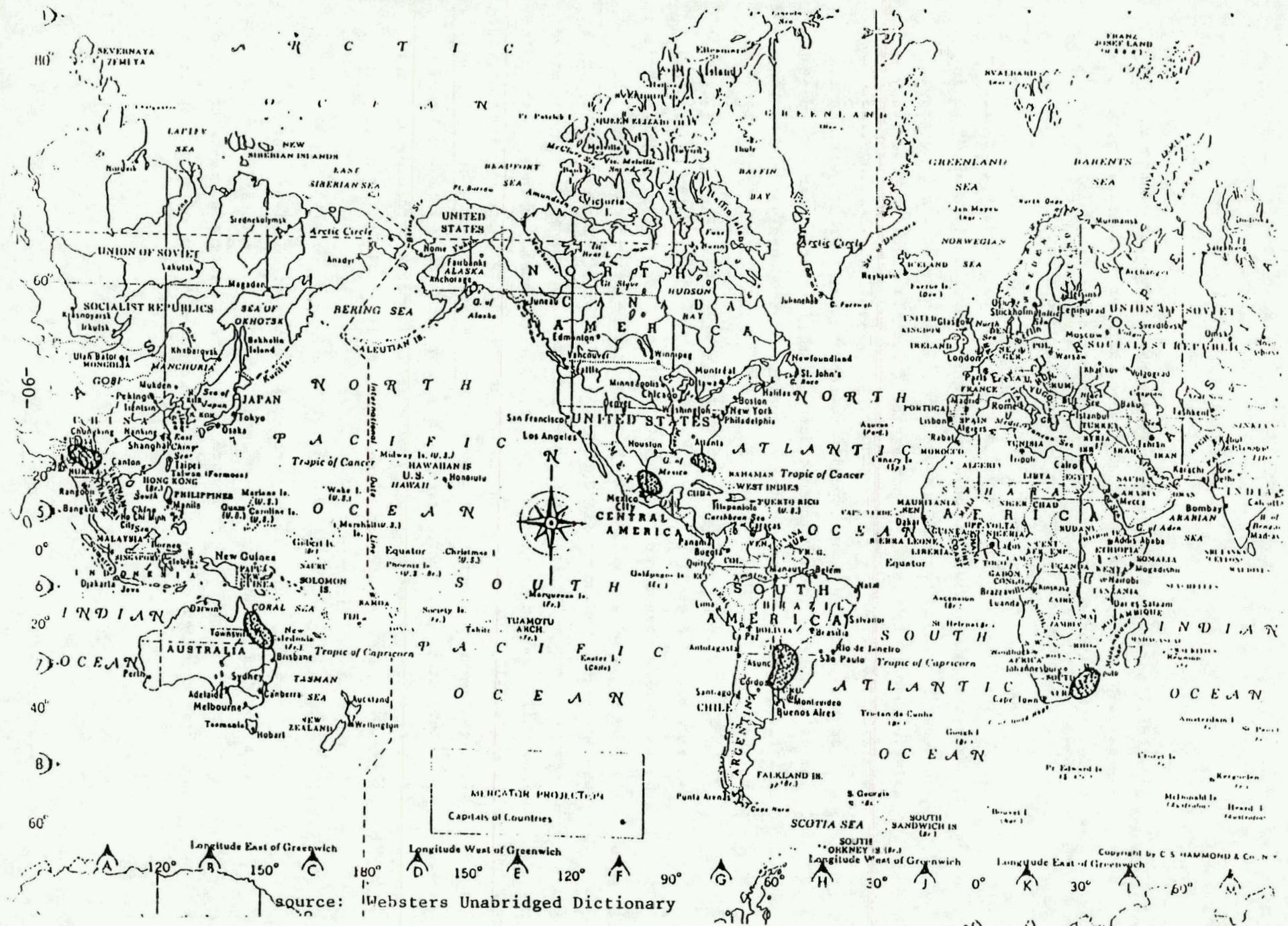
species or provenances may prove useful or better adapted to specific site conditions. However, immediate commercialization efforts must concentrate on improvement of eucalypts growing in the area that show superior characteristics.

Tissue culture propgation allows for replication of phenotypic characteristics which often are representative of superior genotypes. Improvement of planting stock can be accelerated immensely by selecting high-performance "clones" for outplanting. Due to the relative success of *E. camaldulensis* on mined land in Central Florida, Biomass Energy Systems, Inc. is undertaking a program of producing clonal stock from "select" trees. *In vitro* propagation from seed of premier *E. grandis* and *E. robusta* mother trees also are underway for testing in the field.

5.2   Spacing and Density. Plantlets will be machine planted
using a spacing of 5 feet between plants in the row and 10 feet
between rows (1.5 m x 3 m). This will provide a planting density of
871 plants per acre (2,152/ha) and allow each plant a potential grow-
ing space of 50 square feet (465 dm^2). As a supplemental spacing
regime, rows may be alternately spaced at 8 feet (2.4 m) and 12 feet
(3.7 m), with a continued 5 foot (1.5 m) spacing within the row (Fig. 5-4). This
would allow stem spacing experimentation while maintaining the recom-
mended planting density. Spacing variation between rows should be
considered in those areas where bedding is required. Potential damage
to lateral roots through compaction will be reduced by allowing an extra
two feet (0.6 m) for the harvesting machinery.

The selection of a 10 foot (3 m) distance between rows is based on
presently available harvesting equipment, although future equipment develop-
ment and/or modification may allow woody biomass plantings at a greater
density. Consideration also must be accorded the cost of producing plant-
ing stock, as well as survival and yields. Some close-spaced plantings
have experienced early mortality. In plantings of 1 foot by 1 foot (0.3 x
0.3 m), mortality was approximately 50 percent (Hillis and Brown, 1978).
At a plant cost of $0.08 each, and a production of 42.8 tonne/ha at age 3,
wood value would have to be $207.68/tonne just to recover the cost of
plants. In the same study, a planting of 2 feet by 2 feet (0.6 x 0.6 m)
experienced an early mortality of 36 percent. Production at this spacing
at 3 years was 32.9 tonne/ha. Using the same cost factor ($0.08 per plant),
wood values to recover plant cost must be $67.55/tonne. At a spacing of
2 feet by 8 feet (0.6 x 2.4 m) survival was 93 percent, and the wood value
to recover the cost of plants would be reduced to $15.96/tonne.

Sachs, et al. (1980)   experimented with a density of 17,790
E. grandis seedlings per hectare in southern California, with twice a
year harvests. Yields were 22 oven-dried metric tons per hectare per
year. While there was an overall low initial mortality of 8 percent,

Figure 5-4

Example of Plantation Design

Spacing Average 5' x 10' (1.5 m x 3.0 m)

5'
(1.5 m)

8'
(2.4 m)

12'
(3.7 m)
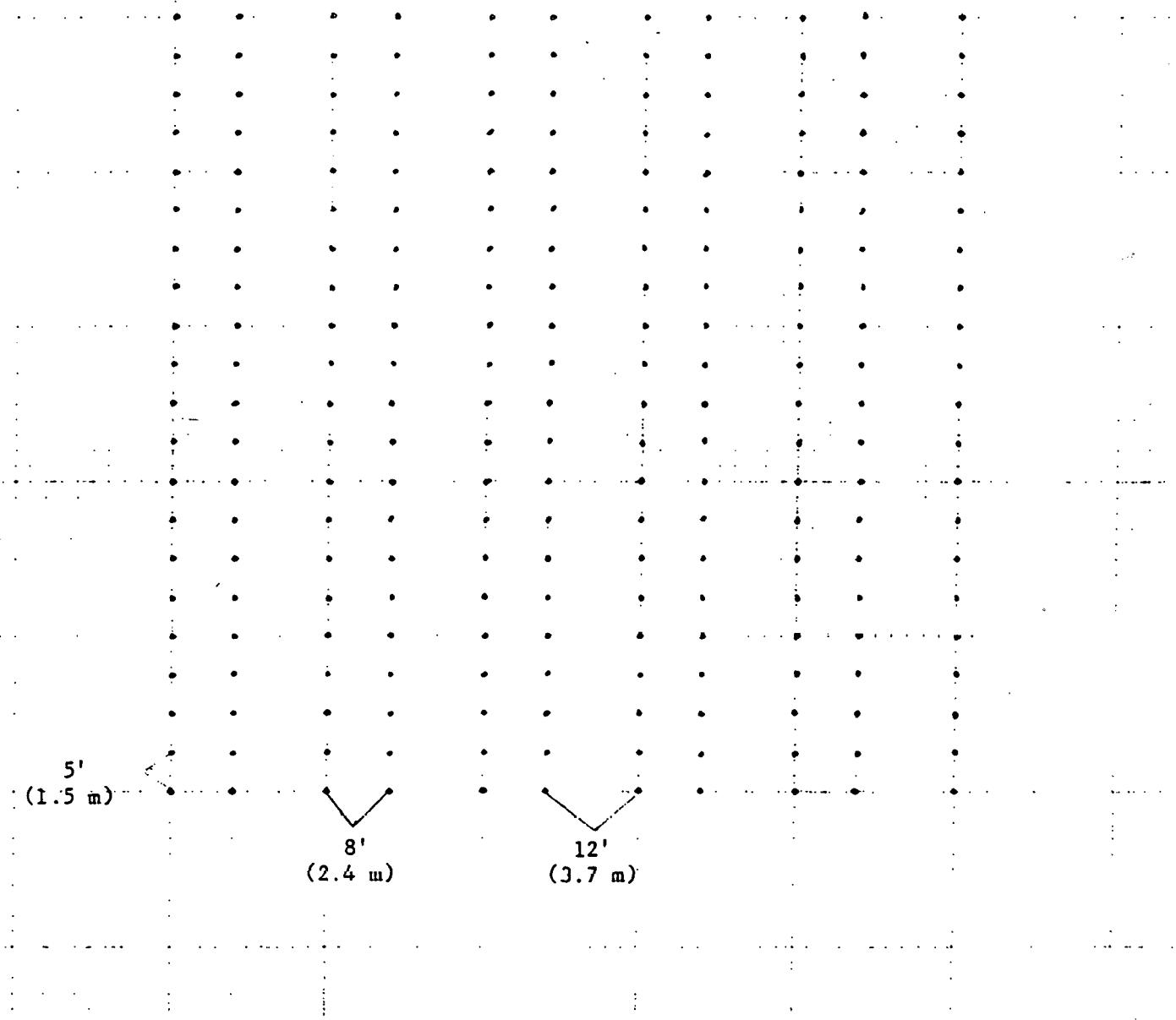
some plots had a high mortality. While this approach produces a high yield of biomass, we have rejected it for our BESI plantations for a number of reasons, the cost of establishment versus yield being foremost.

Studies of close spacing of popular (*Populus spp.*) hybrids and jack pine (*Pinus barksiana*) reveal high mortality at six years for 9 x 9 inches (1.9 x 1.9 cm) and 12 x 12 inches (2.54 x 2.54 cm) spacings. The authors caution against extrapolating to large scale forest plantings (Dawson, et al., 1980).

Various spacing studies indicate that maximum annual incremental growth occurs at 5-6 years in spacings where individual stems have 65-195 square feet of growing space (595-1, 821 dm^2) (Walters, 1980). Height growth at age 5 appears to be about equal at all spacings. At age 5, the widest spacing shows a 25% advantage over the closest spacing when contrasting dbh values. This advantage increased to about 31 percent at age 15. Walters (1980) indicates that the widest spacing used, 14 x 14 feet (4.3 x 4.3 m), probably is best economically for sawtimber yields. As spacing was reduced, cubic foot (m^3) production increased. Walters (1980) speculates that a spacing narrower than 8 x 8 feet might result in a greater volume per unit area.

Our choice of the spacing of 5 feet (1.5 m) within the row and an average of 10 feet (3 m) between rows, considers a projected maximizing of volumetric increases over a predicted rotation age, coupled with presently available off-the-shelf equipment and requirements to consumate an economically sound program of woody biomass production and use.

5.3 <u>Methodology</u>. Automated, or at least semi-automated equipment for planting containerized stock, is in various stages of development. No off-the-shelf automated tree planter is presently available because of the wide variety of container sizes being employed by plant growers. However, both Don Demerest of Speedling (pers. comm.) and Ed Bradley of

Southern Machinery (pers. comm.) have indicated that they can furnish automated equipment guaranteed to perform to specified planting requirements. Nursery production in Todd Planter Trays (Speedling) offers the convenience of planting directly from the nursery tray, a system we intend to employ. This eliminates the necessity of pulling and repacking plantlets prior to delivery to the planting site. Without the shock of pulling and repackaging, the need for refrigeration is eliminated. Moderate air circulation and adequate moisture controls are necessary requirements. One expert anticipates no problem in pulling plantlets directly from the Todd Trays on the planting machine (Demerest, pers. comm.). Cost savings in packaging, handling, transportation, and storage are anticipated.

Plants can be held in planting trays for two weeks or longer, if absolutely necessary, after removal from the nursery. Daily inspection and watering is required to maintain the planting stock in a plantable condition. Other extraordinary labor and/or time consuming procedures, such as heeling in, should be avoided. The greatest cost savings is achieved when the plants move directly from the greenhouse to the planting machine.

Proposed plantations will be designed to take advantage of reasonably long, uninterrupted rows. Clonal planting blocks of 160 acres (65 ha) are recommended with rows one-half mile (approx. 805 m) in length. Each row requires 528 plantlets, or less than 9 compartmentalized Todd Planting Trays (8" x 16") for a round trip of the planting machine. Utilization of 160-acre (quarter section) planting blocks are a harvesting asset because of compatibility with the internal road network. Compartmentalized planting blocks also simplify the management of individual clonal blocks.

Planting will be done at the speed which most nearly optimizes the hand/eye coordination of the planter with the speed of the tractor. The speed of the tractor also is limited by the quality of site preparation, the tracking efficiency of the planter, and the topography of the site.

Under ideal planting conditions and with optimum site preparations, we would not expect a two-man crew planting by hand to exceed a daily production of 1500 plants. Labor at $5/hour for a 10 hour/day results in a planting cost of about $0.07 per plant, or nearly $64 per acre. Using the same labor cost and adding a tractor and mechanical tree planter, we can increase by at least 10-fold the number of plants planted. Assuming

the same ideal planting conditions and optimum site preparation,
Jonathon Futch of Futch Timber Company (pers. comm.), indicates that
planting will, on a day in day out basis, exceed 25,000 plants per day.
Assuming an expenditure of $15,000 for five year life equipment and
50 gallons per day fuel use, the cost for machine planting will probably
be less than one cent per plant.

5.4 Seasonal Considerations. Poor success is frequently experi-
enced in forest-type plantings (primarily pine) performed in Central and
South Florida during December through May. The degree of winter-planting
success generally diminishes southward from Ocala. Winter rainfall in
Florida is usually the result of cold fronts moving in a northwesterly
to southeasterly direction across the United States. In many cases these
fronts, which cause so much hardship for other locales in the nation,
are pushed eastward or northeastward by air convection currents associated
with the warm Gulf waters surrounding peninsular Florida. Central and
South Florida usually escape the hard freeze, low temperatures associated
with these cold fronts. This plus is somewhat offset by a deprivation
of winter moisture. The spring months of March-May are even drier. If
you're vacationing in Florida, warm, dry, and sunny is your winter
preference; but, if you're a planter or grower of eucalypts then you
"bet your trees and take your chances" by planting during Florida's
predictably dry winter/spring seasons. One of the best ways to hedge
your bet is to plant drought resistant, cold hardy lines of E. *camaldulensis*.
Normal weather patterns for central Florida, and prior historical data,
confirm the occurrence of high rainfall from June through October, and
low accumulations from November through May. In order to take advantage
of adequate moisture and warm temperatures necessary for good plant
establishment, eucalypt planting primarily is recommended for June through
October, although later plantings may take place in November and December.
The resistance of the plants to cold and drought is essential for winter/
spring plantings.

Eucalypts planted during the optimum summer/fall planting period
should reach heights exceeding normal frost inversion patterns well
in advance of anticipated frosts in Central Florida. Later plantings,
while probably not attaining the heights necessary to escape frost
damage, should have established adequate root systems and stored
sufficient plant food reserves to resprout and otherwise recover when
temperatures moderate. Ben Swendsen, Ranch Manager for Lykes Bros.,
Inc. (pers. comm.), confirms the rapid recovery of cold damaged young
eucalypt plants when weather moderates. Damage to plants set out by
Lykes Bros., Inc. during July through September 1980 varied from slight
to nearly complete defoliation during the 1980-81 winter months. Trees
(1980 planting) completely defoliated in February 1981 showed little
evidence of damage and were approaching heights of 20 feet (6 m) or more
by the fall of 1981. These same trees were damaged severely a second time
by a January 1982 freeze.

5.5 Air Quality. The combustion of fossil fuels releases many
hazardous chemicals and particulates into the atmosphere. Air pollution
levels are high enough in some urban areas and their airsheds to cause
damage to vegetation. Vegetative damage induced by sulfur dioxide (SO_2)
and fluorides such as hydrogen fluoride (HF) and silicon tetrafluoride
(SiF_4), oxidants such as ozone (O_3), and others are well documented (Loomis
and Padgett, 1973).

There is no documented literature on pollution damage to trees of
the genus Eucalyptus; but, there is strong evidence that all plants can
be damaged at some level by air pollutants. Potential problem areas might
be immediately adjacent to heavily-trafficked highways or phosphate
chemical plants which have, at times in the past, emitted levels of
pollutants harmful to nearby vegetation. In actuality, air pollution
damage is not anticipated. If air quality becomes a problem, genetic
selection for pollution tolerant genotypes could be initiated. Man's efforts
to maintain adequate levels of air quality generally will protect eucalypt
trees as well. Large acreages of eucalypt forests should enhance the
overall regional air quality.

5.6 <u>Native Vegetation as an Indicator of Land Suitability for Eucalypts</u>. Vegetation responds to variations in topography, soil, moisture, and climate by organizing as distinct plant communities best suited to particular edaphic conditions. Consequently, much about conditions at the planting site can be inferred from the local native plant community. Vegetative indices are particularly useful where detailed soil mapping has not been performed, as in Hardee and DeSoto Counties.

Scrub and sandhill vegetation occupy the xeric forest sites and indicate deep, droughty sands. Wetlands, both forested and non-forested, occupy the lowland areas. Hardwood hammocks can be found on a variety of xeric to hydric sites, although most now occur in lowland areas. The vast

flatwoods and prairie lands extend across the imperfectly drained flatlands. This last vegetative category coincides with areas currently deemed ideal for widespread cultivation of eucalypts. In addition, xeric sites have potential for drought tolerant eucalypts.

The natural landscape of the five-county study area has been significantly altered as a result of agricultural and urban development. Within these general categories, a variety of specific uses and management practices determines the extent of vegetative cover. In turn, the density and vigor of existing vegetation is directly related to the potential vegetative competition for planted eucalypts—a critical consideration in eucalypt establishment (Meskimen, 1971).

The rangelands primarily consist of cut-over flatwoods and palmetto prairie. Eucalypts in Glades County are grown on these lands. Site preparation includes chopping, discing, and bedding. The prairie sites have no stumps. Intensive site preparation appears successful in reducing competition to newly planted eucalypts; but, it must be effective for at least the first year so the trees can capture the site. Although all shrubs are eliminated, vigorous herbaceous growth often rebounds in the first 6 months, doubling herbage yields withing one year (Moore and Swindel, 1980). This situation provides ample opportunities for growth suppression of the young eucalypts due to competitive stress. The current success with eucalypts in South Florida may be attributed in part to the shallow-rooted nature of the competing native grasses.

Improved pasture and cropland provides a wide variation in herbaceous competition. Bermuda and bahia are common, deep-rooted pasture grasses. Roots commonly descend up to 6 feet (2 m) into the soil in search of food and water, presenting a severe stress potential for trees. Intensive site preparation alone would only rearrange the rhizomes which would

resume vegetative growth quickly. Under such conditions,
herbicide treatments are needed. One logical alternative would be
to sell the sod prior to planting, although a herbicide treatment
probably would still be necessary. Newly-abandoned cropland provides
a fertile substrate for tree growth, provided herbaceous colonization
is controlled. Older abandoned farmlands require intensive efforts
to control ruderal plants.

Mined and newly-reclaimed land is the product of the most effective
vegetative control known to man. Inversion of soil horizons and destruc-
tion of topsoil. Maintenance would be necessary but minimal due to the
lack of seed or rhizomes in the soil. Older mined lands present more
difficulty in regard to vegetation control and would require the elimina-
tion of competition similar to that required of older abandoned farmlands.

The study area is presently quite depauperate of forestlands.
Forests, excluding wetlands, cover less than 5 percent of the total
land area. Riverine and scrub forests dominate this acreage. Extensive
stands of longleaf pine (*Pinus palustris*), and to a lesser extent slash
pine (*Pinus elliottii*), once covered the vast flatlands and sandhills
of the region. Clearcutting and controlled burning have all but eliminated
these forests in exchange for rangeland uses.

The droughty sandhills not planted to citrus have a variety of
scrubby vegetative associations. Oak scrubs composed of Bluejack oak
(*Quercus incana*), Chapman's oak (*Quercus chapmannii*), Scrub live oak
(*Quercus geminata*) and Turkey oak (*Quercus laevis*) predominate. Most
of the pines have been eliminated except for areas colonized by sand pine
(*Pinus clausa*). Due to the limited economic utility of these lands in
their natural state, citrus groves are rapidly replacing the native
vegetation. An excellent opportunity exists for coppice management of
naturally occuring oak thickets, and cultivation of sand pine. This type
of biomass cropping would be low in commercial productivity but extremely
valuable from a natural ecosystem conservation perspective. BESI intends
to employ methods of maintaining native forest communities within the
eucalypt plantations on the sites least suited for eucalypts.

The greatest existing natural woody biomass resource exists
along the valleys of rivers, creeks, strands, as well as in isolated
lowland pockets. These wetland and lowland forests are highly pro-
ductive due to increased availability of nutrients and moisture.
Most of the forests are second and third generation regrowth. These
forests provide significant values to man for fish and wildlife
habitat, water quality enhancement, and recreation. Clearing is not
recommended for native forests. However, it may be desirable to manage
these riparian forests by selective cutting or strip clearcutting as a
means of balancing environmental and economic values. As these forests
mature, pressures to harvest the timber will increase. Currently, there
is no effective restriction of logging activity on private lands.

More damaging in the long-term is the complete elimination of
streamside forests along tributaries and in headwaters area, as well as
free access of cattle to stream courses. These areas could sustain
short-rotation cutting of selected species while maintaining their
support functions to more critical downstream ecosystems. Other non-
forested areas adjacent to stream forests could be converted to biomass
plantations. Bald cypress (*Taxodium distichum*), red maple (*Acer rubrum*)
and sweetgum (*Liquidambar styraciflua*) are ideal candidates for establish-
ment in soils too waterlogged for eucalypts. BESI does not expect
eucalypt plantations to displace native forests, particularly forested
wetlands, because of the high cost of clearing; and, even more importantly,
because most of the remaining native forest sites are not suitable for
highly mechanized eucalypt plantations.

6.0 SPECIES SELECTION

6.1 Eucalypt Suitability. The Mitre study (Howlett & Gamache, 1977)
indicated that eucalypts are potentially the best biomass source for Florida.
Eucalyptus camaldulensis is one of the most widely planted species out-
side of Australia, and has consistently met with establishment and growth
success in field trial locations. Individuals of this species have proven
adaptable to soil types ranging from very wet to very dry, and very clayey
to very sandy. In Central Florida, where temperatures occasionally fall
below 20°F (-8°C), the less cold-tolerant species normally planted in ·
South Florida (e.g., *E. grandis* and *E. robusta*) might have unsatisfactory
production and survivorship. These plantings were severely damaged in
the January 1982 freeze. Further investigation is warranted before either ruling
out or recommending a Central Florida planting of the two species used in ·
South Florida.

The original source of *Eucalyptus camaldulensis* planted in Florida
is presumed to be from seed grown in Spain (hence, a localized identifica-
tion of "Spanish cam" has evolved over the years). Reinforcing other studies,
and confirming the potential of *E. camaldulensis* as a biomass candidate,
is our own study of two 10-acre (4 ha) plantings in Polk County, Florida. ·
These plantings confirm the cold resistance of this species, since the
1980-81 winter (December 1980-February 1981) was the coldest prolonged
Florida winter in 150 years. Yet, tree by tree examination in Polk County
showed little in the way of freeze damage.

Planting recommendations for Central Florida most notably have been
limited to *E. camaldulensis*, *E. tereticornis*, and *E. viminalis*. There is,
to our knowledge, no plantation-type planting of *E. viminalis* in Florida.
Of the *E. tereticornis* plantings observed, damage due to cold (as evidenced
by leaf burning or browning and leaf loss) affected more than 75 percent of
observed stems as opposed to less than 25 percent damage to *E. camaldulensis*.

Both *E. camaldulensis* and *E. tereticornis* at the ST-76 planting on
St. Regis Paper Co. property in Sumter County, approximately 10 miles
(16 km) west of Groveland, suffered heavy damage. However, the most success-
ful undamaged trees appeared to be *E. camaldulensis*. The ST-76 site is
50-75 miles north of the proposed planting areas of Polk County and subject
to much more severe winter weather.

6.2 <u>Monocultural Containment.</u> Not all Florida eucalypts are able
to produce viable seed. This was an important consideration in selecting
E. camaldulensis as a candidate species. There has been considerable
environmental concern expressed over plantation eucalypts escaping into
the wild and dominating natural systems. While *E. camaldulensis* has been
known to flower nearly the year-round, Geary and Meskimen (in ms) state
that both *E. camaldulensis* and *E. tereticornis* normally flower from mid-
November to mid-January in Central and South Florida. Almost without
exception, immature seed capsules of "Spanish cam" are aborted, said to be
caused by a fungal pathogen. Ample evidence has been observed around the
base of mature *E. camaldulensis* to confirm the occurrence of flowering
and fertilization in the form of aborted, immature capsules. Attempts to
harvest seed largely have been unsuccessful.

The non-production of seed, while limiting in some respects, offers
an ecological and environmental advantage over many exotic plants. There
has been much written about encroachment of certain exotic (non-native)
species which have been introduced into Florida, particularly in the southern
portion of peninsular Florida which has subtropical growing conditions that
encourage plant establishment. These concerns have been addressed in the
impact assessment document. Eucalypts have been widely planted throughout
South Florida for over a hundred years without posing a significant invasion
problem.

6.3   Propagation. The non-seed producing characteristic of
Florida's "Spanish cam" was known from the outset of this project,
necessitating vegetative propagation to reproduce select trees of this
species, in this instance through tissue culture. Eucalypts may be re-
produced by grafting, but this is slow and costly, with uncertain results.
Large-scale clonal plantation establishment has been accomplished in
Brazil using rooted cuttings. The cost of labor in the U.S. frequently
prohibits such labor intensive methodology, even though a high degree of
success may be achieved elsewhere. Our limited experience with propagation
of rooted cuttings indicated excessive costs per established plant when
grown for any reason other than research. Based on small scale production
to-date, high yield ecualypts produced by tissue culture and multiplied in
large quantities cannot be cost competitive with seedlings unless the
increased yield is factored into the comparison.

6.3.1   Selection Criteria. As part of the examination of two
"Spanish cam" plantations in Polk County, all stems with a dbh greater than
9 inches (22.8 cm) were located and plotted within the stands for easy
r elocation.   Diameter is the single greatest contributor to volume and
has received the highest priority in our selection system (even-aged
planted stand). As an example, see Table 6-1 showing tree volumes for dia-
eters ranging from 5 to 18 inches and heights of 50 to 90 feet. A one
inch increase in diameter causes a volume increase greater than that
created by a ten foot increase in height through most diameter classes and
height increments.

Crooked and/or forked trees have been eliminated by our selection
process because of increased handling and transportation costs. These
greater costs result because of higher labor costs (additional time to re-
duce to single stem) and increased equipment costs because of poor stackabil-
ity on wood hauling and handling equipment. Also, a high incidence of .
forking in the stands of eucalypts we have examined results in a disproportion-
ate incidence of wind damage with resulting volume reductions and losses in
yield.

TABLE 6-1

VOLUME (cubic feet) COMPARISON
USING TWO VARIABLES

HEIGHT (in feet)

DBH	50	60	70	80	90
5"	2.68	3.14	3.59	4.04	4.50
6"	3.86	4.52	5.17	5.82	6.48
7"	5.26	6.15	7.04	7.93	8.82
8"	6.86	8.03	9.19	10.36	11.52
9"	8.69	10.16	11.63	13.11	14.58
10"	10.73	12.54	14.36	16.18	18.00
11"	12.98	15.18	17.38	19.58	21.78
12"	15.45	18.06	20.68	23.30	25.92
13"	18.13	21.20	24.27	27.34	30.42
14"	21.02	24.59	28.15	31.71	35.28
15"	24.13	28.22	32.31	36.40	40.50
16"	27.46	32.11	36.77	41.42	46.07
17"	31.00	36.25	41.51	46.76	52.01
18"	34.75	40.64	46.53	52.42	58.31

The small crown of a large volume tree is often an indicator of an exceptional wood producing factory. Ability to convert minimal amounts of radiated energy into wood biomass warrants the further investigation of the full potentiality such a tree may possess as part of a clonal plantation, and as a parent tree for tissue culture propagation.

Height is an overall consideration in the selection process. The presence or absence of competition influences height, making it a more difficult perimeter to judge. Given the choice between a tall, straight, small crowned, large diameter tree or a short tree exhibiting the same qualities, we select the taller tree because of its greater volume.

These selection guidelines were made without any knowledge of the modest number of select trees we might find available at the Grace (sand tailings) and Agrico (overburden) plantings. The guidelines of choice included three steadfast criteria: (1) minimum dbh of 9 inches (22.86 cm); (2) not forked; and (3) straight stem.

6.3.2 <u>Selects--Number and Location.</u> After these guidelines were adopted, a thorough survey of the plantations were made. Results of the survey reduced the cumulative number of candidate trees to 15 at Grace and 23 at Agrico. A reevaluation of both stands added 8 more trees at Grace and 13 at Agrico. These candidate additions were made to provide more genetic diversity. To insure a minimum of compromise from our original criteria, those trees initially selected are further classified as "A" selects and the second group is referred to as "B" selects.

"A" selects at Grace represent less than 0.25 of 1 percent of the original planting. When "B" selects are added, the combination represents less than 0.4 of 1 percent of the base population. At Agrico, percentages are slightly higher, 0.4 of 1 percent and 0.6 of 1 percent based on original planting. These percentages are considerably lower than the original selections made in the South Florida improvement program. For example, in 1966, 119 E. *robusta* were selected from a base population of 2,304 (5.2%) (Dvorak, et al., 1981).

6.3.3   Selects--Induced Sprouting. Successful vegetative
reproduction of eucalypts is increased by the juvenility of the material
to be reproduced. Juvenile material can be obtained in two ways: (1) felling
or (2) wounding. Sprouts should be allowed to elongate, and then gathered
for production of rooted cuttings or introduction into tissue culture.

Some trees were felled and some wounded at each plantation
site. All felled trees were cut with a chainsaw. Stumps were cut at an
angle of at least 10° to insure no rainfall collection on top of the stump
which might lead to rotting and less than optimum coppicing. The height
of stumps on the high side ranged from a maximum of 11 inches (27.9 cm)
to a minimum of 5 inches (12.7 cm). Height on the low side ranged from
7 inches (17.8 cm) to 1 inch (2.5 cm). Stump diameters, measured above
any obvious swell, ranged from 19 inches (48.3 cm) to 12 inches (30.5 cm).

Wounding was done with either a three inch (7.62 cm) or five
inch (12.70 cm) masonry chisel sharpened to a fine knife edge. The above-
ground wounding height ranged from 3 to 4.5 feet (0.9 to 1.4 m). This was
a height of convenience to minimize kneeling and reaching around the tree.
Wounding was done by making a girdling type cut through the bark and cambium
layers into the woody portion of the tree. Cuts generally were about 0.25
inch (5 mm) in width and 0.75 to 1.0 inch (18 to 25 mm) in depth. There has
been no evidence of crown discoloration, leaf loss, or any other indicators
of tree mortality associated with the wounding. However, wounding can be
too shallow. A possible effect of deep wounding could be structural weaken-
ing of the tree contributing to wind damage and fungal infection. No such
effects were observed.   If wounding occurs when the tree is undergoing
rapid growth, the healing process begins almost immediately. Healing can
be so rapid that no sprouting occurs.

An additional assessment of sprouting entailed wounding by chainsaw. A 0.25+ inch cut (0.63 cm) was made through the bark and cambium layers into the woody portion of the tree. Care should be taken to avoid cutting too deeply or the tree will fall and leave a damaged stool. This method was efficient and induced sprouting in 17 days or less. See Table 6-2 for cutting and wounding data relative to sprouting.

Deep wounding at Agrico, if it occurred, was only happenstance. Deep wounding at Grace was planned. The 100% sprouting of deep wounded trees at the Grace plantation reflects the need for severe wounding.

Original, but sketchy information suggested that sprouting is induced by wounding if the flow of auxins is restricted for up to thirty days (G. Meskimen, pers. comm.). A method thought to block auxin flow was the insertion of many plastic cards into the wound in a fan type arrangement. Our earliest efforts at wounding included the use of several types of artificial blocks such as plastic cards, rubber bands (when cut 14 x 5/8 inches / 36 cm x 1.6 cm), butyl rubber and Scotty's Latex Korker.

Our experience revealed that: (1) trees sprout with or without induced blocks; (2) even when inserted with the upmost care, all blocks do not remain in place; (3) a wide wound is required to achieve penetration of the cambium layer; and (4) wide wounds do not lend themselves to holding foreign material in the form of blocks. Following our first attempts, no artificial blocks were used. In our opinion deep wounding does not require artificial blockage to induce sprouting. The best months to induce sprouting remains unknown. Trees wounded deeply in March, April and July all sprouted. There may be a seasonal advantage for wounding, but more research is needed to determine an optimum time for quantity vigor, suitability for placement into culture, and ultimate plantlet performance. The original plan to spread the felling and/or wounding over a six month period was aborted because of an immediate and high priority demand for more select vegetative material to go into tissue culture and rooted cutting experiments.

TABLE 6-2

Analysis of Select Sprouting --
Felled Versus Wounded

| | AGRICO | | GRACE | |
	Class A	Class B	Class A	Class B
Trees Felled	7	0	15	0
Average DBH(inches)	10.6	NA	10.4	NA
Average DBH(centimeters)	26.9	NA	26.4	NA
Trees w/Collectable Sprouts	6	NA	15	NA
Trees Wounded	16	13	0	8
Average DBH(inches)	10.0	10.3	NA	10.9
Average DBH(centimeters)	25.4	26.2	NA	27.7
Trees w/Collectable Sprouts	9	5	NA	8

6.3.4 <u>Juvenile Material Management.</u> Stumps and wounded trees subsequently were managed for the continuing production of juvenile vegetative material. As sprouts elongated to approximately three feet (1 m), they were cut back to a minimum of 10 nodes, or about 12 inches (30.5 cm) from the base. First observations of juvenility in sprouts of *E. camaldulensis* includes stem squareness, an ephemeral characteristic. As sprouts elongate with growth, this squareness rapidly disappears. The significance of square stems to the suitability of juvenile material for tissue culture and/or rooted cuttings requires further study, since success depends on the degree of rejuvenation of the parent tree or stool as a continuing donor of vegetative material as well as the response of the cuttings in the laboratory and nursery.

7.0 MAINTENANCE AND MANAGEMENT

The basic thrust of the Florida eucalypt plantation manager must be to operate at a profit. The manager must weigh the expense of each cultural practice and expertly weave it into achieving his overall goals. Certain natural occurrences can be mainpulated by management; but, some acts of nature are uncontrollable. The manager needs to recognize those things he can control and determine the cost effeotiveness of the possible management practices.

7.1 Fire Protection.

Maintenance and management of the eucalypt forest through its first rotation (6-8 years) will include fire protection by initially installing firelines as required, then replowing, discing, or harrowing the established lines on an annual basis. Based on current Florida Division of Forestry charges of $19 per hour, and an estimate of two miles per hour (Mark Hebb, pers. comm.), fireline plowing costs are estimated to be about 12¢ per acre per year (30¢/ha).

Fireline plowing (new or renewed) ohould be performed at the conclusion of the normal Central Florida rainy season and prior to first frosts which escalate fire danger. Short rotation eucalypt biomass forests potentially are low risk hazards to catastrophic wildfire; however, the shallow lateral root system of the trees could be severly damaged by a slow moving ground fire. Schory (1960) considered Florida eucalypts to be vulnerable to fire, but also observed that fire-damaged trees coppiced readily.

The overburden plantation at Agrico was burned on January 16, 1981 by a slow to medium moving wildfire. There was no apparent damage to trees larger than 3 inches dbh (7.6 cm). Damage to smaller trees ranged from a minor set-back to complete mortality. This plantation, vulnerable by virtue of its location near a well-traveled roadway, has been periodically plagued by fire. No estimate can be made of tree and/or growth losses attributable to fire over the years.

A eucalypt biomass plantation is most vulnerable to catastrophic
fire loss during the first 18 months after planting; however, there is
little fuel accumulation because of suppression of competing vegetation
during this period. Stands vary greatly in the amount of understory
vegetation that accumulates fuel later in the rotation cycle. Whole
tree chipping reduces the accumulation of slash as fuel. The alleopathic
effects from leaf fall may help to prevent fuel accumulation. With the
proper maintenance of plowed firelanes, we do not expect fire loss to be
a significant risk.

Fires in eucalypt plantations in small to moderate blocks (160 acres/ 65 ha) with short-rotation harvesting typically are not catastrophic. Hc er, leaf, bark, and branch litter can accumulate to the point of posing poten___l fire problems, particularly to young coppice growth. Clonal block plantings and planned road systems lend themselves to low cost fire protection. According to Michel Boulay (pers. comm.), eucalypts are planted in France in buffer strips as a fire protection measure for other forest habitats. Widespread buffer-type plantings of eucalypts along highways and fire breaks could help control wildfires as well as produce woody biomass. Eucalypts are widely planted in California for windbreaks along highway corridors.

7.2 **Vegetative Competition.** The control of competing grasses and other vegetation within the eucalypt plantation is the single-most important growth-stimulating cultural practice. These controls should be maintained on an "as needed" basis for as long as eighteen months after initial plantation establishment. Control of competing vegetation can be obtained and maintained by mechanical or chemical means, or the two in combination.

Initial site preparation should offer a planting site devoid of competing plant growth. If grasses begin regrowth prior to plantation establishment, light discing should be employed. After plantation establishment, herbicide can be applied approximately 2 feet (0.6 m) on either side of the plants, perhaps in conjunction with discing between rows. This should be done as required and until the eucalypts are approximately eighteen months of age.

Prior to discing, the extent of lateral root elongation between rows should be evaluated. Discs with depth gauges should be utilized and cutting depths set so as to minimize root damage. This is particularly important in bedded plantings where roots between beds may be at or near the ground

surface. The frequency of treatment will be influenced by climatic conditions, site quality, plantlet performance, and the initial site preparation.

It is important to choose a chemical herbicide that: (1) is compatible with eucalypts; (2) is environmentally acceptable; (3) has relatively long lasting effects; and (4) is affordable. Candidates for evaluation and further testing include Roundup, Chipco Ronstar G, Surflan, Devrinol, Paraquat, Sinbar, and Oust, as well as other possibilities.

Oust, a new herbicide undergoing testing and development, was applied to four test plots in June 1981 through a cooperative effort between BESI and Jerry Stephenson (DuPont's Florida Agrichemical Marketing Representative). The plots used for tests contained 1,125 square feet each (104.5 m^2), with dimensions of 4.5 x 250 feet (1.4 x 76.2 m). A survey of the plots two months after treatment revealed complete control of undesirable vegetation with applications of 1.5 and 2 pounds per acre (1.68 and 2.24 kg/ha). We anticipate that no more than three treatments would be required to control competing vegetation over 18 months. However, the cost could be prohibitive.

Present chemical application costs, based on citrus spray equipment rentals (Jim Allen, pers. comm.), are about $10 an acre (0.4/ha). Herbicide cost is estimated at $24/acre ($59.31/ha) and necessary discing at $6/ treated acre ($14.83/treated ha). The total expense for the chemical, its application, and post-application discing is estimated to be $40/acre ($100/ha).

7.3 <u>Disease/Insects</u>. The proposed Florida eucalypt plantations
will require intensive culutral practices typical of monocultures. As
species and genetic diversity are compressed to enhance wood production,
these reductions favor the spread of disease. A method of reducing
susceptibility to epidemic disease may be as simple as clone separations
of one mile (1.6 km), or such other block sizing and distance factoring
as may be deemed appropriate. For example, just 16 clonal genetic sources
can give a separation of at least 1.5 miles (2.4 km), while 64 sources
can offer a separation of 3.5 miles (5.6 km).

Diaporthe cubensis has been reported in South Florida eucalypt
plantings (Hodges et al., 1979); however, no evidence of the disease was
found in North Florida and South Georgia plantings. The report also
indicates that this disease affected *E. grandis* but not *E. rubusta*. *Diaporthe
cubensis* was first reported in Cuba as a trunk cancer on several species
of *Eucalyptus* (Bruner, S.C., 1917). Studies in Brazil show great variability
in resistance to *Diaporthe cubensis* between various species (Hodges, et al.,
1976).

Natural ecosystems have yielded resistant genes for incorporation
into resistant varieties of important food crops (Leppik, 1970). Disease
resistant eucalypt species, or genetic resistance within species may be the
foundation upon which to build large scale, high production clonal forests.
At the present time diseases or insects affecting eucalypt production in
Florida are minor. The forest manager should be aware that the possiblity
exists for the endemic situation to become epidemic. Changes in foliage
color, high stem mortality, dieback of limbs, and cankers are a few of
the obvious indicators.

.7.4 <u>Grazing</u> or browsing damage to newly planted eucalypts is most severe when the tree's root system has not become well established and the crown is within reach of cows. Without perimeter fencing, some damage should be expected if cattle are allowed continued access to the newly planted forest. This damage may only be by trampling if attractive food supplies abound elsewhere; but, it can be catastrophic from actual plant consumption during low forage production periods. In some cases, large trees may be killed by animals rubbing against them; but, the relatively small acutal losses do not justify the expense required to deny cattle access to the forest. Once trees are established, cattle use may even be beneficial. There are no data available to evaluate the relationship.

Small experimental plots are an exception and should receive protection from cattle on a year-round basis.

7.5 <u>Wildlife</u>. In the native eucalypt forests of Australia there are a variety of habitats which lend themselves to use by a wide range of native species, including the famous koala bear. The eucalypt forest, as introduced into Florida, will provide habitats initially suitable for sustaining and encouraging wildlife use. This is a situation which may be similar to much of the Australian forest where available food is scarce and animal populations are low (Cremer, 1969). Even the koala, which can consume 2.2 pounds (1 kg) of *Eucalyptus* leaves per day (Ride, 1970), is not considered a serious pest. Only on rare occasions will they defoliate and perhaps kill trees (McNally, 1957).

The Polk County eucalypt plantings show no visual evidence of stress caused by coexistance with native wildlife. The Glades County plantings show some browsing damage by deer on the outer perimeter of block plantings, as well as antler rubbing. It is reported that a small experimental planting near New Smyrna Beach has been severly damaged because of browsing by deer (Dixon, pers. comm.). The forest manager should be alert to the possiblity of potential damage and take appropriate action when required.

7.6 <u>Cold</u>. Field examinations of the Polk County *E. camaldulensis* plantings (Agrico and Grace) on February 1, 1982 revealed that the severe freeze of January 11-12, 1982, when temperatures dipped to the teens and low 20's for up to 6-12 hours, caused little damage. The young tender coppice growth resulting from cutting or wounding select trees and managed by BESI as a source of juvenile material from March to late October 1981 suffered almost negligible damage. In most cases, sprouts from felled and/ or wounded trees had grown 3 to 5 feet (1-1.5 m) since the last collection of juvenile material in the fall of 1981. Obvious cold damage consisted of slight leaf burning of the top six inches (15 cm) only, of most coppice shoots examined.

The wounded and other standing trees in the plantations showed only minor damage at the very tip end of branches, with undamaged flowers occurring about 12 inches (30 cm) from branch ends.

E. tereticornis at the west and south sides of the Grace planting and on the north side of the Agrico planting showed a 50 to 75 percent leaf burn, but no immediate evidence of wood damage.

The same cold which reached 22°F (-6°C) and lower in Glades County caused severe bark and cambium damage to most stems and branches less than two inches (5 cm) in diameter, and probable damage to stems and branches up to four inches (10 cm) in diameter. Except for a very few individual stems, *E. grandis* and *E. robusta* plantings in Glades County were totally browned by the cold. The *E. camaldulensis* seed orchard on State Road 74 was virtually untouched by the same cold. Some scattered browning of leaves was observed during a field trip to the area on February 2, 1982. It is apparent that *E. camaldulensis* offers a tolerance to cold not available from *E. robusta* or *E. grandis*. The cold tolerance of *E. camaldulensis*, in conjunction with its growth performance in Polk County, enforces its selection as BESI's species of choice.

7.7 Drought. Central Florida exhibits definite long-term
weather patterns. Dry in the spring, wet in the summer, and alternately
wet and dry in the fall and winter, depending on frontal activity.

BESI has considered the undeniable advantage of irrigation and
weighed it against the exorbitant cost of watering the forest. Irrigation
systems used by the citrus industry range from $750/acre ($1,850/ha) for
low volume drip or mist types to $1,000 and up/acre ($2,470+/ha) for high
volume overhead irrigation. Watering by truck, even if at a modest cost
of $20 per hour and a high watering volume of four trees per minute, would
represent a cost of $72/acre ($180/ha) each time plants were watered.
Irrigation is not practical or economically feasible.

Except for small experimental plantings, the cost of irrigation is
prohibitive using any system now available. Planting should be performed
during those times of the year when prior records indicate rainfall adequate
for plantlet establishment can be expected. Cloning of drought resistant
trees is highly desirable for spring and winter plantings.

7.8 Access. Access to the forest through a well planned system
of roads, benefits almost every segment of the forest management plan.

In the event of fire, the rapid movement of firefighting equipment
to the fastest moving part of the fire can often mean the difference between
minimal or catastrophic losses. The eucalypt forest is not likely to
burn with the intensity or speed of some other forest types; but, retaining
the capacity for early arrival at the fire remains extremely important.

The frequency with which roads cut through the forest facilitates
harvesting, inspection for disease, and the general day to day attention
the forest manager and his staff need to furnish the forest to promote
its well being and profitability.

The easy access and frequency of roads does provide some potential problem for trespass, vandalism, and wood theft; however, the capacity for close surveillance inherent to a good road system outweighs problems posed by theft, trespass, and vandalism.

Consideration of all forest management activities and the ability to achieve the predetermined goal of profitability at harvest, will determine road frequency. Road construction costs need to show a return through increased yields or lower per unit costs.

8.0 HARVESTING

   8.1 Background. Large industrial users of wood select independent
contractors to furnish woody raw materials. Wood sources include privately
owned, publicly held, and company controlled lands. The pulp and paper
companies use a dealer/producer harvesting operation, where dealers con-
tract with large companies to furnish a certain volume or weight of wood
on a regular basis, subject to periodic adjustments by the company. The
dealer, in turn, has a number of independent producers who cut and deliver
to a specific site a certain amount of product on a regular basis, usually
weekly. Delivery sites may be rail sidings, wood concentration yards, or
the primary mill site. Distance to the mill from the forest dictates the
mode of raw materials transport. Generally, as the cost of fuel and labor
increases, the distance that wood can be delivered economically by truck
to the mill decreases, and/or the size of trucks and wood loads increases.

   Harvesting scenarios can be as numerous as the various types of
equipment available, operational or prototype. Such equipment is currently
undergoing rapid evolution with the state-of-the-art advancing dramatically
each year. Thus, it would be unwise to select any one specific method
and loose the flexibility of change when faster, more economical equipment
arrive on the scene.

   The first eucalypt energy plantations will not be ready for harvest
until 1989-90. Every harvesting system must perform four separate
activities beginning with the standing tree in the forest and ending
with the delivery of the tree to the processing plant. These activities
are: felling, skidding, yarding, and hauling.

   8.1.1 Felling. Felling is the cutting or shearing of
individual trees. The most widely used felling equipment is the chainsaw,
as well as the most hazardous to the workforce. For smaller trees ranging
up to 30" (76.2 cm) at ground level, shear or scissor type feller bunchers
on wheels or tracks take much of the sweat and danger out of the logger's
labor. The feller buncher is a machine which uses a hydraulic clamp

to hold the tree while cutting or pinching the stem at near ground level with a mechanical shear, acting like a draw knife or scissors. Machines can accumulate cut trees in bunches up to the basal area accumulation limits of the individual design. When maximum accumulation is reached, the machine then lays severed bunches of stems on the ground in neat convenient stacks. Topography and climatic conditions are two of the limiting factors to be considered when choosing felling equipment. For flat Florida terrain, feller bunchers offer a fast mechanical method for felling trees and can operate most of the year in almost all locales.

8.1.2　Skidding. The skidding operation utilizes four-wheel drive, rubber-tired skidders to move the stacked trees or logs to central loading points. In some cases, as dictated by either terrain or climatic conditions, steel tracked crawlers or draft type animals may be employed in the skidding operation. Skidders usually move more than one log or one tree at a time. This is determined by individual manufacturers specifications which usually measure capability in tons and/or holding capacity in square feet or meters. The butt ends of logs or trees to be skidded are held up off the ground by a steel cable or hydraulic grapple arm mounted at the rear of the skidder on a stationary or moveable "A" frame type arrangment. Only under the most adverse logging conditions would any type other than a rubber-tired skidder be considered for our Florida biomass operations.

8.1.3　Loading or Yarding. After logs or trees are relocated by the skidder to the central loading point, they are readied for shipment to a wood concentration yard or the process plant wood storage area. In a fuelwood or wood to methanol operation there will be no waste. All wood energy will be utilized. Trees will be limbed and topped to conform to maximum road hauling limits and the stems loaded on large trucks for delivery to the concentration yard or plant. The balance of the tree (limbs and tops) can be chipped and blown into covered trailers by whole-tree chippers. Whole tree chippers are mobile and can move to various loading or yarding sites and quickly set up for operation. Most whole tree chippers have a

grapple on the end of a flexible knuckle boom which can reach out, grasp, and place wood to be chipped onto a motorized conveyor. This conveyor has pressurized rollers to hold and feed the tree parts to high speed cutting knives that reduce the wood to chips up to 4 inches (10 cm) in size.

8.1.4 Hauling. Chips are transported by enclosed or covered tractor-trailer vans to the process plant wood chip storage or utilization area. The delimbed whole trees may be hauled by conventional logging trucks or tractor-trailers. A combination of the loading operation with hauling could be the lopping off of tops and branches (assumes a clear bole to maximum legal hauling lengths) with a rotary cut-off saw. The saw can be a separate unit or an auxillary attachment to other required rolling stock. The lopped tops and branches should end up in convenient piles at the rear of the log truck. The mobile chipper will pick up and chip this material leaving the forest site free of slash or waste material which could either slow or preclude coppice regrowth or increase potential fire danger.

Hauling will be limited by height, length, and weight of the load. Florida's maximum legal gross weight per transport unit is 80,000 pounds (36,287 kg), unless a lessor weight is stipulated. Maximum legal length from the front bumper of the tractor to the rear of the load is 55 feet (16.8 m), or 65 feet (19.8 m) with a special annual blanket permit. Special permits for individual trips may be issued for even longer loads. Height limits are generally less than 14 feet (4.3 m); but, they are controlled by the height of obstructions along the travel route and gross weight of the load. Log trailers loaded butt first probably cannot exceed weight limits and stay within maximum underpass heights. According to E. Cremer (pers. comm.), it is possible to carry 35 to 37 tons (31-3/4 to 33½ tonnes) by loading half the butts toward the truck cab and the other half toward the rear of the log trailer. If all travel is to be over private roads, weight limits do not pertain and the main consideration may be breaking down the road through excessive weight.

8.2 Wood Storage on the Plantation. There are advantages to
storing cut stems on the plantation. Under this harvesting scenario
the tops and branches would be chipped and sent to the plant while the
stems would be stockpiled at planned loading sites within the plantation
for a period of time, perhaps for 3 to 6 months. Most of the green wood's
moisture would be released by the felled stem. Reduction in wood moisture
increases fuel effeciency, reduces hauling costs of raw materials, and
increases wood volumes which can be transported as single load increments,
yet maintaining legal over the road weight limits. These advantages
should more than offset the additional cost of handling the stems twice
at the plantation site.

In the case of green wood with a 50 percent moisture content, 40 tons
of green wood, consisting of 20 tons water and 20 tons wood, can not be
hauled as a single load. If wood is dried to a 25 percent moisture content,
then the same 20 tons of wood contains only 6.6 tons of water and a 26.6
ton load could be legally hauled when weight is the only limitation
(Figure 8-1).   Samples of Polk County *Eucalyptus* chipped green
wood contained approximately 50 percent moisture by weight, while samples
of Polk County *Eucalyptus* felled five months before chipping contained
only 13.5 percent moisture. As moisture content decreases the cubic foot
volume of wood in a constant weight load increases (Figure 8-2).

Yet another major advantage of in the woods storage of stems would
be the reduction in the size of the yard and volume of wood stored at
the plant site. The risk of a large fire loss at the plant yard likewise
would be diminished. BESI currently intends to store about 50 percent of
the harvested stems only in the woods for at least 3 months before
transporting them to the methanol plant.

FIGURE 8-1

Tons of Water as Moisture Content Decreases
(Decreasing Weight)

Tons of H2O in Constant 20 tons of Wood

Moisture Content of Wood in percent.
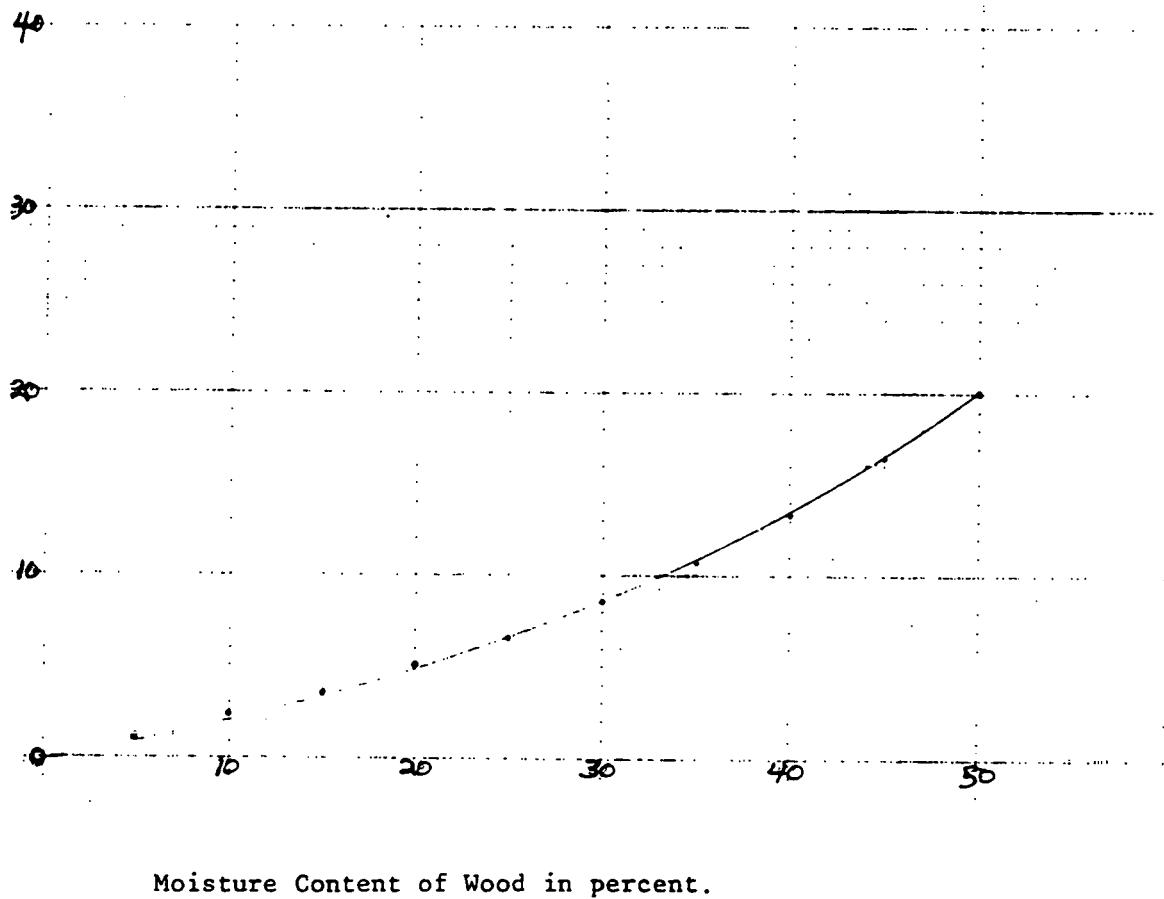
FIGURE 8-2

Cubic Foot Increase as
Moisture Content Decreases

(Constant Weight)

Moisture Content of Wood in Percent
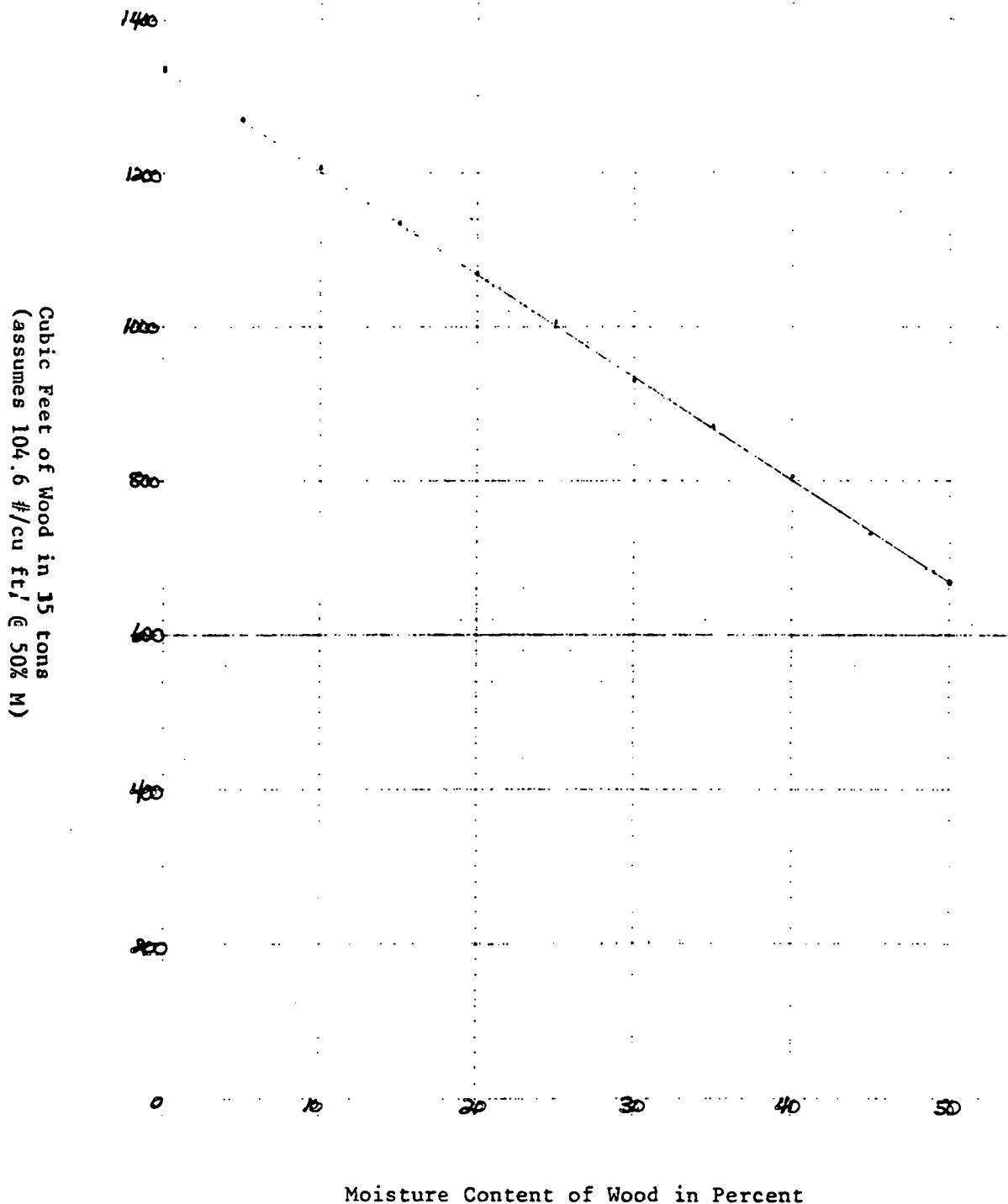
8.3 Logistics of Delivering Wood to the Plant. This analysis
assumes that:

(1) 65 percent of the wood required for plant operation will
be in the form of whole tree logs,

(2) 35 percent of the feedstock will arrive as chips derived
largely from limbs and tops,

(3) the plant requires an estimated 6,000 tons of green wood
per day.

Daily plant consumption will be 3,900 tons of whole stems and 2,100 tons
of chips. There will have to be 156 loads of logs and 106 loads of chips
delivered each day, based on 240 delivery days per year and the use of
standard transport operating within the legal limits. In the plant yard
storage of stems will range between 1,500 and 3,000 truck loads, a 10-20
day supply.

If we assume an average road speed of 35 miles per hour, 20 minutes
to load and unload log trailers, and 35 minutes to load and unload chip
trailers, then the distance from the loading point in the forest to the
unloading or utilization point at the plant cannot exceed 12 miles. This
also assumes that log trucks will cycle 10 times and chip trucks 8 times
on a daily basis. To operate from a further distance would require some
combination of: (1) larger trucks, (2) increased average road speed,
(3) reduction in loading and unloading time, (4) more trucks, or (5) rail
transport. Nineteen log truck prime movers yields an 82 percent efficiency
rate, while 13 chip truck prime movers yield and 81 percent efficiency rate.
This efficiency rate would allow for an approximate 20 percent downtime
of vehicles and maintain the necessary equipment to log the mill. A higher
effeciency rate would require less equipment.

To process at the plant a total of 156 loads of logs requires 1,560 minutes of unloading time and necessitates three or four plant unloading points. The 105 loads of chips will take 2,625 minutes to unload and requires six unloading points at the plant.

If 261 separate loads of wood enter the plant on each of 240 scheduled delivery days, then one truck enters the plant every 2.5 minutes during a 10 hour work day. This is a challenging exercise in the transport of large quantities of material. Transport by rail, or a large enough site to contain the methanol plant and a preponderance of the plantation acreage in close juxtaposition, would greatly modify the above logistics. On-site movement of wood can be accomplished with much higher payloads in specialized vehicles that could not travel the public highways.

8.4 <u>Transportation Alternatives</u>. The use of concentration yards removed from the plant site other than on the plantation storage may be a viable alternative. Advantages of concentration yards include additional stock piling facilities for wood; a local marketplace for wood accessible to small, occassional purveyors of wood; and a permanent, mechanical, and rapid unloading point. While any transloading is an additional cost factor, the cost usually can be carried by both buyer and seller when advantageous to both.

Wood transported to a rail siding usually is the least efficient, most expensive, and most physical because mechanical unloading equipment is not usually available and hand labor is required. Except for rare instances, wood loading at rail sidings has been done by small producers cutting wood from small isolated tracts. The wood generally has been loaded by hand onto a small truck, then unloaded and stacked by hand on the rail car. The Seaboard Coastline freight office in Lakeland has no knowledge of

any loading of wood at a rail siding in the last several years other than at mechanized woodyard locations. Such experience with rail transport of wood in Florida has little relevance to the methods that would be employed to maximize efficiency if rail should prove to be an economic mode for moving wood to the plant. Wood transported to the primary mill by truck normally has been the most efficient and least costly since transloading is unnecessary.

The region is well-traversed by roadways and rail lines. These existing facilites are adequate to perform the necessary task of wood transport following harvests. However, it is anticipated that trafficability will be slowed down in those areas that currently are subject to congestion. A major problem could surface where transportation routes, particularly highways, converge at the methanol facility. Adequate lead time will be available for expansion and upgrading of existing transportation facilities where needed.

8.5 _Feedstock Ownership_. Most large users of wood own a substantial
portion of the wood required to sustain continued, uninterrupted operations.
The southern based pulp and paper companies usually own in fee or control
through long-term leases (66-99 years) at least 60 percent of their fore-
seeable merchantable and growing stock requirements. As interest rates
increase and land values rise, longterm leases for both the leasee and
the leasor take on added attractiveness. Leases can be a fixed or escalat-
ing cash payment for a specific number of years, or a lesser cash payment
and a portion of net or gross proceeds at the time of harvest. The land-
owner usually has some sort of minimum guarantee. Through ownership,
or at least long-term control, large wood users can accurately forecast
long-range raw material costs, make definitive management plans for
harvesting and planting to insure long-term continuing sustained yields.
There also are significant tax advantages for the wood user in growing and
supplying the feedstock, particularly for the conversion of biomass to a
gasoline substitute like methanol. BESI intends to be a major eucalypt
producer.

8.6 _Harvest Costs_. When considering harvesting costs, for the
purpose of simplicity, we include costs from the cutting of the wood to the
stockpiling at the plant. Harvesting costs include equipment purchases or
rental, direct and indirect labor costs, transportation costs to the primary
point of use, and interest charges for equipment.

Wood harvesting systems vary from almost entirely hand labor to almost total mechanization. Generally, as hand labor decreases, productivity increases and per unit costs decrease. These cost reductions occur in spite of large front-end expenditures allocated to the initial purchase of sophisticated harvesting equipment, its annual maintenance requirements, and periodic replacement. Southern-based wood harvesting operations generally consider an annual work time of 240 days. This will vary by location based on rainfall, road systems, ground conditions, and volumetric requirements to "log the mill".

8.7　Harvesting Methodology. For our purposes, we have discarded as too labor intensive all logging systems except "whole tree chipping in woods" and "feller-buncher with whole tree (stem) transport to mill". Since we will require in excess of 1.5 million tons per year for plant operation, we must utilize the most labor efficient harvesting systems operational at the time of harvest. Prototype systems under development will be considered as they become operationally available.

Advantages of "whole tree chipping in woods" include complete utilization of the above-ground woody biomass, increased surface area for air-drying, more efficient combustion with less moisture, and ease in handling and transport. Primary disadvantages include removal from the forest of nutrients and minerals in the leaves and twigs and possible spontaneous combustion problems in conjuction with chip storage.

Advantages of the "feller-buncher with main stem transport to mill" method include leaving in the woods nutrients found in the green leaves and twigs. However, the failure to utilize as much as 35 percent of the harvestable above-ground biomass may be unsound. Therefore, the grower of the woody biomass should, from an economic standpoint, utilize whole tree chipping methods, or some combination of methods which moves the entire biomass growth from the woods to the mill.

A combination of whole tree logging in conjunction with chip harvesting of limbs and tops will: (1) allow total above-ground biomass utilization; (2) reduce the requirements for chip storage at the primary plant site, since less than 35 percent of the volume by weight will be in the form of chips; (3) reduce the hazard of spontaneous combustion by keeping the chip pile to smaller, more manageable proportions; (4) reduce overall capital expenditures for harvesting equipment; and (5) allow the bulk of the above-ground woody biomass to enter the plant processing system at the lowest cost. Indeed, chips may be fed directly into the plant and not stockpiled except for periods of shut-down and when deliveries exceed consumption.

While no new harvesting equipment technology is necessary, some innovation on the part of the harvesting organization will be required. Limbs and tops will need to be wind-rowed at the plantation periphery. Placement should be such that neither the wind-rowed piles nor their conversion to chips interferes with the coppice regrowth of the stand. Delimbing gates, cutoff saws, chainsaws, axes, or a combination of any or all of these devices may be required for the cost effective processing of limbs and tops.

Company owned harvesting equipment run by company employees has not been ruled out at this time. Because of the Central Florida location and the lack of experienced woods workers, recruitment and training of a skilled harvesting workforce will be necessary. Most pulp and paper companies have used company employees to run equipment while working as the woods force to "log the mill". For a variety of reasons, company harvesting operations generally have been unsuccessful. BESI will carefully examine harvesting options when eucalypt stocks are about one year from maturity in 1988-89 and make the necessary and prudent decisions at that time as to details of the harvesting operation. Tax laws and depreciation allowances in effect at that time may be the overriding determinant in the decision making process.

9.0 EUCALYPT BIOMASS PRODUCTION ESTIMATES

9.1 <u>Background</u>. Our woody biomass production predictions are based on growth studies of the previously described Polk County *Eucalyptus camaldulensis* plantations on sand tailings and overburden. A production study of *E. grandis* and *E. robusta* by Meskimen (1979) offers a base for projections of production for flatwoods.

Estimates found in Table 9-1 are based on the earliest available data and use a volume formula which reflects only "merchantable volume" (pulpwood). Our literature search disclosed no satisfactory formula which equated a standing eucalypt to its total above ground biomass volume. The estimate of 5.9 cubic feet of wood weighing 613 pounds ($0.17m^3$ and 278 kg) understates the true volumetric measurement of the total above ground biomass; but, it does accurately predict average tree weights based on dbh, total height, and site quality parameters.

The purchase of wood thirty years ago depended almost entirely on ocular estimates, or a series of time consuming measurements. Today, wood is purchased almost entirely on the basis of weight. In some cases, measured weight is converted to a locally acceptable unit of measure. In Florida, the cord is a standard term used by purchasers of pulpwood; however, the weight of a cord varies by both geographical location and species. For instance, the weight factor for South Florida slash pine is greater than that for North Florida slash pine. In some cases, a cord also varies by volumetric measure. Citations in the literature range from 80 cubic feet ($2.3 m^3$) to 92 cubic feet ($2.6 m^3$) when describing a cord reduced to solid wood content.

TABLE 4-1. PRELIMINARY EUCALYPT GROWTH AND ENERGY PROJECTION

Value	Tailing/Debris Planting Site E. camaldulensis Estimated				Pasture/Flatwoods Planting Site E. grandis Estimated				Overburden/Cropland Planting Site E. camaldulensis Estimated			
	Existing	Low	Med	High	Existing	Low	Med	High	Existing	Low	Med	High
Age	6.33 yrs	6	6	6	7½ yrs [11]	6	6	6	6.33 yrs	6	6	6
Spacing (in feet)	6'x12'	5'x10'	5'x10'	5'x10	8'x14' [11]	5'x10'	5'x10'	5'x10'	6'x12'	5'x10	5'x10'	5'x10'
[8] Live Tree/acre	329	523	610	697	268 [11]	523	610	697	424	523	610	697
[14, 15] Mean DBH	4.76"	6.0	6.6	7.3	NA	6.2	7.0	7.8	4.61"	6.4	7.1	7.9
[14, 15] Mean Height	42.18'	50	60	70	54.5 [11]	55	65	75	42.96'	60	70	80
[9] Cu. ft/tree	4.07	3.80	5.43	7.60	6.44	4.43	6.52	9.19	3.30	5.17	7.24	9.98
[7] Dry #/tree	109.0	101	146	203	166.8	119	175	246	88.3	138	195	267
[6] Dry ton/acre	17.7	26.4	44.4	70.8	22.5	31.2	53.4	85.8	18.7	36.0	59.4	93.0
[2, 12, 13, 15] Green ton/acre/year	7.0	11.0	18.3	29.2	7.0	12.8	21.9	35.3	7.3	14.9	24.3	38.3
[1, 12, 13, 15] Dry ton/acre/year	2.8	4.4	7.4	11.8	3.0	5.2	8.9	14.3	3.0	6.0	9.9	15.5
[14, 15] cord/acre/yr	2.3	3.6	6.0	9.6	2.5 [11]	4.2	7.2	11.6	2.4	4.9	8.0	12.6
[3] M^3/ha/year	14.8	23.2	38.6	61.8	16.1	27.0	46.3	74.7	15.4	31.6	51.5	81.8
[10, 16] BTU/year @ 8236	4.6×10^7	7.3×10^7	1.2×10^8	1.9×10^8	4.9×10^7	8.6×10^7	1.5×10^3	2.4×10^8	4.9×10^7	9.9×10^7	1.6×10^8	2.6×10^8
Oil equiv. [4, 5]	8.4	13.2	22.2	35.3	9.0	15.6	26.7	42.8	9.0	18.0	29.6	46.4
[10, 16] BTU/year @ 8460	4.7×10^7	7.4×10^7	1.3×10^8	2.0×10^8	5.1×10^7	8.8×10^7	1.5×10^8	2.4×10^8	5.1×10^7	1.0×10^8	1.7×10^8	2.6×10^8
Oil equiv. [4, 5]	8.6	13.5	22.8	36.3	9.2	16.0	27.4	44.0	9.2	18.5	30.5	47.7
[10, 16] J/year @ 8622	4.8×10^7	7.6×10^7	1.3×10^8	2.0×10^8	5.2×10^7	9.0×10^7	1.5×10^8	2.5×10^8	5.2×10^7	1.0×10^8	1.7×10^8	2.7×10^8

9.2 __Projections__. Production predictions (Table 9-1) have been made for three different soil types found in Central Florida: flatwoods; sand tailings; and overburden. Each of these soils was divided into low, medium, and high growth ranges. Predicted growth increases are based on: (1) an increase in planting density from a previously recommended density of 605 stems per acre (1,495/ha) to 871 stems per acre (2,152/ha); (2) volumetric increases through vegetative propagation of genetically superior materials; (3) improved site preparation and control of competing vegetation for eighteen months; (4) fertilization as appropriate to stimulate growth and avoid phosphate toxicity; and (5) increased survival.

Predictions of the growth potential of E. *camaldulensis* range from a low of 11 green tons per acre per year (24.7 gt/ha/year) on the poorest soils under poor conditions to 38.3 green tons per acre per year (85.9 gt/ha/year) on the best soils under the most favorable conditions. Based on a seven year rotation, production is estimated to range from 77 green tons per acre (173 gt/ha) to 268 green tons per acre (600 gt/ha). Table 9- 2 compiles these data.

9.3 __Weights and Volumes__. A sample of three trees, six, seven and eight inch dbh (15.2, 17.8, and 20.3 cm), varying from 50-60 feet (15.2-18.3 m) in height, was cut flush to the ground and weighed. Stems, up to an approximate three inch dbh (7.6 cm) top, were weighed separately from limbs and crowns. Based on actual weight measurements, the mean weight green of these three six, seven, and eight inch (15.2, 17.8, and 20.3 cm) dbh trees, 50, 55, and 60 feet (15.2, 16.8, and 18.3 m) tall, was 613 pounds (278 kg). The average stem weight was 500 pounds (227 kg) and the average weight of the limbs and crown was 113 pounds (51 kg). Approximately 18 percent of the total average weight was in limbs and crown (Table 9- 2).

TABLE 9-2

TREE WEIGHTS (GREEN)

DBH		HEIGHT		VOLUME		ACTUAL WEIGHT			
						STEM		CROWN	
inches	centimeters	feet	meters	cubic feet	cubic dm	pounds	kilograms	pounds	kilograms
6	15.2	50	15.2	3.86	109.3	340	154.2	180	81.6
7	17.8	55	16.8	5.70	161.4	560	254.0	80	36.3
8	20.3	60	18.3	8.03	227.4	600	272.2	80	36.3
7*	17.8*	55*	16.8*	5.86*	166.0*	500*	226.8*	113*	51.4*

* Averages

Based on data provided by our plant design consultants, Polk County *E. camaldulensis* green wood samples had a moisture content of 50.7 percent. Thus, in a bone dry state, an average stem would weigh 246.5 pounds (11.8 kg), the limbs and top would weigh 55.7 pounds (22.3 kg), and the total dry above ground biomass weight would be 302.2 pounds (137.1 kg). If the average tree contains 5.9 cubic feet of wood, then the equivalent of 15.7 trees would be needed to provide one 92 cubic foot cord of wood, and six trees would be needed to provide one cubic meter of wood.

Assuming a mean average production of 22 green tons per acre per year (49.3 tonne/ha/yr) and a seven year rotation, the total biomass production per rotation will be 154 green tons per acre (345.2 tonne/ha).

9.4 Methanol Plant Feedstock Requirements. To produce 100,000,000 gallons (378,541,200 liters) of methanol will require about 4,000 tons (3,619 tonnes) of wood per day. Based on an above-ground biomass green weight of 613 pounds (278 kg) for each tree, biomass harvesting requirements would be:

AREA REQUIREMENT

Plantation Survival Rate	Daily Acres	Hectares	Annual Acres	Hectares
70%	21	8.7	7,665	3,175
80%	19	7.6	6,935	2,774
90%	17	6.7	6,205	2,445

A thirty day start-up wood inventory of 120,000 tons (108,862 tonnes), consisting of more than 2 million cubic feet (65,000 m^3), would require storage space of about 3.2 acres (1.3 ha) if wood is piled to a 50-foot (15.m) height, or 6.4 acres (2.6 ha) if stacking height is limited to 25 feet (7.6 m). This wood inventory storage at the plant site could be reduced substantially by storing cut stems in the plantation for three months.

A typical whole tree logging crew, operating under average field conditions, should produce ten 25-ton (22.7 tonne) loads of wood per day. Using a 240 day annualized harvesting schedule, daily plant delivery will be about 6,000 tons (5,500 tonnes) and will require 30 operational logging crews, of 8-10 workers each, assuming an 80% efficiency rate.

9.5 <u>Estimated Costs, Yields, and Gross Revenues</u>. Under typical Florida conditions, and todays prices, it is estimated that site preparation, plantlet purchase, and planting will cost about $500 per acre ($1,235/ha). Included in site preparation is the removal of residual stumps, chopping or double chopping surface vegetative materials, discing with a heavy disc, applying 0.5 tons per acre (1.12 t/ha) of ground rock phosphate (P_2O_5), discing with a medium disc, bedding, applying herbicides, planting, and establishing necessary firelines. The cost of the internal road system is independent of site preparation.

Average yield based on average growth and survival for clonal tissue cultured plantlets is estimated to be 154 green tons per acre (345 gt/ha) during a seven year rotation. Using a gross value of $30 per ton ($33.07/ tonne) for wood chips, which understates present F.O.B. West Coast values of $80-85/BDT (Darr, pers. comm.), provides a gross return per acre of $4,620 ($11,700/ha).

Using an estimated harvesting cost of $10 per ton ($11.02/tonne), the per acre harvesting cost is $1,540 ($3,805/ha). Harvesting costs will vary by harvesting method employed, distance from the forest to the utilization point, fuel prices and consumption, and the cost of labor and benefits. An estimate of whole tree harvesting costs is compiled in Table 9-3 and an estimate of whole tree chipping costs is compiled in Table 9-4.

By subtracting installation costs of $500 per acre ($1,235/ha) and harvest costs of $1,540 per acre ($3,805/ha) from a gross value of $4,620 per acre ($11,700/ha) we arrive at a gross return of $2,580 per acre ($6,375/ha) over the 7 year rotation from which must be deducted costs for management, purchase or rent of land, interest charges, and return on investment. There are, of course, ancillary financial benefits to be derived from inhousing the site preparation and harvesting operations. Furthermore, a more mid-range, less conservative prediction of green chip market value in 1990 would be $50/ton instead of the $30 value used in this analysis.

TABLE 9-3

Estimated Daily (Per Ton) Operating
Costs for Whole Tree Harvesting

	Daily Operating Costs
1 Feller Buncher	$ 113.75
1 Chainsaw	1.75
2 Skidders w/hdy Grapple	192.50
1 Log Loader/w Cutoff Saw	113.75
2 Prime Movers @ 55¢/mile/600 mile/day	660.00
3 Log Trailers @ 10¢/mile/400 mile/day	120.00
1 Pickup	17.50
Miscellaneous tools	3.50
Subtotal	$1,226.25

	Annual Overhead Costs
Depreciation	$ 93,743.79
Interest, Taxes, etc.	100,000.00
Truck Ins., Use Tax, License	10,000.00
Bookkeeping, etc.	5,000.00
Legal fees	5,000.00
Office expenses	5,000.00
Workmans Compensation	24,300.00
Other labor overhead	19,440.00
Total Annual Overhead	$262,483.79

Annual Working Days--240

Overhead Cost Per day	$ 1,093.68
Labor/Field Supervisor $1500/mth	75.00
6 persons @ $5/hr--10 hr/day	330.00
Operating Costs Per Day	1,222.75
Total Daily Costs	$ 2,721.43
Costs per ton per day (500 T/day)	$5.44

TABLE 9-4

Estimated Daily (Per Ton) Operating
Costs for Whole Tree Chipping

	(per day) Daily Operating Costs
2 Feller Bunchers	$ 227.50
1 Chainsaw	1.75
3 Skidders w/hdy Grapple	288.75
1 Chipper	192.50
2 Prime Movers @ 55¢/mile/600 mile/day	660.00
3 Van Trailers @ 10¢/mile/400 mile/day	120.00
1 Welder	3.50
2 Pickups	35.00
Miscellaneous tools	3.50
Subtotal	$1,532.50

Annual Overhead Costs

Depreciation	$158,361.81
Interest, Taxes, etc.	150,000.00
Truck Ins., Use Tax, License	10,000.00
Bookkeeping fees	5,000.00
Legal fees	5,000.00
Office expenses	5,000.00
Workmans Compensation	37,500.00
Other labor overhead	30,000.00
Total Annual Overhead	$400,861.81

Annual Working Days--240

Overhead Cost Per Day	$ 1,670.26
Labor/Field Supervisor $1500/mth	75.00
10 persons @ $5/hr--10 hr/day	550.00
Operating Costs Per Day	1,532.50
Total Daily Costs	$ 3,827.76
Cost per tone per day (400 T/day)	$9.57

10.0 SYNOPSIS

Unbeknown to most of mankind, wood is on the threshold of again dominating the world's energy and chemical markets. Singular reliance on exhaustible and environmentally imperiling fuels has brought man to near catastrophe. The acid rain crisis will expand to nightmarish dimensions before being brought under control. The greenhouse effect will intensify over the next century before peaking. Global leaders will launch a massive forestation effort, planting trees of all kinds wherever they will grow. These new stocks of wood will feed our fuel and chemical appetites, capturing from coal and oil a major share of the market. As a fringe benefit, the vast new plantations will decrease soil erosion, create topsoil, increase rainfall, store carbon dioxide, and fulfill many of the invaluable other functions of forest ecosystems.

The rapid rise of wood consumption as a fuel is one of the best kept secrets in this era of energy transition. Wood fuel use is sky-rocketing in the United States and in many other countries as well. Indeed, there already is a shortage of wood feedstocks, but world forestry inventory methods are so inadequate that the magnitude of the shortages are not appreciated. The world market value of wood can be expected to increase steadily and perhaps dramatically over the long term. Recognition of the world shortage of wood fibers for quality paper production was the underlying basis for Daniel Ludwig's impressive and farsighted Jari project. Deforestation and desertification around the world has depleted forest stocks far more rapidly than the relatively feeble efforts at reforestation compensate for their loss. Even in the United States, the overall annual harvest now is thought to exceed annual growth.

Perhaps the greatest benefit from the oil shortages and high prices imposed on the world by the oil producing countries has been the impetus given to seeking biomass alternatives. Science and technology responded and continues to respond by developing new and effective uses for biomass feedstocks, and especially for wood and its chemical constituents. These

new technologies will spawn new industries which will create products with economies of scale, and all from renewable organic feedstocks.

It was in this atmosphere of technological innovation that BESI undertook the mission of pioneering a large scale *Eucalyptus* energy plantation to methanol project. After two years of studying the feasibility of the concept, we are convinced that *Eucalyptus* offers a fast growing, renewable, woody biomass resource readily adaptable to Central and South Florida's soil and climatic conditions. Based on the best available research, establishment of eucalypt biomass plantations in Central and South Florida is ecologically, environmentally and economically sound, indeed desirable. Brazil has one of the largest eucalypt plantations in the world, some 100,000 acres, where they have produced 18 tons/acre/year in the third rotation! Future yields of 45 tons/acre/year are considered reasonable. Following the guidelines and recommendations set forth in this silvicultural document, relying on plantlets produced by the tissue culture cloning of select trees, we believe Florida yields in excess of 20 tons/acre/year are possible at the onset. By the end of this decade, Florida eucalypt chips can be expected to sell in markets seeking their fiber, energy, and chemical feedstock properties, for about $50/ton.

As for benefiting the great State of Florida, we are convinced the full and productive use of under-utilized Central and South Florida lands to grow eucalypts will increase the governmental tax base, create new jobs, encourage and stimulate industrial development, and increase the flow from the spigot of sun-derived energy.

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