Eucalyptus: Biology, Adaptation, Production and Potential*

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*Adapted from DOE (2011) section 5.1.7, pages 113-114.

Abstract:
Eucalyptus spp*.* Is the world's most widely planted hardwood species. It has been established and produced successfully in warmer regions of the U.S. for decades, and is positioned for commercialization as a biomass feedstock in the U.S. South. Plantation management options for Eucalyptus as a short-rotation woody crop include both single-stem and coppicing systems, with harvests every 3-7 years with average annual yields ranging from about 4 to 14 dry tons acre^{-1} year^{-1}. Current breeding efforts aim to develop freeze-tolerant varieties of commercial varieties, which are expected to expand the potential range of eucalyptus as a biomass feedstock into USDA Hardiness Zone 8.

Introduction:
Eucalyptus spp*.* is the world's most widely planted hardwood species. Its fast, uniform growth, self-pruning, and ability to coppice (regrow after harvest) make it a desirable species for timber, pulpwood, and bioenergy feedstocks (Figure 2). It has been domesticated for various products and has been widely commercialized in the tropics and subtropics.

In the United States, eucalyptus was introduced as early as the 1850s on the West Coast to produce dimension lumber and has been produced commercially in Florida since the 1960s. Though eucalyptus has naturalized in areas of the Southwest raising concerns of invasiveness, there is no evidence of spreading in the Gulf South. In anticipation of an increased role in biomass production, ongoing efforts aim to develop eucalyptus cultivars for improved yield and frost resistance in the southern United States (Dougherty and Wright, 2012).

Biology and adaptation. There are over 700 species of eucalyptus, adapted to various ecological conditions across its native range of Australia. Less than 15 species are commercially significant worldwide. In the South, genetic improvement programs are selected for fast growth, cold tolerance, desirable growth form, and reduced lignin. Genetic improvement programs aim to improve varieties for various growing conditions (Gonzalez, Wright, & Saloni, 2010; Rockwood, Carter, Langholtz, & Stricker, 2006). Recent efforts in the southeastern United States indicate a number of promising species and varieties. *Eucalyptus benthamii* demonstrates greater cold tolerance and may be planted in areas of the Gulf and Atlantic Coastal Plain from southeast Texas to southeastern South Carolina. Sites near the northern edge of the deployment zone, especially those at higher elevations, have a higher risk of freeze damage. Plantations just north of the deployment zone can succeed but periodic severe freeze events can cause significant growth loses. It is expected that increased development of frost-tolerant varieties will expand the potentially productive range northward into USDA Hardiness Zone 8b. While eucalyptus is known to be established in California and other areas of the Southwest, at this point this region is not an area of emphasis of production of eucalyptus for biomass. Further assessment of yield viability and environmental impacts would be needed before deployment of eucalyptus in the Southwest.

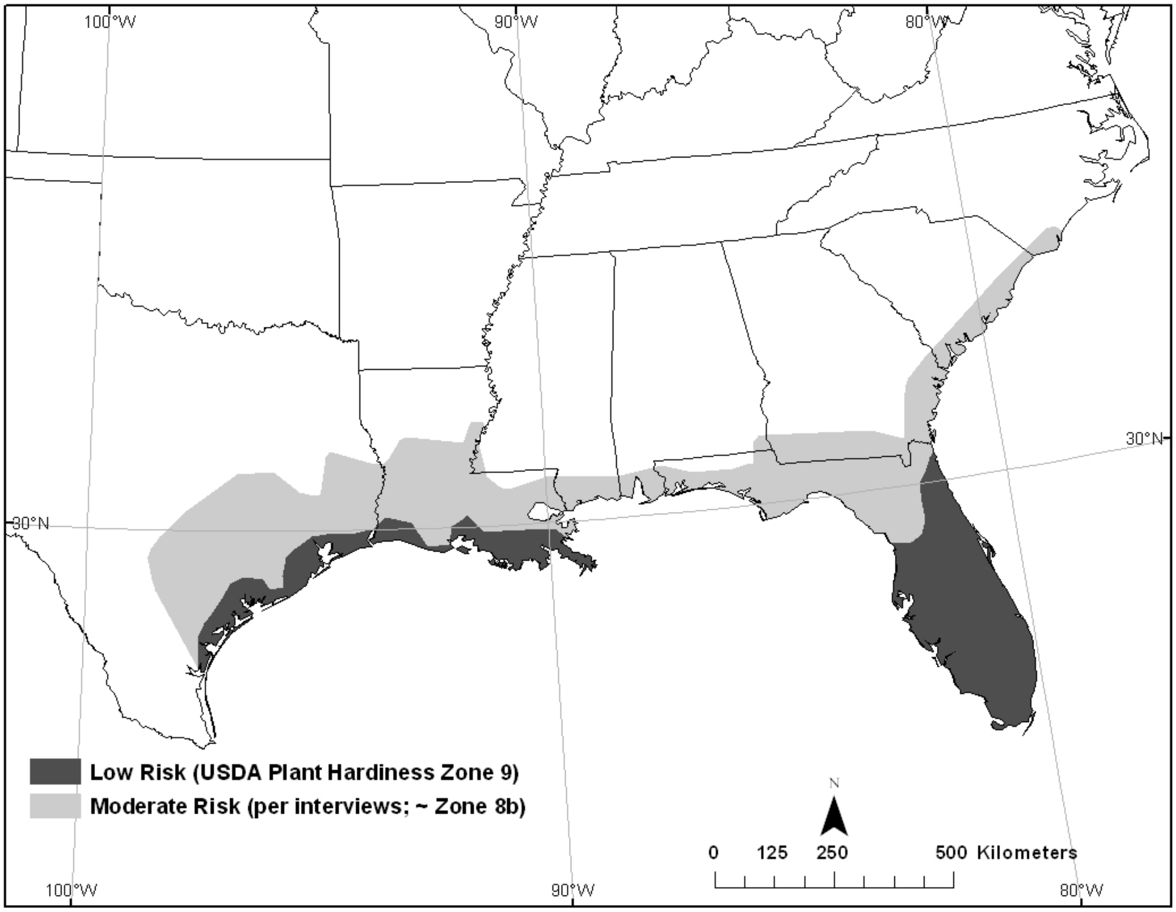

Figure 1: Map of locations for potential feedstock locations for *Eucalyptus* in the United States that could be used for bioenergy (as estimated by Kline and Coleman(Kline & Coleman, 2010) (2010) based on the USDA Plant Hardiness Zones and interviews with experts).

Cold tolerance in eucalypts is related to acclamation to cooler temperatures, stand vigor and soil nutrition. Vigorous, healthy trees can tolerate much lower temperatures than trees that are struggling to establish. Thus, proper site selection and silviculture are the keys not only to good growth but also to winter survival. The ideal plantation sites for eucalypts are fine-loamy or coarse-loamy soils. These are soils that have a slight to moderate accumulation of clay (argillic horizon) beneath the surface “A” horizon. Plantations can be established on poorly- to well-drained soils within these categories with good site preparation and ideal silviculture regimes, with the best performance on moderately well-drained soils with at least a 15-inch depth to a restrictive horizon. Eucalypts can be grown on many of the pine plantation areas of the southeastern United States with the exception of excessively well-drained deep sands and very poorly-drained sites.

Production and silviculture. Eucalyptus production practices in different parts of the world vary with site conditions, desired products, and scale of commercialization. Genetic selection has led to commercialization of genotypes with unique advantages in different applications. They are commercially propagated by both seed and cloning of tissue culture. For conventional pulpwood production, stands are typically established at a planting density of 600–1,000 trees per acre, and harvested every 6–10 years. They may be replanted at harvest, which can benefit from improved genetic material, or regenerated from coppice growth, which eliminates the cost of replanting. Economically optimum time between harvests may be 3–4 years, with replanting after 2–5 harvests, on stands with initial densities of 3,400 trees per acre in Florida (Matthew Langholtz, Carter, Rockwood, & Alavalapati, 2007). Silvicultural strategies in the United States continue to evolve with changing markets, genotypes, and applications.

Because of high growth rates and tolerance to a range of growing conditions, eucalyptus can be produced in innovative ways, providing non-market benefits. For example, research trials demonstrate that *E. grandis* and *E. amplifolia* can be used for restoration of phosphate-mined lands (M Langholtz, Carter, Rockwood, & Alavalapati, 2009; Matthew Langholtz et al., 2007; Rockwood, Naidu, Segrest, Carter, Rahmani, Spriggs, Lin, Alker, Isebrands, et al., 2004; Rockwood et al., 2006). *Eucalyptus* spp. has been shown to be effective at phytoremediation of reclaimed wastewater, municipal waste, storm water, and arsenic-and trichloroethylene-contaminated sites (Matthew Langholtz, Carter, Rockwood, Alavalapati, & Green, 2005; Rockwood, Naidu, Segrest, Carter, Rahmani, Spriggs, Lin, Alker, & Isebrands, 2004). Eucalyptus plantations that provide these types of environmental services may be viewed more favorably by the public, and compensation for non-market environmental services would improve the profitability of these systems.

Potential yield. Eucalyptus yields are influenced by precipitation, fertility, soil, location, management, and genetics. *Eucalyptus* spp. yielded 7.6–14.3 dry tons per acre annually after 3–5 years of growth on a clay settling area in central Florida, comparable to 8.9–13.8 dry tons per acre estimated for eucalyptus in Florida (Rahmani, Hodges, Stricker, Kiker, & Tuohy, 1998), but higher than the estimated 4–7.6 dry tons per acre estimated by Klass (Klass, 1998), who observed that yields could be improved with SRWC development in the subtropical South. *E. grandis* is a high-yielding species in southern Florida, while *E. amplifolia* has the advantage of being more frost tolerant, with current trials as far north as South Carolina. Expected yields for *E. benthamii* for the short-fiber pulpwood markets with rotation lengths of 6 to 10 years and those focused on biomass markets will have rotations of 2.5 to five years can average from 4 to 12 dry tons of wood per acre per year over full rotation. Current research programs in silviculture and genetics are working to improve these growth rates by 25-50% and to expand the potential planting area north of existing plantation areas.

Sustainability. Intensive management of eucalyptus, characterized by short rotations of genetically uniform monocultures, has dramatically increased yields over recent decades. These tree plantations maintain some sustainability attributes associated with forested landscapes, while at the same time facing sustainability challenges common in agriculture (Binkley & Stape, 2004). Infrequent tilling in tree plantations reduces risk of soil erosion associated with annual crops, and carbon sequestered in eucalyptus stand biomass exceeds the amount of carbon sequestered in herbaceous crops.

Conclusions. Eucalyptus has proven to be one of the most productive and economically viable biomass crops in the world, with expansive commercialization on all populated continents. As with other biomass crops, high yields require fertilization and water. Intensively managed plantations offer both environmental benefits over conventional agricultural systems and potential environmental downsides if native ecosystems are displaced. It is expected that eucalyptus will continue to be produced commercially in the United States and will play an increasing role as a feedstock for bioenergy systems.

Figure 2. Eucalyptus plantation in Florida (Courtesy of ArborGen and R. Gonzalez, NCSU).

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