Research Program Summary

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Short Rotation Woody Crops; Dendroremediation

A decreasing forest land base and increasing demand for wood necessitate more intensive forest management in Florida. Woody biomass production research is addressing these needs by developing short-rotation woody crop (SRWC) systems through tree improvement, silvicultural, and biometric studies with Eucalyptus, cottonwood, cypress, and slash pine. Eucalyptus species that grow very rapidly (up to 20' per year) are: E. amplifolia - freeze hardy and suited to good sites in northeastern Florida, E. camaldulensis - suitable for a wide range of sites in central and southern Florida, E. grandis - very productive in southern Florida. Cottonwood is vigorous on good sites in northern Florida. Cypress may grow rapidly on upland sites, and slash pine can be intensively cultured statewide. SRIC can produce energywood, landscape mulch, and pulpwood in two to 10 years; e. g., 5- to 8-year-old SRIC Eucalyptus makes a desirable landscape mulch.

Tree improvement studies with each SRWC species identify genetic variation that is very important in achieving highest productivity, particularly in Eucalyptus. In southern Florida, over 600 clones, open-pollinated progenies, and control-pollinated progenies are in genetic tests, seed orchards are in place for breeding and seed production, and commercial quantities of E. grandis seed are available. A statewide series of clonal tests has been installed, and artificial freeze tests may be used to identify freeze-resilient Eucalyptus. Within each Eucalyptus species, especially productive and freeze-resilient clones are sought for commercial propagation as seedlings, rooted cuttings, and/or micropropagules. As part of a regional cottonwood improvement program, a genetic base population of select trees is being assembled for testing in Florida. Variation between and within cypress varieties is being examined. To increase slash pine growth in peninsular Florida, slash pine hybrids are under evaluation.

Silvicultural studies contribute to further development of SRWC systems. Eucalyptus studies include assessments of site, planting density, site amendment, and wastewater application factors. Eucalyptus is being evaluated on over 20 sites ranging from organic soils in the south, through phosphate mined lands and sandhills in central Florida, to clay soils in the west. Productivity in response to planting densities ranging from 500 to 4,000 trees/acre is being determined. Eucalyptus response to organic fertilizer and to sewage effluent, stormwater, and irrigation runoff applications is being investigated, and tree water use is being monitored. Cottonwood's productivity in response to sewage effluent has been studied through four years; more intensive cultural options will be initiated. Cultural factors influencing phytoremediation potential of Eucalyptus and cottonwood are under investigation. Silvicultural options for enhancing cypress growth are incorporated into research being conducted at six sites. Studies of site amendment and planting density influences on growth of improved slash pine begun in 1980 have been extended to include the effects of these factors on wood properties.

Modeling the productivity of SRIC species in response to genetic and silvicultural options is in progress. For superior slash pine progenies, growth and yield model components including survival, height-age, and diameter distribution functions are being developed. Techniques developed for slash pine modeling will be applied to Eucalyptus and cottonwood.

Research Projects

CRIS Project FOR-04168

Project Title: Fast Growing Forest Tree Management Systems for Florida and Similar Areas

Investigator(s): DL Rockwood, DR Carter, and GF Peter

Objectives: 1. Develop various cottonwood, *Eucalyptus*, cypress, and slash pine management systems, 2. EvaIuate short rotation woody crop, mined land reclamation, and dendroremediation systems

Justification

To increase productivity of various forestry applications in Florida and similar areas, forest research needs to develop and evaluate new management systems. Management options for appropriate fast-growing tree species grown as short rotation woody crops (SRWC) for applications such as energywood and dendroremediation (i.e., phytoremediation using trees) include genetic improvement, intensive culture, and short rotations on agricultural, forest, and non-traditional sites such as reclaimed mined and contaminated lands. In the near term, the opportunities for SRWCs in Florida and similar climatic and edaphic areas include *Eucalyptus* species grown under diverse conditions in the Gulf Coast region, eastern cottonwood (*Populus deltoides*, *PD*) on agricultural quality sites or in intensive culture in the Southeast, cypress (*Taxodium distichum, TD*) on upland sites throughout Florida and adjacent states, and slash pine (*Pinus elloittii*, *PE*) on reclaimed titanium and phosphate mined lands. The productivity and environmental benefits accruing from such intensively-managed forests permit less intensive and multiple use management of other forest lands.

1. Develop SRWC Management Systems

Genetic, silvicultural, and propagation developments collectively can increase the productivity of *Eucalyptus* species in Florida. *E. grandis* (*EG*) may be grown in southern and central Florida (Rockwood *et al.* 1989, Rockwood 1997, Rockwood *et al.* 2002). *E. amplifolia* (*EA*) also has potential to be grown as a SRWC from central Florida northward to perhaps 50 miles inland from the Gulf Coast. *EG* and *EA* have demonstrated high energywood productivity on reclaimed phosphate mined lands (Rockwood *et al.* 2002).

Because of its wide adaptability and superior productivity on appropriate sites, *PD* was chosen by the USDOE for SRWC biofuels in the Southeast. *PD* can be vegetatively propagated for maximum capture of genetic gains. While the number of available, well-tested clones suitable across the Southeast and for Florida is still relatively limited, new clones are under development (Land *et al.* 2001).

TD mulchwood comes primarily from naturally regenerated second growth stands, and, with environmental pressure likely to preclude harvesting natural *TD* swamps, major producers project that *TD* in natural stands may become unavailable within five years. Fortunately, intensive culture and genetic improvement may lead to productive *TD* plantations on upland sites (Rockwood *et al.* 2001).

Phosphate and titanium mining in Florida and the Southeast may impact over 120,000 ha often classified as productive forestlands. Current reclamation practices for mined lands may have a negative impact on *PE* productivity (Mathey 2001, Proctor *et al.* 2003).

Market opportunities resulting from new management systems for *EG*, *EA*, *PD*, *TD*, and *PE* in Florida and similar areas are wide ranging. *Eucalyptus* is in high demand in the US for some processes and products (McGrath 1987). For example, its pulp is more absorbent than pulps of native hardwoods, whose value, including pulpwood, in the 12 southern states was $2.3 billion in 1991 (McKeever and Howard 1996). In 1995, imported *Eucalyptus* pulp was valued at $500 million (Ferguson 1996). Currently, *EG* is primarily used as an alternative to *TD* mulch but has demonstrated high energywood productivity on reclaimed phosphate mined lands (Rockwood *et al.* 2002), and markets may exist for solid wood products such as flooring. Establishment of eucalypt plantations for a variety of wood products would not only increase the productivity of Florida's forest lands but would also help preserve environmentally-sensitive native hardwood and *TD* stands. Current demand for *TD*, over 100,000 Mg for mulch annually, exceeds growth statewide, and the situation is likely to worsen as *TD* mulch production expands.

The magnitude of US CO_2 emissions illustrates the opportunity for SRWCs (treepower.org/globalwarming/quickfacts.html). As a contributor to the US's world leading carbon emissions of 1.36 billion metric tons, Florida is the eighth ranked state with 0.06 billion metric tons, and 12 southern states collectively emit 39% of the US total, as much carbon as China, the world's third leading contributor. Of the total fuel mix (coal – 36.3%, natural gas – 23.0%, petroleum – 19.9%, nuclear – 16.9%, hydroelectric – 0.1%, other – 3.9%) used by Florida's utilities to generate electricity, 79.2% comes from ~$3 billion of fossil fuels, almost all of which are imported.

Other fossil fuel emissions may also be reduced by SRWCs. SRWCs contain almost no sulfur and have about 50% of the nitrogen content of coal, and their use would considerably reduce SO_2 and NO_x emissions, which cause acid rain and smog, respectively. While smog has historically not been a concern in Florida, the American Lung Association recently graded most counties in central Florida as "F." In recent tests at a large power plant in central Florida, co-firing 2.5% SRWCs reduced NO_x emissions ~7%.

SRWCs are a carbon-neutral source of energy and do not contribute to CO_2 enrichment of the atmosphere. Co-firing of SRWC biomass with coal is a near term approach that can make use of existing utilities with relatively minor modifications. SRWC nutrient requirements can be met by the application of waste products such as sewage sludge or by irrigation with reclaimed water, leachates, or effluents. This also has the potential to treat wastewaters prior to their discharge to comply with discharge consents.

Florida, one of the most likely states for the production of biomass for renewable energy, has low opportunity cost land for developing biomass crops (Rahmani *et al.* 1999). Land available for SRWC production in peninsular Florida includes over 70,000 parcels totaling 2.5 million ha that are used as crop and pasture land, natural or planted forest, reclaimed land, power plants, waste treatment facilities, food processing, other processing facilities, and transportation terminals, etc. Crop and pasture land totaling 877,000 ha has the highest potential biomass production. Potential biomass production for all types of land-use in peninsular Florida exceeds 13 million Mg per year. Some 81,000 ha of mined lands and more than 161,000 ha of pastureland in central Florida are marginal lands with a very low opportunity cost but have potential for biomass production (Stricker *et al.* 1995).

2. Evaluate SRWC and Other Management Systems

Successful demonstration of SRWC production and cofiring in Florida could lead to SRWC development in the Gulf Coast region and similar environments. Central Florida alone, at 13,000 MWs, has more fossil fuel electrical generating capacity available for cofiring than the "farmbelt" states of Iowa, Kansas, Nebraska, or Minnesota. The Gulf Coast region has 10% of the entire US electrical generating capacity. If Florida's electric utilities used SRWCs to generate just 2% of total electricity produced, a new farming industry with an economic impact of over $100 million per year would be created. Superior *PD* clones identified in this project will be suitable for 1.6 to 17.8 million ha in the Southeast, depending on competing land uses, and an estimated 52,600 to 234,700 ha in Florida, primarily in the northwest (Graham *et al.* 1997). *EA* has adaptability for the lower Gulf Coast, and improved *EG* will be suitable for central and southern Florida. Propagation of superior genotypes will provide planting stock for operational SRWCs. The cultural practices and systems developed will provide guidelines for maximizing SRWC productivity while minimizing environmental impacts. Similarly, cofiring experience gained will guide utilities implementing SRWCs. Assuming successful outcomes from the project, agriculture and fuel processing consortia, essential for full scale commercialization, may be formed to execute SRWC fuel contracts with electric utilities.

Contaminated sites, landfills, wastewater treatment facilities, stormwater collection areas, mined lands, agricultural lands, and forestlands provide SRWC planting opportunities. An estimated $30-49 billion US phytoremediation market in 1999 (33% organics, inorganics, and metals in groundwater; 17% landfill leachate; 32% organics and metals in soil; 10% inorganics, organics, and metals in wastewater; 2% radionuclides; 6% other) is projected to grow to $235-400 billion in 2005 (Glass 1999). In the US, 153 cities have already developed over 4,000 ha of brownfields at 922 sites, but over 200 cities have some 10,000 ha of brownfields awaiting development. Over 3,500 municipal solid waste landfills in the US occupy some 300,000 ha. The number of arsenic contaminated sites, as an example, is huge as Florida alone has over 3,200 sites formerly used to dip cattle in arsenic containing pesticides. Agricultural dendroremediation needs could encourage agroforestry approaches combining SRWC and dendroremediation, such as riparian buffers and shelterbelts, to address the annual loss of 1.4 billion Mg of sediment, 2.6 million Mg of nitrate-N, and 1 million Mg of P from US croplands (Schultz *et al.* 1995).

Related Current and Previous Work

1. Develop SRWC Management Systems

A. Genetic Resources - *EG* is best suited to southern Florida's subtropical and tropical flatwoods and muck soils but can also be grown successfully in central Florida if freeze resilient stock is used. Some 3,200 *EG* accessions, more than 1,600 stored seedlots, and over 300 maintained clones constitute a valuable genetic base. Available *EG* seedlots are primarily derived from GO77, a 4th-generation seedling seed orchard established in 1977 and developed through combined tree selection, progeny testing, and provenance testing. Genetic gain potentials for a new 5th-generation seedling seed orchard are encouraging (Rockwood *et al*. 1989), but larger gains may be expected from clonal selection and testing. Over 250 clones have been evaluated for tree size, freeze-resilience, survival, and stem form; some 10 clones were comparable to superior clones previously selected for use in southern Florida (Meskimen *et al.* 1987). Large numbers of rooted cuttings can be produced from these superior clones, and four clones have been micropropagated commercially. While productivity of cuttings and plantlets may greatly exceed that of seedlings, seedling cost favors the commercial use of improved seedlings (Rockwood and Warrag 1994). *EG* plantations on some 6,000 ha in southern Florida are managed for mulchwood production, and since 1996, planting of superior seedlings has steadily increased.

Development of *EA*, the most appropriate eucalypt for the Gulf Coast region's more temperate climate with more frequent and severe freezes, has been less intensive but has followed similar strategies. Currently in place is a 1st-generation *EA* seed orchard of 80 trees selected on the basis of sib and individual superiority. Several clones of good form, size, and freeze-hardiness have been selected and tested (Rockwood *et al*. 1993).

Genetic improvement must continue if *EG* and *EA* are to increase in commercial feasibility. Development of freeze-tolerance is still of utmost importance for each species. In addition to significant improvement of freeze-tolerance, increases in productivity, adaptability to various sites, evaluation of wood properties, and determination of propagation options must be addressed.

Considerable selection and testing developed many *PD* clones suitable for bottomland sites in the Mississippi River valley region. Only three of 10 of these clones grew well in an effluent sprayfield near Tallahassee (Rockwood *et al*. 1996). To provide an adequate genetic base for planting *PD* throughout the Southeast, USDOE initiated a multiagency research program in 1995 that assembled plant materials from previous programs and new geographic sources, archived and characterized this material, crossed among selected clones, and coordinated multilocation testing of the derived materials. In Florida, a clone bank of 114 clones and a clone test of more than 1,000 clones at the North Florida Research and Education Center near Quincy have resulted in some 44 clones for continued testing (Land *et al.* 2001).

For *PD*, *EG*, and perhaps *EA*, genetic engineering has considerable potential. Increasing the rates of secondary growth should increase stem growth rates. Overexpression of specific cyclin genes has increased dry weight in annual plants (Doerner *et al.* 1996, Cockcroft *et al.* 2000). As the amount of energy in wood is determined by wood density and lignin content, increasing either while decreasing the level of carbohydrates should increase the energy released during burning. All of the structural and some of the regulatory genes in the lignin biosynthetic pathway have been identified (Anterola and Lewis 2002, Kawaoka and Ebinuma 2001). For example, down regulation of the NtLim1 transcriptional activator (Pal-box), which stimulates transcription of PAL, 4CL, and CAD, reduces lignin content by 20% in tobacco.

Limited *TD* genetic improvement has occurred in the US, e.g., Whitesell and Walters (1976). Most genetic variability in *TD* is among trees rather than among provenances (Liu *et al.*, 1990). However, provenance variation was shown by Allen *et al.* (1994 a, b) when families from brackish water sources performed better than freshwater provenances subjected to salinity and flooding stress. Faulkner and Toliver (1983) indicate that variation in seed size is correlated to seedling performance. In other countries where *TD* is a promising exotic, El-Said Imam *et al.* (1972) used early selection based on seedling performance in a nursery in Egypt. In China, where the species is widely used in agroforestry and silvopastoral systems (Huang *et al.* 1991) and as shelterbelt trees in farmlands (Xu and Long 1983, Kemp 1980), fast growing clones have been developed from selected seedlings (Ma and Lin 1979).

In southern Florida, hybrids between *PE* and *P. caribaea* tend to outperform native *PE* (Rockwood 2001). Individual hybrid families that offer substantial productivity gains over the hybrid average on the relatively infertile flatwoods of southern Florida may be more productive on phosphate mined lands in central Florida.

B. Applications. Cofiring up to 5% SRWCs is the most cost effective means of creating renewable energy while using existing power plant infrastructure. Florida has several coal-fired power plants that can cofire biomass at a fraction of the cost of other renewable energy options. Still, the total cost of growing, harvesting, transporting, and cofiring SRWCs must be at a cost reflecting a slight premium above the cost of coal, which delivered to electric utilities in Florida, currently ranges in price from \$1.50 to \$1.75 GJ^{-1}. Building a new stand-alone biomass energy power plant does not currently compete with natural gas generation options.

Delivered cost of *EA*, *EG*, and *PD* grown in central Florida has been estimated between \$1.76-2.66 GJ^{-1} and is very dependent on harvesting costs, as approximately 66% of the cost of delivered energywood may be due to harvesting with conventional feller-bunchers. Double row planting, which could enhance yield and reduce harvesting cost through the use of double row harvesters such as the Claas, a high capacity forage harvester, is challenging, however, on bedded clay settling areas (CSA) created by phosphate mining.

Collaborative engineering research led to EPA/Florida DEP permitting two coal-fired power plants to cofire energywood: Lakeland Electric's McIntosh Unit #3 (pulverized coal) and TECO Energy's Gannon Unit #3 (coal-fired cyclone). TECO's co-firing at Gannon is the primary source of Green Energy for its Smart Source marketing program. TECO's Polk Power Station, which combines "coal gasification" and "combined cycle" to produce electricity 10-12% more efficiently than a conventional coal power plant, is another cofiring prospect.

While SRWC plantations are intended primarily for energy utilization, coproducts and alternative higher-value uses would improve their economic viability and provide an incentive for development. A ready commercial alternative for *EG* and *EA* is mulchwood. *EG* has been used for pallet manufacturing. *EG*, *EA*, and *PD* are also very suitable for pulp and paper production, preservative-treated posts or poles, chemical extractives, animal bedding, sawn timber for flooring, utility construction timber, and very likely reconstituted wood panel products such as wood strand cement board (WSCB), a blend of 40% wood and 60% cement (e.g., AMROC®-PANEL). With the Gulf Coast region's high humidity, decay potential, termite incidence, and wind damage risk, WSCB, already manufactured and widely used in Europe, is a likely alternative to traditional building construction products because of its exceptional durability and strength.

In Florida, several species have shown potential for nutrient, metal, and hydrocarbon dendroremediation (Rockwood *et al.* 2001, Cardellino 2001, Rockwood *et al.* 2003). For example, baldcypress is promising for Cu remediation, accumulating over 15mg kg^{-1} in stem biomass. Fast growing trees such as *PD* and *EG* have a high demand for water and nutrients.

PD and *Eucalyptus* species have wastewater dendroremediation potential (Rockwood *et al.* 1996, Pisano and Rockwood 1997). Three *PD* clones were recommended to optimize biomass production and nutrient uptake in sewage effluent sprayfields. In a stormwater dry retention treatment pond at Tampa, *EG* after 44 months averaged 9.4 m in height, with biomass allocations to stemwood, stembark, branches, and foliage of 44, 10, 30, and 15%, respectively. Relative concentrations of N, P, and K in plant tissues were typically foliage > stembark > branches >> stemwood. Although water use could be as high as 1,600 mm annually, the exact amount of water and nutrients taken up depends on climate, tree vigor, and the timing and extent of stormwater applications. One *EG* clone appears superior for stormwater dendroremediation in central Florida. Stormwater dendroremediation using *EG* may effectively combine water renovation and nutrient recycling with growth enhancement to produce mulchwood, pulpwood, and\or fuelwood.

After three years, *EG* more than doubled *PD* biomass in response to sewage effluent, compost, and\or mulch in a study at Orlando (Rockwood *et al.* 2003). Both mulch and compost increased production by providing additional nutrients and suppressing weed growth. Biomass production removed up to 534 kg N ha^{-1} and 198 kg P ha^{-1}. Compost derived N contributed significantly to the N demand, reducing the uptake of reclaimed water derived N. The improved growth and hence increased nutrient uptake on compost amended soil did not compensate for the additional nutrients supplied, resulting in considerable N leaching from the root zone.

EG's superior productivity has obvious potential environmental values, as well as economic implications. *EG* plantations can increase water loading and reduce nutrient leaching, even when compost amendments are applied. *EG* may reduce N and P leaching by up to 75% when water only is applied and 85% when mulch is added for weed control. Even with incorporation of up to 11.2 Mg ha^{-1} of compost, *EG* may still reduce leaching by some 50%.

PD growth and arsenic (As) uptake at a CCA contaminated site in Archer, FL, varied with season, plant tissue, and clone (Cardellino 2001, Rockwood *et al.* 2003). As concentrations were leaves >> branch bark > stem bark > branch wood > stem wood. Leaves from the lowest part of the crown had more than twice the As of leaves from the upper crown, but branch wood, stem bark, and stem wood As changed little with crown or stem position. Variability over time in leaves was relatively small but seasonal as As concentrations in middle- and upper-crown leaves were less in May than in October. Variation among clones was large for the tree components with the highest As concentrations, e.g., a threefold difference was common between the clones with the lowest and highest concentrations in leaves. Twofold and larger differences in branch bark concentrations were common. The ranges for branch wood, stem bark, and stem wood were of similar extent. Several high and low As concentrating *PD* clones were noted. Total As uptake by *PD* will be a balance between biomass production and As concentration. Annual harvesting of *PD* clones will likely result in the highest As removal. To maximize As removal, high density planting, e.g., 1 x 1 m, of high concentrating clone(s) should be practiced.

In a toluene dendroremediation study at St. Augustine, FL, after 29 months, 15 cm diameter plastic "training" tubes inhibited above ground growth of *PD* and *EA* and presumably root growth and access to groundwater (Rockwood *et al.* 2003). *PD* and *EA* were equally vigorous, but *EA* had higher survival, and an *EA* progeny was the most productive genotype. Toluene was detected in leaf and branch samples of *EA* but not *PD*. The root systems apparently extended below the groundwater elevations as soil hydraulic conductivity increases were observed.

While SRWCs and dendroremediation may often be justified as independent ventures, combining the two can increase their economic feasibility, and incorporating both into agroforestry systems has promise for further enhancing annual income possibilities, a critical aspect for acceptance. Of five agroforestry systems identified by Garrett and Buck (1997) that represent opportunities for incorporating SRWC and dendroremediation, riparian systems and shelterbelt systems have the greatest potential (Rockwood *et al.* 2004).

SRWCs in the riparian component of agroforestry systems dendroremediate as well as provide numerous other benefits. Poplar trees in riparian systems effectively lower subsurface NO_3-N concentrations and stabilize degraded agricultural streambanks while growing rapidly (O'Neil and Gordon, 1995). SRWCs as part of a 20 m-wide multispecies riparian buffer strip in central Iowa effectively removed nutrients, pesticides, and sediments in addition to stabilizing streambanks, providing wildlife habitat, affording commercial timber and other products, and improving the aesthetics of the agroecosystem (Schultz *et al.* 1995). As noted by Isebrands and Karnosky (2001), "timberbelts," multirow shelterbelts of SRWCs, can provide the environmental benefits of windbreaks\shelterbelts while producing the economic benefits of timber products.

Today, most *TD* wood comes from second growth forests (Conner and Toliver 1990) and is mainly used to produce mulchwood (Ewel and Davis 1992). *TD* occurs naturally on saturated and seasonally flooded soils, along river swamps or in the characteristic swamp domes formed by runoff from the surrounding area (Ewel 1990). The uniqueness of these wetlands (Nessel *et al.* 1982) has prompted public pressure to conserve *TD* forests (Sutter and Kral 1994). Although Sternitzke (1972) suggested that these areas can be managed sustainably, the need for plantations to supply the *TD* mulch industry is now evident.

Most of the limited knowledge about *TD* plantation silviculture concerns nursery practices since *TD* is valued as an ornamental (Haller 1978). Some attempts to propagate *TD* by cuttings have been successful (Copes and Randall 1993, Pezeshki and DeLaune 1994). Some studies on containers and spacing at the nursery level are reported (Stauder and Lowe 1984). Potted plants subjected to various nitrogen fertilization regimes and moisture levels grew better in a saturated-aerated soil regime irrespective of the fertilization treatment, and urea was a better N source (Dickson *et al.* 1972). The few studies on field growth and performance are based on naturally regenerated second-growth *TD* domes. Sewage effluent increased growth while controlled-release fertilizer had no significant effect (Fitzpatrick *et al.* 1986). The Ewel and Davis (1992) hypothesis that thinning *TD* swamps is not economical because nutrients, not light, are limiting is supported by the observation that fertilization with sewage effluent increased growth rates of mature *TD* domes (Nessel *et al.* 1982). *TD* has potential for rapid growth under intensive silvicultural conditions (Rockwood and Geary 1991, Rockwood *et al.* 2001).

In central and southern Florida, *PE* hybrids that outperform native *PE* (Rockwood 2001) could increase pine plantation productivity for traditional and other products. *PE* hybrids are suitable to use for the conventional pulpwood, chip-and-saw, and sawtimber obtained from these regions. They may also be utilized for energywood and mulchwood if markets for conventional products are not competitive.

2. Evaluate SRWC and Other Management Systems

An *EG* economic analysis indicated the importance of input costs, harvest prices, progeny, rotation, and the no-coppice\coppice decision (Rockwood *et al.* 2003). *EG* progeny 3309 had significantly higher yields and, at a stumpage price of \$10 Mg^{-1} for mulchwood and a 4% real discount rate, was most profitable “without coppice” with a land expectation value (LEV) of \$7,300 ha^{-1}, equal annual equivalent (EAE) of \$290 ha^{-1} yr^{-1}, and internal rate of return (IRR), assuming sunk land costs, of 29%. The optimal rotation age was 33 months. Overall returns for the average *EG* progeny were considerably less, but LEVs still exceeded \$2,470 ha^{-1} (with coppicing). *EG* mulchwood production appears profitable compared to alternative agricultural uses. Whether coppicing is preferable to harvesting\replanting depends on relative seedling and coppice yields, seedling establishment costs, and output prices. Mulchwood is presently the most likely commercial use of *EG*, although increasing demand is expected for energywood by electric utilities (Segrest *et al.* 2001).

However, the social value of *EG* for wastewater dendroremediation includes both returns from biomass harvest as well as environmental values associated with reduced nutrient leaching. The value of this service is difficult to quantify but might be estimated using known costs for alternative methods of wastewater remediation. Such additional benefits make the overall value of *EG* extraordinarily appealing, especially if private landowners are able to capture those environmental benefits via some form of subsidy.

Further, optimal production decisions for *EG* would be influenced by the incorporation of environmental benefits. For example, the decision to harvest *EG* at 33 months to provide maximum benefits from biomass (e.g., mulchwood) harvesting might be lengthened (or shortened) depending upon known relationships between the age of *EG* plantings and nutrient uptake potential.

Societal and political factors in the energy and forestry sectors greatly influence development of SRWC systems. Greater use of wood for energy requires removal of technical and nontechnical barriers by developing technologies that make fuelwood more cost effective and competitive and policies that expand fuelwood markets and by promoting the economic and environmental benefits of fuelwood (Trossero 2002). SRWCs used for dendroremediation and suitable for energywood and other timber products, unlike hyperaccumulators, may not require special treatment or disposal, and therefore could provide an income in combination with gradual site cleanup and lower risk to groundwater and human health.

This project's three investigators, numerous cooperators, widely distributed field studies, and resulting experience and data will address two objectives, namely,

1. Develop various *PD*, *Eucalyptus*, *TD*, and *PE* management systems
2. Evaluate SRWC, mined land reclamation, and dendroremediation systems

with anticipation of accomplishing the following research by September 2009 (Table 1), assuming sufficient extramural funding from sources such as the Florida Institute of Phosphate Research, the Florida Organic Recycling Center for Excellence, Ecology & Environment (E&E), Lykes Bros., Iluka Resources, and various governmental and private entities.

Table 1. Anticipated timelines for Objective procedures.

Objective - Procedure	Year				
	2004-05	2005-06	2006-07	2007-08	2008-09
1A – Identify superior *PD* clones	x	>	>	>	X
- Select best *EG*	x	>	>	X	
- Evaluate *TD* genotypes	x	>	>	>	X
- Assess *PE* hybrids	x	>	>	>	X
- Develop *EG*, *EA*, and *TD* orchards	x	>	>	>	X
- *PD*, *EA*, and *EG* wood improve.	x	>	>	>	X
1B – SRWC guidelines	x	>	>	X	
- Commercial SRWC plantings	x	>	>	>	X
- Growth and yield modelling	x	>	>	>	X
- Harvest assessment	X	X			X
- *TD* management	x	>	>	>	X
- Titanium mine reclamation	x	>	>	>	X
- Dendroremediation by SRWCs	x	>	>	>	X
2 - Economic analyses	x	>	>	>	X
- Social/political assessment			x	>	X

x, >, X = beginning, continuation, and completion of activity

Procedures

1. Develop Various *PD*, *Eucalyptus*, *TD*, and *PE* Management Systems

Several existing and new field studies will assess SRWC options including genetic variation, site amendments, vegetation control, planting densities and configurations, and rotation lengths across broad geographic, climatic, and edaphic ranges (e.g., Table 2).

A. *PD*, *Eucalyptus*, *TD*, and *PE* Genetic Resources. Genetic improvement of *PD*, *EG*, *EA*, *TD*, and *PE* hybrids will utilize established and new genetic tests that provide excellent bases for identifying superior clones and progenies and roguing and establishing seed orchards. For *PD*, clonal tests involving more than 1,000 clones may include regionwide tests in AL, FL, KY, MO, and NC managed by Mississippi State University and seven tests in FL managed by UF.

Table 2. Representative SRWC field studies contributing to genetic and cultural assessments of *PD*, *EG*, *EA*, *TD*, and *PE*.

Study	Location	Estab. Date	Species	Description
70	Palmdale, FL	8/97	*EG*	4,500 trees from 145 progenies and 20 hybrids
72	Orlando, FL	4/98	*PD*, *EA*, *EG*	1,076 trees from 3 clones, 6 and 6 progenies + compost, mulch, and/or sewage effluent
74	Old Town, FL	6/98	*EA*, *EG*	80,000 trees from 50 and 15 progenies
79	Cross City, FL	1/99	*TD*	660 trees from 20 accessions + compost
81	Quincy, FL	7/99	*PD*, *EA*	4,850 trees from 1,100 clones and 50 progenies
82	St. Augustine	8/00	*PD*, *EA*	630 trees from 15 clones and 15 progenies + Toluene
84	Green Cove Springs, FL	12/00	*PE*	2,055 trees + 9 cultures on mined and unmined sites
86	Waldo, FL	2-3/00	*TD*	1,800 trees from 14 accessions + 6 cultures
90	Lakeland, FL	4-6/01	*PD*, *EA*, *EG*	200,000 trees from 6 clones, 6 and 6 progenies + 5 cultures
91	Palmdale, FL	8/01	*EA*, *EG*	980 trees from 4 progenies, 18 progenies, 4 clones, and 10 hybrids
92	Ft. Meade, FL	3/02	*PE*, *TD*	2,600 trees from 36 pure and hybrid progenies, 3 progenies and 6 accessions + 3 cultures
94	Lakeland, FL	12/01	*PE*, *TD*	1,700 trees from 33 pure and hybrid progenies, 9 progenies and 26 accessions
95	Orlando, FL	4/02	*PD*, Poplar	2,000 trees from 10 and 1 clones + TCE, PCE

96	LaSalle, IL	3/02-4/03	Poplar, willow	1,074 trees from 18 and 24 clones + TCE, PCE
101	Palmdale, FL	7/02	*EG*	1,180 trees from 29 progenies from two seed orchards, and 5 clones
102	Belle Glade, FL	12/02	*TD*	4,124 trees from 38 progenies and 29 accessions, + 6 cultures
104	Gulfport, MS	3/03	*PD*	7,000 trees from 11 clones + TCE
105	Archer, FL	4, 8/03	*PD*, *EA*, *EG*	770 trees from 44 clones, 8 and 30 progenies + 2 cultures + As
106	Valdosta, GA	4/03	*EA*	220 trees from 11 progenies
107	Hoboken, GA	4, 8/03	*EA*, *EG*	1,265 trees from 40 and 25 progenies

Measurements of height, diameter, *Melampsora* leaf rust resistance, relative wood density, and coppicing success will be taken during a five-year evaluation period. The resulting data will contribute to identification of clones suitable for planting in the Southeast, as well as in Florida.

The *EG* test base exceeds 50 studies, primarily in southern FL, involving over 1,000 open-pollinated (o-p) progenies, 40 control-pollinated progenies, 300 clones, and 30 hybrids. *EA* genetic tests in FL, GA, and LA now number 20 and include more than 300 accessions, 25 o-p progenies, and 50 clones. Height, DBH, freeze-resilience (on a 10-point scale primarily reflecting stem damage: 0=undamaged, ..., 9=freeze killed), survival, stem form on a 5-point scale, and coppicing ability will be measured in all tests through at least four years. Clones and progenies superior in size, resilience, survival, form, coppicing, and wood properties will be identified. Superior clones will be considered for inclusion in clonal orchards and for commercial propagation. Progeny results will guide the choice of trees for commercial seed collections.

TD tests currently totaling 16 throughout Florida include some 200 accessions and 100 o-p progenies of pondcypress and baldcypress. Height, diameter, survival, wood density, and coppicing data during an eight-year evaluation period will be used to evaluate genetic variability within *TD*, identify orchard trees for commercial seed collection, rogue first-generation orchards, and select cloning candidates for propagation and clonal orchard establishment.

PE hybrid tests in central and southern Florida will compare Florida and Queensland improved *PE* with various hybrids involving *P. caribaea*. Growth and pest resistance through eight years will guide the recommendations of commercial seedlots for these areas.

EG, *EA*, and *TD* seed orchards will be developed to provide genetically improved seed. For *EG*, 4th-generation and 5th-generation seedling seed orchards and a clonal seed orchard will be rogued. For *EA*, a 1st-generation seedling seed orchard will be rogued, and a clonal orchard will be developed. For *TD* seed production, one 1st-generation seedling seed orchard in northern Florida will be rogued and expanded, and another in southern Florida will be rogued. As possible, a *TD* clonal orchard will be established with selections from five-year-old field studies.

Three initiatives are anticipated for improving the wood of *PD*, *EA*, and *EG*. By isolating and overexpressing cyclin genes in cambial meristem, we will evaluate stem growth increases due to increased rates of secondary growth. We will test if upregulation of this transcriptional activator in secondary xylem cells increases lignin content. A second approach to increase lignin will be to reduce cellulose levels through down regulation of CesA genes. Objectives of 1) isolate full-length cyclin, Pal-box and CesA cDNAs from *Populus* cambial meristem and differentiating secondary xylem cells, 2) confirm cDNA identity and function, 3) construct vectors for overexpression of cyclin(s) and Pal-box and underexpression of CesA in differentiating secondary xylem cells, 4) generate 5-10 independent transgenic lines of *PD* and *EA* with these gene constructs, and 5) initiate analyses of cDNA expression, stem growth, and lignin content will be pursued by isolating full length cDNAs from *PD* by specific PCR from cDNA made from secondary xylem. Primers will be designed based on sequences from the genome of *Populus trichocarpa*. *PD* C176 will be transformed. Stem growth rates will be determined by diameter measurements, and lignin contents will be measured by Klason lignin.

For improving *EG* for solid wood products such as flooring, ultrasonic stiffness will be used to screen superior growth clones. By establishing a correlation between ultrasonic stiffness characterizations from cored wood samples of as many as 30 clones with their sawn lumber evaluations, a screening protocol will be used to select clones for commercial use.

Biotechnics Management will perform chemical analyses and other preliminary assessments for making WSCB from *EG*, *EA*, and *PD*. Stem sections of representative rotation-age trees from six *PD* clones, six *EG* progenies, and six *EA* progenies in Study SRWC-90 will be chemically analyzed in Europe for adherence with cement. Genotypes meeting the chemical standards will be further evaluated for structural, fire, and other properties related to building materials.

B. Develop Guidelines for Applications of *Eucalyptus*, *TD*, *PD*, and Slash Pine. Applications of SRWCs in Florida and similar areas may be derived from several large studies that evaluate silvicultural practices and genetic options. The 2.8 ha Study 72 near Orlando demonstrates *PD* and *EG* growth on effluent irrigated and compost amended sandhills. A 6 ha study maintained by JEA near Jacksonville, FL, representing *PD* growth on effluent irrigated sandhills, will be augmented with the top new *PD* clones from the Southeast and superior *EA* progenies; water and nutrient use by the trees and movement in the system will be monitored. The 48 ha Study 90 near Lakeland evaluates *EG*, *PD*, and *EA* responses to genetic and cultural options, including three bed widths with 1, 2, and 4 rows/bed, for SRWCs on CSAs. Useful guidelines for commercial scale planting of *EA* will be derived from the 32 ha Study 74 and a 18 ha planting near Cross City, FL. A 2-year-old planting near Sumterville, FL, evaluates *PD*, *EA*, and *EG* productivity in response to genetics and a 2 x 2 factorial combination of compost and irrigation. In the 2.4 ha Study 81, 0.8 ha harvested in April 2003 will compare 3-year coppice rotations of *PD* and *EA* with longer rotation yields.

Should funding develop, at least one 16 ha commercial scale planting will be installed based on the results of previous studies of *PD*, *EG*, and *EA* using reclaimed water and evaluating site amendments, genetics, planting density and configuration, and their environmental impacts. Superior *PD*, *EG*, and/or *EA* genotypes will be established in large blocks using *PD* from a clonal nursery, *EG* seedlings from superior mother trees in seed orchards, and *EA* seedlots from a progeny tested 1st-generation seed orchard. *EG* and/or *EA* planting stock grown in air-root trainers will be compared with conventionally grown propagules to document nursery methods resulting in greater outplanting success. Site amendments will bracket carbon sequestration potentials for incorporating organic materials. Prospective planting sites include a central Florida CSA and Lakeland Electric's wastewater treatment area. If possible, this research will couple current and promising cogongrass management strategies with planting *PD*, *EG*, and/or *EA* for long-term cogongrass elimination and native plant reestablishment.

Growth modeling will extend existing preliminary growth and yield models for *EG***,** *EA***,** *PD*, and *TD* to predict yield potential over time for various products. The above described plantings will document management options and costs for commercial SRWC production in Florida and similar portions of the Southeast.

Harvest systems used for commercial SRWCs in the U.S. and Europe may be compared and contrasted with feller-buncher systems common in the South. Time and motion studies will be completed for large scale harvests with two or more harvest systems to establish cost effective SRWC harvesting methodologies for *PD*, *EG*, and *EA*. Annual vs. 2-4 year harvests may be possible. Interactions among crop configuration, harvest frequency, crop yield and harvester efficiency will be evaluated. Superior production and harvesting systems will be identified through performance of individual components (soil type, land preparation method, fertilization practices, planting method, planting configuration, planting density, SRWC species and genotype, cultural practices, harvest method, harvest frequency, plantation yield performance at first harvest and succeeding harvests, etc.) and combining them within a mathematical model.

Recommendations for relatively short-rotation plantation management of *TD* will be developed from over 15 studies (including those listed in Table 1). The performance of more than 200 baldcypress and pondcypress seedlots under silvicultural options including site amendment (fertilization, compost), bedding, and planting density on three site types (flatwoods, CSAs, muck soils) representing prospective *TD* plantation land bases will be analyzed to determine the most promising genetic and cultural combinations.

Restoration of mined lands depends on development of methods that insure forest sustainability. Two studies on reclaimed satellite mined and unmined lands in northeast Florida (Table 1) address silvicultural methods for *PE* on titanium mined lands through a partial factorial of treatments involving subsoiling and non-subsoiling, four fertilizers (granulite, a 5-3-0 organic derived from anaerobically digested sewage sludge, diammonium phospate, a 16-4-8 blend with balanced micronutrients (Mg, Mn, Cu, and S), and 0.35% aluminum humate), weed control using 4% glyphosate and no weed control, and a mycorrhizae treatment. These studies are supplemented by a chronoseries of mined vs. unmined comparisons (10 plots per mined type per age) ranging up to 20 years of age.

To assess the dendoremediation prospects for SRWCs, *PD*, *EA*, and/or *EG*–based systems will be evaluated in established studies on a wide range of contamined sites: Archer (As contamination), St. Augustine (toluene contamination, managed by E&E), Orlando (PCE and

TCE contamination, managed by CH2M Hill), Gulfport, MS (TCE contamination, managed by CH2M Hill), and LaSalle, IL (PCE and TCE contamination, managed by E&E). *PD*, *EA*, and *EG* growth and As uptake in Study 105 will be assessed in response to site amendment (compost, fertilizer), mixing with Chinese brake fern (*Pteris vittata*, an As hyperaccumulator), clone, season, and plant tissue. Study 82 with *PD* and *EA* will monitor growth, toluene uptake, and soil hydraulic conductivity responses to establishment method (various "training" tubes) and clones\progenies. In Study 95, *PD* and poplar clones planted as 6' whips in compost filled cylindrical planting holes will be monitored for growth and contaminant uptake. Study 96 will assess the importance of species and clones, propagule type (whips vs. cuttings), and establishment method (planting tube vs. auger hole). Over all studies, more than 100 genotypes, four kinds of propagules, six types of establishment methods, and five types of culture will be evaluated for remediating four contaminants. Greenhouse screening studies will be conducted as possible.

2. Evaluate SRWC, Mined Land Reclamation, and Dendroremediation Systems

SRWC systems must be compared against various economic alternatives for lands with SRWC potential. Our analyses of SRWC economic returns will indicate the importance of input costs, progeny, planting configurations, rotation age, yields, harvesting options (e.g., conventional feller-bunchers vs. double row harvesters such as the Claas), the decision to coppice or not coppice, stumpage and transportation prices, and market options. Yields and costs for *EA*, *EG*, and *PD* will be updated, and models for *PE* on reclaimed mined lands and *TD* on upland sites will be generated. At varying stumpage prices and using real discount rates, LEVs, EAEs, and IRRs, assuming sunk land costs, optimal rotation ages and overall compared to alternative uses, with and without coppicing will be estimated.

Further, optimal production decisions for SRWCs as influenced by the incorporation of environmental benefits will be explored. For example, *EG* harvesting in wastewater recycling systems could depend on relationships between the age of *EG* plantings and nutrient uptake.

Social and political factors influencing the energy and forestry sectors will be examined. Greater use of SRWCs for energy may require removal of nontechnical barriers by promoting the economic and environmental benefits of cofiring and other applications. The social values of SRWCs for dendroremediation will include both returns from biomass harvest as well as environmental values. The value of these services will be estimated using known costs for alternative methods of remediation.

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