Biomass 5 (1984) 65-77

Economic, Environmental, and Social Advantages of Intensively Managed Short Rotation Mesquite *(Prosopis* spp*)* Biomass Energy Farms

Peter Felker

Caesar Kleberg Wildlife Research Institute, Texas A&I University, Kingsville, TX 78363, USA

(Received: 26 July, 1983)

ABSTRACT

Constraints to wood-fired power plants larger than 50 MW stem from the inability to obtain sustainable forest by-products within a 100-km (60-mile) haul. Intensively managed biomass farms that produce 16 t ha^{-1} $year^{-1}$ *(7 dry tons* $acre^{-1}$ $year^{-1}$*) can support a 500-MW generating facility or a large petrochemical plant on a renewable basis with a biomass farm of 22-km (14-mile) radius. Selected strains of arid-adapted nitrogen-fixing trees of the genus* Prosopis *(mesquite) have achieved yields of 14·5 t* ha^{-1} $year^{-1}$*; in Texas natural* Prosopis *stands occur on 22 million ha (55 million acres).* Prosopis *also occurs on semi-arid lands of Africa, South America, and the Far East. Managed biomass farms of* Prosopis *would be capable of supporting large petrochemical or electrical generating facilities with fuel costs less than either oil, gas, or coal in Texas. Wood-fired conversion facilities produce negligible* SO_2*, little* NO_x*, and no radioactive waste; the ash can be recycled on biomass farms, which should be less objectionable than strip mines.*

Key words: semi-arid, fuelwood, nitrogen-fixing trees, less developed countries.

INTRODUCTION

Studies of commercial or industrial scale wood-energy production and its potential in the United States have almost exclusively supported the

Biomass 0144-4565/84/$03.00 –

use of forest by-products and residues from existing stands.[1,2] Short-rotation, woody biomass plantations (3–8 years) have been suggested as sources of wood energy and petrochemical feedstocks,[3] but they have not yet attracted the support of industry probably because of a concern to use more effectively existing stands. The production of wood energy in intensively managed, short rotations (3–8 years) has significant economic, environmental, and industrial management advantages over the harvesting of existing stands. This study illustrates these advantages using data from mesquite (*Prosopis* species) biomass production trials in California and Texas.[4]

The genus *Prosopis* contains 44 species of nitrogen-fixing trees and shrubs that are native to the semi-arid and arid lands of North and South America, Africa, the Middle East and India.[5] While this paper demonstrates that *Prosopis* has considerable potential in the United States, the Food and Agricultural Organization of the United Nations[6] and the World Bank[7] have identified the semi-arid lands of the less developed countries (LDCs) as deserving first priority for fuelwood production. Fuelwood plantations are urgently required in the semi-arid LDCs not only to provide energy but to reduce the pressure on existing shrubs and trees which are being overcut thus leading to desertification.

In the United States, wood energy currently supplies approximately $1{\cdot}9 \times 10^{18}$ J ($1{\cdot}8$ quads or $1{\cdot}8 \times 10^{15}$ Btu), which is nearly the same as the amount provided by nuclear energy.[8] If conservatively priced at $2.10 per GJ ($2 per million Btu) this wood replaces approximately $4 billion of alternative fuels in the United States annually. Research on short rotation, woody biomass production is being carried out in the fiscal year 1983 by the United States Department of Energy (DOE) in 20 locations throughout the United States at a funding level of less than $2 million. A $2 million per year budget is very low given the current utilization of wood energy and the funding levels of energy research in coal, nuclear, gas, and oil exploration. Indeed in 1981, at least one major oil company spent $3 million on one dry well in South Texas.

The highest biomass productivity of 32 accessions tested in Riverside California was from a *P. chilensis* (0009) accession that had an average dry-matter productivity of $13{\cdot}4$ t ha^{-1} year^{-1} (6 dry tons acre^{-1}) over three seasons with an average annual rainfall and irrigation of 460 mm (18 in).[9] Another test plot of *P. chilensis* (0009) in the California Imperial Valley that received approximately 700 mm (28 in) yearly irrigation and rainfall had a production of $11{\cdot}7$ t ha^{-1} dry-matter during the first year's growth and produced an additional 16·9 t ha^{-1} during the second year's growth.[4] The greater biomass production in year 2 was the result of canopy closure during the second season. Although the study was discontinued in the third year, it is likely that further biomass productivity would have been equal to or greater than the second year's production. Parental lines have been identified in the California Imperial Valley with greater productivity than *P. chilensis* (0009). Seed propagated *Prosopis* progeny are exceedingly variable because the trees are obligately outcrossed. Therefore, clones were made of exceptional individual trees, the largest of which had 17 cm basal diameter and a 53 kg dry weight at the end of two seasons' growth.[4] The herbicides Treflan and Simazine and the insecticide Orthene have provided good pest and weed control in California; however, they are not adequate in the Kingsville area of South Texas because of higher rainfall resulting in greater insect and weed diversity.

PROPOSED BIOMASS FARMING SYSTEM

From the results of the California and the early Texas work, we propose development of biomass farms that employ the following.

1. Clonal material from either rooted cuttings or tissue culture (work is now in progress in both these areas) of trees that produced 53 kg dry weight in two seasons in the California Imperial Valley on a 1·5 × 3·6 m spacing.
2. A 3 × 3 m spacing for 1111 trees per ha (450 trees per acre).
3. A three-year rotation with a harvest goal of 47 dry t ha^{-1} at the end of three years (7 dry tons $acre^{-1}$ $year^{-1}$).
4. A mesquite combine developed by Ulich[10] that can harvest mesquite at a cost of $15.40 per dry metric tonne ($14.00 per 2000 lb).
5. The harvest of coppice regrowth (stump resprout) in three-year rotations.
6. Fertilization with P, K, and S every three-year rotation at rates commensurate with removal of these nutrients in the biomass (no nitrogen is required since these trees are nitrogen fixers).
7. The recycling of ash from the conversion technology on the biomass farm (this should theoretically eliminate P, K, S, and micronutrient requirements).

8. Use of the herbicides Treflan and Simazine for weed control only for the first year until stand establishment is secure.
9. Use of marginal land receiving 450–685 mm (18–27 in) annual rainfall.
10. Preparation of a weed-free seed bed by bulldozing existing brush and disking the cleared land.

WOOD PRODUCTION COSTS

The \$27.75 dry metric tonne production cost for mesquite chips (18 200 Btu kg^{-1}) in Table 1 yields an energy cost of \$1.41 per GJ (\$1.48 per million Btu). This compares favorably with other South Texas

TABLE 1
Plantation Grown Mesquite Woodchip Cost Estimates

Item	*Cost per rotation per hectare*		
	Initial planting	*1st coppice rotation*	*2nd coppice rotation*
Land rental – 3 years @ \$24.70 h^{-1} $year^{-1}$	74·00	74·00	74·00
Site preparation – bulldozing and discing	440·00	–	–
Seedlings via tissue culture – 1111 @ 0.35¢	389·00	–	–
Planting costs – mechanical transplanter	52·00	–	–
Herbicides – Treflan and Simazine for use in stand establishment	54·00	–	–
Fertilizer costs – 281 kg triple super phosphate, 446 kg muriate of potash, 45 kg sulfur	195·00	195·00	195·00
Total production cost	1 204·00	269·00	269·00
Production (15·7 dry tons ha^{-1} $year^{-1}$ x 3 years)	47 tons	47 tons	47 tons
Production cost per metric tonne	25·61	5·72	5·72
Harvesting cost per metric tonne	15·40	15·40	15·40
Harvested cost per metric tonne	41·01	21·12	21·12

Average cost per dry metric tonne over 9 years (three rotations) = \$27.75 or \$1.41 per GJ (\$1.48 per million Btu).

energy sources, such as natural gas which costs \$2.84 per GJ (\$3.00 per 1000 ft^3 or \$3.00 per million Btu), crude oil which costs \$5.70 per GJ (\$35.00 per bbl or \$6.00 per million Btu) and western coal which ranges from \$27.50 to \$49.50 per metric tonne (\$1.40–\$2.46 per GJ or \$1.48–\$2.60 per million Btu) (J. Morris, San Antonio Utility, and B. Miller, Central Power and Light, pers. comm.). While the mesquite wood chip production cost estimates do not include interest or return on the investment and are admittedly crude, they indicate sufficient promise to continue further mesquite biomass farm development.

The most costly item in mesquite wood chip production (Table 1) is the harvesting with a combine modified from a rubber-tired, 97 kW (130-hp) Massey Ferguson diesel tractor that can fell, collect, and retain natural stands of mesquite up to 20 cm in diameter at a cost of \$15.40 per dry metric tonne (\$14.00 per English ton).[10] When averaged over three rotations, harvesting accounts for 55% of all costs. Harvesting costs account for 73% of all costs for coppice rotations after site preparation, seedling, and planting costs have been paid for. By fine tuning harvesting equipment to handle ranges narrow in stem diameter and regular plant densities and spacings, more economical swath harvesters should be possible. For example, a DOE report indicates that agricultural forage choppers can harvest and chop forage for \$0.94 per green metric tonne (*ca.* \$3.30 per dry ton), while the chipping alone of large diameter trees with a Morbark 22 chipper costs \$3.85 per green metric tonne (\$7.70 per dry ton).[11]

After harvesting costs, site preparation costs are the next most expensive item. Substantial opportunities are available to defray these costs by harvesting large mesquite pieces (35 cm in diameter, 1·8 m long) for furniture wood that sells for \$212 per m^3 (\$0.50 per board foot) in the rough and \$1700–\$2540 per m^3 (\$4.00–\$6.00 per board foot) in planed and cured form, by harvesting 35-cm to 15-cm diameter material for firewood use in homes that sells for \$27 per stacked m^3 (\$100 per cord), and by chipping the remaining material for boiler fuel at \$27.50 per dry metric tonne. If judiciously carried out, it is possible that harvesting of existing brush might cover all site preparation costs and perhaps show a profit. Elimination of site preparation costs will reduce three rotation average production costs from \$1.42 to \$1.26 per GJ (\$1.49 to \$1.26 per million Btu).

Seedling costs from tissue culture have been derived from estimates of a commercial tissue culture laboratory (H. Bollinger, Native Plants

Inc., pers. comm.) and are a substantial portion of the initial investment ($389 per ha). However, little information is available to assess possibilities for decreasing these costs (current work employs seedlings that cost $0.12 each).

A substantial opportunity is present to obtain the plant's fertilizer mineral requirements free as a by-product of ash disposal from the conversion technology. This will reduce three rotation costs from $1.42 to $1.21 per GJ ($1.49 to $1.21 per million Btu).

It has been difficult to arrive at an equitable land rental and it is even more difficult to project equitable land rentals for the future. Nevertheless, a $24.70 per ha per year land rental is a considerable improvement over the $5.00 per ha per year returns that cattle ranchers experience currently.[12]

Planting, seedling, and herbicide costs do not significantly contribute to production costs but continued research on planting techniques, seedlings, and herbicides is essential to insure high production levels and possible impacts on ease and costs of harvesting.

LAND AND WATER RESOURCE BASE

Mesquite has been estimated to occur in the United States on 30 million ha.[13] Large areas of mesquite grow on upland sites (away from river bottoms) in regions with rainfall ranging from 700 mm (28 in) near Corpus Christi, Texas, to approximately 200 mm (8 in) midway between Phoenix, Arizona, and the Colorado River. In areas where groundwater accumulates, mesquite is abundant at 76-mm (3 in) annual rainfall along the Colorado and Gila Rivers and in Death Valley with 46-mm (1·8 in) annual rainfall.

Water supplies of sufficient quality to be used in commercial agriculture are overcommitted in the southwestern United States, as exemplified by Supreme Court battles between Arizona and California over Colorado River water entitlements and by the depletion of fossil fuel groundwater resources in southern Arizona and the Texas Panhandle. It is inappropriate to use high quality irrigation water on biomass farms of the scale required for commercial chemical feedstock production or power generation. Since some *Prosopis* grow well in one-half seawater,[14] irrigated biomass farming with *Prosopis* will be attractive if water too saline for use on agricultural crops were available. Approximately 240 million m³ of water from irrigation tile drains in the California Imperial Valley is too saline for reuse on agricultural crops and currently is drained into the Salton Sea (B. Meeks, USDA Imperial Valley, pers. comm.). Large areas in northwestern California's San Joaquin Valley, as well as significant portions of South Texas coastal sorghum and

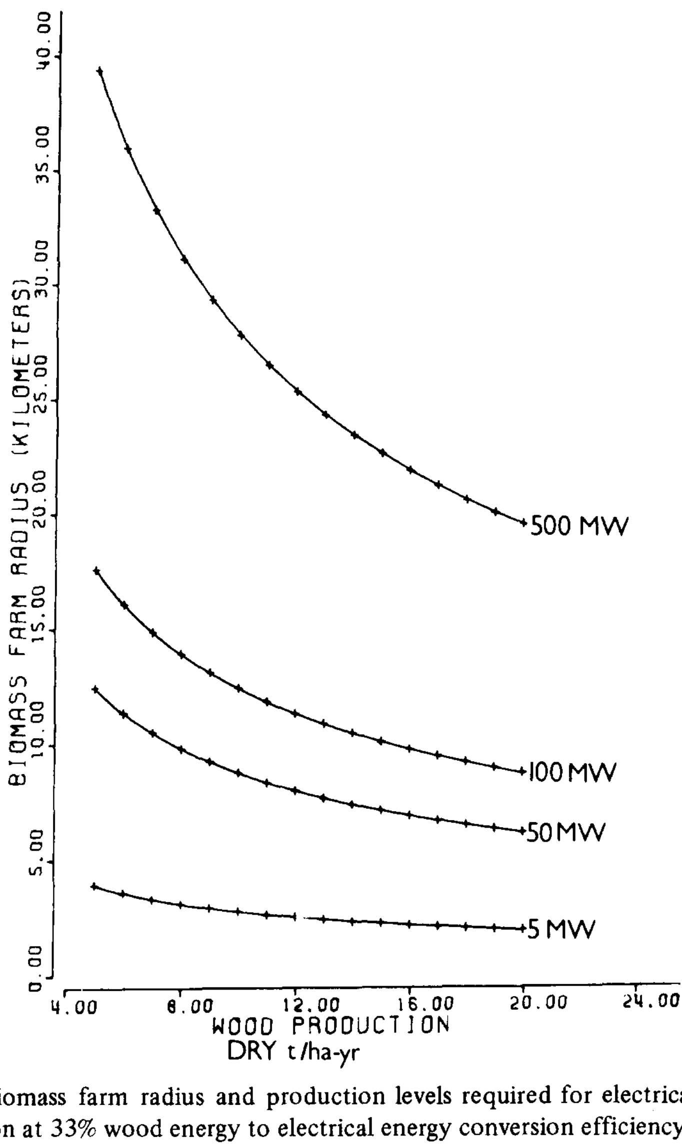

Fig. 1. Biomass farm radius and production levels required for electrical generation at 33% wood energy to electrical energy conversion efficiency.

cotton growing regions, have saline groundwater too close to the surface to permit tiling that will allow farming. However, these areas should be suitable for mesquite biomass farming.

Some inexpensive energy sources do not readily lend themselves to deliver the enormous quantities of energy currently used in the United States. Figure 1 graphically expresses the size of biomass farm required to power commercial-sized power plants assuming a 33% wood energy to electrical energy conversion efficiency and a $6\cdot2 \times 10^{-4}$ MW year per dry metric tonne wood energy content. This figure assumes an unrealistic 100% use of land area encompassing the electrical generation facility and avoids areas required for access roads, municipalities, etc. Nevertheless, it provides a concept of the biomass farm size required for electrical generation. At our projected yield of 15·7 metric tonnes ha^{-1} $year^{-1}$ (7 dry tons $acre^{-1}$ $year^{-1}$), a circle of radius 2·2 km (1·38 miles), 7·0 km (4·35 miles), 9·9 km (6·15 miles) and 22·1 km (13·8 miles) is required for 5, 50, 100, and 500 MW power plants, respectively.

Approximately a dozen 10–20 MW wood-fired power-generating plants currently operate in the United States, but no wood-fired power plants larger than 50 MW currently exist.[2] Constraints to wood-fired power plants over 25 MW probably stem from the inability to obtain forest residues on a sustained basis within an 80 km (50 mile) haul.[2] From the model presented, it is clear that even 500 MW plants would be within a 24–32 km (15–20 miles) haul if a dedicated biomass plantation provided the fuel source. Thus, power-generating facilities supported by biofuel plantations could have a sufficiently short hauling distance to support 10 times larger facilities than are possible when the feedstock is derived from forest by-products and residues. Capital costs of 500 MW power plants are in the half-billion dollar range[15] so that acquisition of 154 000 ha at $2500 per ha or $0.4 billion might not be unreasonable if the land could supply energy in perpetuity.

ENVIRONMENTAL ASSESSMENTS

Environmental assessments of mesquite biomass farming should be compared to the environmental assessments of alternative coal- and nuclear-supported systems that are likely to be major energy sources in the latter part of this century. The environmental assessment must compare entire systems including coal or uranium mining, energy conversion, and the disposal of the waste products.

Deterioration of air quality is less likely from wood than from either coal or oil because of lower wood sulfur and nitrogen contents.[1] To meet increased air quality standards, some institutions have found it less costly to retrofit coal systems to burn wood rather than to install SO_2 scrubbers.[8] Wood-burning systems would not contribute to acid rain or cause net increases in atmospheric CO_2 levels. Particulate emissions from wood can be reduced to meet US Environmental Protection Agency (EPA) standards with conventional equipment.[1] The ash produced from wood is generally less (1–2%) than ash produced from coal (6–8%); positive benefits from wood ash can be obtained from ash distribution on the biomass farm to recycle phosphate, potassium, and micronutrients. Build-up of nearly 1-cm thick layers of leaf litter has been observed in three years beneath nitrogen-fixing *P. chilensis* trees. This litter contributes to increased soil nitrogen, organic matter, and cation exchange properties. Waste disposal from nuclear plants is clearly a more difficult scientific and political issue. Dense stands of established biomass farms can provide habitat for birds and small mammals and will be considerably less objectionable than strip mines.

Commercial biomass farming on semi-arid lands may be capable of providing the capital and economic incentive required to halt increasing desertification in many of the semi-arid developing countries. For example, many of the semi-arid regions of the Sahelian zone of Africa are experiencing severe environmental degradation because of overgrazing and cutting of firewood.[16] These human induced processes have greatly reduced the tree cover that has resulted in substantial soil erosion. Previous reforestation efforts based on philanthropic or ecological reasons have not had the resources to accomplish significant reforestation. Many of these areas have climatic conditions similar to our experimental plots and, therefore, it should be possible to revegetate and maintain the land with the use of biomass energy farms with the cost borne by the production of energy. Biomass farms designed to provide chemical feedstocks for moderate sized chemical plants (in US terms) can involve revegetation of hundreds of thousands of hectares. Low land values and low labor costs occur in many of the environmentally degraded semi-arid regions and will provide attractive investment opportunities.

SOCIAL CONSIDERATIONS

The 150 000 ha located in a 22 km radius required for a 500-MW electrical generator facility may seem prohibitively large. However, mesquite has been estimated to occur on 22 million ha (55 million acres) of marginal land in Texas, much of which is suitable for biomass farming. Clearly, the farming of hundreds of thousands of hectares of land for energy requires the development of new industries and the employment of thousands of people. Such renewable employment could be extremely valuable in regions where fossil fuel exploration, production, and associated processing industries are expected to decline.

Biomass farmers should enjoy more price stability than farmers producing commodities such as sorghum or cotton since the woody biomass energy prices would be in competition with oil, coal, and gas energy prices. Unlike agricultural commodity markets, wood-energy prices produced by biomass farming may never be depressed from overproduction in bumper crop years since it is unlikely that wood energy will ever dominate the US energy market. The conversion of substantial areas from food farming to energy farming may help to stabilize farm prices and probably would have little effect on retail prices. For example the farmers price of $0.13 per kg of wheat is a small percentage of the price of a loaf of bread on the retail market. Thus, biomass farming may stimulate economies in areas where frequent agricultural overproduction tends to occur.

INDUSTRIAL CONSIDERATIONS

Industrial owners of wood energy plantations will have long-term control over feedstock availability and cost, and they will not have to purchase wood on 'spot' markets. Ownership of energy plantations will correspond more to purchase of oil and mineral rights (leases) than to the commodity energy market. Plantations will allow management on a renewable basis in marginal areas and in areas where wood demand exceeds wood supply. Intensively managed tree production systems will allow use of management subsystems encompassing soil fertility, ash disposal, erosion control, insect and weed control, tree genetics, harvesting, and tree inventory.

An economic analysis of retrofitting existing gas or oil industrial steam production plants (45 000 kg steam per h) in the northeastern United States indicated that a 60% annual return on the retrofit investment will occur if the wood cost is less than $40 per dry ton.[15] No serious problems have been encountered in gasification of mesquite wood chips in a countercurrent fluidized bed reactor.[17] This illustrates the potential for syngas production and ensuing chemical feedstock production. Direct combustion tests with mesquite after being pulverized to pass an 8 mm diameter screen indicate that mesquite can be successfully burned in suspension with the 300°C air that is currently being used on an air preheater for bunker C fuel oil on a 59 MW power plant,[18] indicating that the retrofit of large oil burners will pose no great difficulty. A series of four 3 MW wood-fired gas turbines are due to be installed in Tennessee in 1983 at a cost of $1000 per kW of generating capacity (J. T. Hamrick, pers. comm.) and are reputed to be the most efficient of the wood direct combustion technologies.

CONCLUSIONS

In spite of the potential, commercialization of *Prosopis* biomass farming is not yet possible because of (1) difficulty in producing sufficient quantities of clonal material by rooting cuttings or tissue culture; (2) numerous minor agricultural mechanization problems associated with growing, planting and cultivating; (3) lack of experience with commercial scale harvesting equipment; and (4) lack of experience with medium scale plantings on sites varying in soils, rainfall, frost, etc.

Recent reviews of wood energy have stated that the most rapid gains in wood-energy use have already been obtained by utilizing formerly wasted mill residues.[1] For further large increases in wood-energy use to occur without environmental deterioration biomass farming systems may have to be used.

Tightly managed, short rotation production systems when closely integrated with conversion technologies potentially can compete economically with commercial scale 500 MW electrical generating facilities or 250 tons h^{-1} petrochemical plants. Such systems should be capable of maintaining equivalent or higher environmental quality standards than alternative coal- or nuclear-fired systems while supporting renewable employment and industries.

ACKNOWLEDGEMENTS

The financial support of the Caesar Kleberg Wildlife Research Institute and of the US Department of Energy Grant No. ET-78-G01-3074 and the collaboration with P. R. Clark, J. F. Osborn, G. H. Cannell, and M. L. Lesney is gratefully acknowledged.

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