SILVICULTURE AND ECONOMIC EVALUATION OF EUCALYPT PLANTATIONS IN THE SOUTHERN US

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Demand for hardwood from plantation-grown stands for pulp and bio-energy in the southern US is more than 90 million tons per year and is increasing. In the specific case of bio-energy and pulp, demand for biomass from eucalypts could approach 20 million tons/year by the year 2022. Fast growing species and hybrids of *Eucalyptus* are being evaluated to partially fill this demand gap. Though widely grown in a number of countries for pulp as well as for bio-energy, eucalypts in the southern US have not been extensively researched. Initial growth rates of 18 to 36 green tons/ha/year on rotation lengths of 6 to 8 years are possible. Current estimated costs for energy production from eucalypts in the Southern US are estimated at $3.10 to $3.49 per MBtu, where landowner required return rates on reforestation capital invested range from 6 to 14 percent. Eucalypts as a bio-energy feedstock can be competitive with coal in cost per BTU in the southern US.

Keywords: Eucalypts; Eucalyptus; Plantations; Bio-energy; Southern United States

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INTRODUCTION

Species and hybrids from the genus *Eucalyptus* are amongst the most important for pulp and paper production (Wright 1997). Developments in eucalypt plantations for bio-energy are emerging rapidly in many parts of the world (Gonzalez *et al*. 2011a). Potential bioenergy "products" currently include biodiesel, wood pellets (Pirraglia *et al*. 2010), cellulosic ethanol (Gonzalez *et al*. 2011b), combined heat and power (CHP), advanced biofuels, torrefaction, and electricity generation directly from wood products or from co-firing with coal or other alternative fuel sources. Recent improvements in silvicultural systems and hardwood demand for pulp, paper, mulch, and bio-energy are encouraging commercial development of eucalypt plantations in the southern US. Commercial *Eucalyptus* plantations are being established at a rate of 5,000 to 10,000 ha per year in the southern US.

The US Forest Service has records of eucalypts being planted in California and Florida beginning in the 1870's (Zon and Briscoe 1911). Historically the use of eucalypts in the southern US has been limited by their freeze tolerance (Rockwood *et al*. 2008; Meskimen *et al*. 1987). Recent species tests indicate that *E. benthamii* appears to have sufficient cold tolerance to be considered for use in the southern US. Plantings of this species at locations ranging from southern Texas to the coastal plain of South Carolina survived well through several 2010 winter freeze events. Species such as *E. grandis* and the hybrid *E urograndis* are being planted on a commercial scale in south Florida. These are two of the most important eucalypt plantation species in the world.

Utilization of eucalypt wood and biomass in the southern US will be for a large number of uses including mulch, oriented strand board, lumber, bio-energy, and pulp for papermaking. The estimate of annual hardwood consumption for 2010 in the southern US was 92.5 million tons (Conner and Johnson 2011). Potential future demand for bio-energy from woody biomass is estimated to be 25 million tons (FORISK 2011), of which a large part will be from fast growing hardwood species that coppice such as eucalypts. The authors envision that annual demand for eucalypt could be about 20 million tons/year by the year 2022. The purpose of this article is to discuss establishment requirements and production economics of eucalypt species for plantation use in the southern US.

EUCALYPT PLANTATION ESTABLISHMENT AND MANAGEMENT

There are no published guidelines on eucalypt silviculture or growth and yield in the southern US, though extensive plantation management experience in Australia, Chile, South Africa and Brazil will generate many of the practical systems. Given intensive culture, eucalypt production can be some of the highest in the world. In contrast, when low-intensity culture is applied, production of eucalypt is similar to conventional southern US pine and hardwood plantation species.

To fully benefit from deploying eucalypts, the appropriate growth culture (silviculture) to attain high production rates is important. Proper silviculture for eucalypts will include appropriate nursery technology, site preparation tillage, weed control, and fertilization. When appropriate silviculture is implemented, rotation ages (period from planting to harvest) are in the 6 to 8 year range. Wood production rates of 18 to 36 green tons/ha/year of total biomass are reasonable for the Lower Gulf Coast Region of the southern US.

In Table 1 is an example of a standard silvicultural management regime for establishing a stand of eucalypts.

Table 1. Costs per Hectare Incurred in Eucalypt Case Study Regime, 1482 Seedlings/ha, Seven Year Rotation

Year	Management Activity Description	Cost	NPV
0	Mechanical site preparation	-$247	-$247
0	Seedlings	-$371	-$371
0	Planting labor	-$133	-$133
0	Chemical site preparation	-$116	-$115
1	Herbaceous weed control	-$124	-$115
2	Herbaceous weed control	-$124	-$108
2	Fertilization	-$247	-$216
Totals		**-$1361**	**$1305**

Mechanical site preparation treatments may include disking and ripping to promote root growth. These must be done early enough for soils to have re-settled after mechanical site disturbance. Chemical site preparation, using herbicides with no soil or very limited residue potential, can be completed with conventional ground or aerial operators.

Eucalypt seedlings are currently available as containerized stock. Most seedlings are produced from open-pollinated seed. Planting is completed with contract crews using planting tools similar to those used for bare root pine seedlings. Planting can be done in the fall (September-November) when moisture is adequate or in early spring after the last expected freeze date. Fall planting is preferred. Usually about 1400 seedlings per hectare are planted for biomass production, with 1000 seedlings planted for pulpwood size trees.

After planting, follow-up herbaceous weed control is a must. Weed control should begin early, and control must be maintained at near complete levels. Two weed control treatments may be needed in the first year on some sites. An early year-2 herbaceous weed control may also be necessary. Once the trees have closed canopy, no additional weed control is necessary

Nutrient management is also essential. A soil analysis should be completed to determine if any macronutrient or micronutrient deficiencies exist. Fertilization regimes may include an application before planting to take care of any identified deficient elements and to provide starter nutrients. The regime may also include an individual tree fertilization within year-1 after seedlings have become established. This can be accomplished by spreading a balanced fertilizer with micronutrients evenly around each tree, being careful not to concentrate too much fertilizer near the young seedling. Fertilization should be completed in year-2. Once the stand is fully established and the site fully captured, no additional fertilization is usually required.

Eucalypt Coppice Management

Eucalypts, depending on species and seed source, generally coppice or stump-sprout vigorously. When the tree is harvested, multiple shoots sprout from the cut stump to recapture the site and fuel new post-harvest growth. With access to the stored resources present in the advanced root system, the growth in the first two coppice rotations can be greater than that of a newly planted seedling. Properly managed coppice rotations can be more productive than the initial planted rotation. Exceptions to this would include instances where coppice success is poor, *i.e*. some of the trees from the initial rotation fail to coppice and die, resulting in a secondary stand that has fewer surviving stems or stocking than the initial stand. Other exceptions might include occurrences of low coppice vigor or poor management. Coppice survival and vigor varies based on many factors including season of harvest, stump size, and the vitality of the tree prior to harvest. Coppice can be reduced to one sprout per stump at around six months following harvest.

Another major benefit of a coppice rotation is that the up-front costs of successive plantations are dramatically decreased as compared to the initial rotation directly from seedlings. Lesser up-front cost means greater returns from similar harvest values. Alternatively, it could also mean that lower stumpage prices are required to provide the same rate of return to the investor. Success through coppice does imply management inputs. Like the original planted stand, site resources need to be guarded through herbaceous weed control treatments and potentially amended through fertilization treatments to reach strong productivity. However, the expensive costs of initial mechanical tillage, chemical site preparation, seedlings, and planting labor, are avoided. Amending the management regime and costs in the base case study used above moved the net present value investment cost of $1305/ha from the planting rotation, to a coppice rotation discounted investment cost of $565/ha.

Motivated by the cost savings and increased early growth of coppice, the number of coppice rotations following the initial plantation establishment rotation may be substantial. Willow plantation managers interested in energy production, for instance, may establish an initial plantation and follow it with six or more coppice rotations of three years each (Keoleian and Volk 2005). With any species, the decision to manage the next rotation for coppice is weighed against production potential of the pending coppice stand as determined from coppice survival and vigor, and compared to the expected genetic improvement of available new improved seedlings. With the strong successes in the genetic improvement of varietal eucalypts in many parts of the world, eucalypt coppice rotations are often limited to one or two.

ECONOMIC ANALYSIS

Stumpage Price Analysis for a 1-Rotation Eucalypt Plantation

With an estimate of $1235 to $1359/ha in upfront costs, it is important to determine how much must be paid to the landowner to incentivize the production of eucalypts. The analysis relies on primary drivers, including: (1) the site productivity, (2) the site management methods (reoccurring plantation establishment versus coppice management), and (3) the landowner's required rate of return on investment. Using the base management regime and cash flows provided above, we computed the stumpage prices required to provide the landowner a range of return rates from 6% to 10+% on the plantation investment costs. These required stumpage prices were computed for a range of average annual productivities (mean annual increments), with a total biomass production low of 20.7 green tons/ha/year and a high of 36.2 tons/ha/year. Table 2 illustrates the impacts of productivity and required return rate on necessary stumpage price.

Table 2. Required Stumpage Value for Green Tons per Hectare and Harvest Value by Landowner's Required Rate of Return

Production		6%		8%		10%	
Annual Tons	Rotation Tons	Per-ton Price	Harvest Value	Per-ton Price	Harvest Value	Per-ton Price	Harvest Value
20.7	144.9	$13.54	$1,962	$15.44	$2,237	$17.55	$2,543
28.5	199.5	$9.83	$1,962	$11.21	$2,237	$12.75	$2,543
36.2	253.4	$7.74	$1,962	$8.83	$2,237	$10.04	$2,543

In this scenario, if a landowner invests $1,305/ha early in the investment period, the eucalypt plantation must produce a sales revenue of $1962/ha at the end of a 7-year rotation to yield a 6% rate of return. At the medium level of productivity (28.5 tons/ha/year), the landowner must be paid $9.83/ton to meet this return rate hurdle. With an investment hurdle rate or 10% and the same level of productivity, the landowner must be paid a stumpage price of $12.75/ton to reach their goals. These basic calculations reveal a key point: the viability of an energy production system (such as biomass) in the southern US depends greatly on the technology available to and productivity of its producers.

Eucalypt Plantation-Coppice Regime Analysis

In the coppice management section above, we noted benefits of coppice to include potentially increased productivity and decreased investment costs. For our economic analyses presented here, we used a model of an initial seven-year rotation from planted seedlings followed by two successive seven-year managed coppice rotations. In Table 3, note the productivity change over each rotation. The initial coppice rotation productivity is slightly greater than the initial stand due to the stored root energy used, but the 3rd rotation, also from coppice, shows slightly decreased productivity due to loss of sprouting stumps going into the follow-up coppice rotation. As with the single plantation calculations above, we solved for the average stumpage price required for the landowner to make to a range of required returns, first for the immediate rotation, and then computing an average of the three rotations. Table 3 shows the resulting impact of coppice productivity and savings differences ($565/ha carried versus $1,305/acre as noted above).

Table 3. Required Stumpage Prices by Rotation Origin and Required Return Rate with Medium Productivity

Rotation	Origin	Annual Productivity	Rotation Productivity	Required Stumpage Price		
				6%	10%	14%
1st	Seedlings	28.5	199.5	$9.83	$12.75	$16.37
2nd	Coppice	32.8	229.6	$3.70	$4.80	$6.16
3rd	Coppice	27.8	194.6	$4.37	$5.66	$7.27
Averages		**29.7**	**207.9**	**$5.97**	**$7.73**	**$9.93**

The positive impact is clearly demonstrated in this example. While a per-ton stumpage price of $12.75/ton is required in the rotation from seedlings (to make a 10% return on investment), only a $4.80 and $5.66/ton stumpage price is required from the two following coppice rotations respectively. The impact on the average is also strong, driven down to $7.33/ton by the productivity increase and the management cost decrease.

DELIVERED COST ANALYSIS

The base silvicultural regime for eucalypts, cash flows, and returns necessary to make these regimes attractive to an investor are important to prospective purchasers of this biomass feedstock. Emerging users and electricity producers must be able to afford to purchase it at these prices with cost effects to energy consumers in costs per BTU. Estimates of required stumpage prices plus delivered prices for the base case study were developed. The delivered price includes the stumpage rate plus the rate to put the wood on the truck (cutting, chipping, and loading) plus the haul rate. Using Timber-Mart South (2010) published estimates of logging cost and hauling rate, with a chipping rate of $16.50/ton, a 64.4 km haul to the mill, and a $0.075/ton km rate for a 22.7-ton load, we calculated a cut-and-haul rate of $21.33/ton for our example. Adding this rate to the stumpage prices from Table 3 above, and still assuming a medium productivity rate and 10% required return on investment, produces a delivered price of $34.08 per ton for the initial rotation from seedlings, and a delivered price range of $26.13 to $26.99 per ton for the coppice regimes presented.

Emerging and existing energy ventures would work within delivered eucalypts costs in the range of $25 to 35/ton. This delivered price estimate of eucalypt biomass was compared with coal, which is one of the least expensive sources of electricity production in the southern US. The June 2010 EIA (US Energy Information Administration, 2010) delivered coal price report showed a national average delivered cost of coal to the electricity sector of $2.30/Million BTU for coal. For the southern US, where much of the eucalypts will be grown (MS, AL, GA, SC, FL), the reported price ranged from $2.84/MBTU to $3.97/MBTU. The other primary competitor, natural gas, is higher at $4.50/MBTU (Zhou and Parker 2010). For the case study the comparable delivered price for eucalypts, in dollars/delivered MBTU, was calculated. Similar to coal, which has variable energy potential and moisture content based on the type of coal, eucalypt density, moisture content, and BTU/lb vary by species. Assuming 8000 BTU/lb dry and a 50% moisture content for delivered wood, the BTU/green lb of delivered eucalypts would be 4000 BTU/lb (Gonzalez 2012). For each metric ton (2200 lbs), there would be an estimated 8,800,000 BTU, or 8.8 MBTU delivered. At a delivered price of $26.4/ton for example, this would compute to a dollars/MBTU price of $3/MBTU. The calculated delivered MBTU prices are shown in Table 4.

Table 4. Case Study Delivered $/MBTU Cost for Eucalypts in the Lower Gulf Coast Area for 4000 BTU/lb of Delivered Eucalypt Wood

				Delivered Price by Landowner's Rate of Return		
Rotation	**Origin**	**Productivity**	**Tons/ha/yr**	**6%**	**10%**	**14%**
1st	Seedlings	Medium	28.5	$3.55	$3.86	$4.23
2nd	Coppice	Medium	32.8	$2.85	$2.96	$3.08
3rd	Coppice	Medium	27.8	$2.91	$3.02	$3.16
Averages			**29.7**	**$3.10**	**$3.28**	**$3.49**

Compared to June 2010 regional reported prices from US Energy Information Administration (2010) of $2.84 to $3.97/MBTU for coal, estimates of $3.10 to $3.49/MBTU for delivered eucalypt chips would potentially be a strong additional biomass feedstock for the emerging alternative energy sector. Eucalypt biomass costs are in line with current delivered coal costs for the southern US region and are below natural gas prices. Additional benefits in the southern US include production of electricity and energy from sustainable and locally grown forest plantation resources. Woody biomass consumption for bio-energy is projected to increase from 15.5 million tons in 2011 to 34.5 million tons in 2016 (RISI 2011), and eucalypt plantations will be increasingly important sources of sustainable fiber production. In addition, carbon capture from these plantations (Wright *et al*. 2000) will be important to many consumers.

CONCLUSIONS

Domestic and international investors are evaluating a number of potential bio-energy sites in the Southern US to utilize plantation wood of eucalypts as well as other forest plantation species. With moderate levels of production, eucalypt plantations can provide a feedstock for energy that both competes with coal and meets typical forest investor return rates for private landowners in the southern US. Research is under way to select improved genetic stock and optimize the silviculture for existing eucalypt species and genotypes. The widespread adoption of this feedstock and growth technology will depend on continued alternative energy feedstock cost comparisons, required investor discount rates, and advances in eucalypt species genetics and silviculture.

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Article submitted: January 9, 2012; Peer review completed: February 21, 2012; Revised version received and accepted: March 12, 2012; Published: March 18, 2012.