

# Screening *Prosopis* (Mesquite or Algarrobo) for Biofuel Production on Semiarid Lands<sup>1</sup>

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In many regions of the world, wood is an energy source that is locally available, decentralized, and requires little capital expenditure for either acquisition or conversion to useful forms of energy. In the last 5-8 years these characteristics have led wood to overtake nuclear energy as an energy source for the United States without the enormous federal expenditures of the nuclear R & D program (Smith, 1981).

In some lesser developed countries (LDC's) the lack of wood availability is a severe problem. Laborers in Ouagadougou, Upper Volta may spend 30 percent of their income on cooking fuel (Anon, 1980). In the same region woodcutters must travel 60 km from the city to obtain wood. Virtually all of these rapidly depleting wood resources come from natural stands of unselected genetic stock. In the semi-arid regions much of this wood is either *Acacia* or *Prosopis* which possess self-incompatible flowers which result in an out-crossing breeding mechanism (Self-el-Din, pers. comm; Simpson, 1977). Thus seed propagated progeny from *Acacia* or *Prosopis* are exceedingly variable in biomass production, thorniness, insect resistance, etc. so that artificial regeneration attempts using seed sources can yield disappointing and variable results. Thus seed collections, progeny production trials, and development of superior clonal propagules will ultimately be required to support wood energy based rural economies.

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Abstract: Eighty collections of *Prosopis* have been screened in field experiments for biomass production, frost tolerance, and heat/drought tolerance. Selections have been examined in the greenhouse for nitrogen fixation and salinity tolerance in which one species grew on a nitrogen free media in salinities equivalent to seawater. A 44 percent sugar pod producer was identified and successfully fermented to ethanol by Avgerinos and Wang at MIT. Individual trees have grown 5 to 7 cm in basal diameter and 2 to 3.2 meters in height per year with 600 mm total water application. Dry matter production of 14,000 kg/ha has been obtained at projected harvested costs of \$23.00 per ton or \$1.35 per million Btu and compare favorably with natural gas, heating oil, and coal at \$3.0, and \$6.0, and \$1.50 per million Btu's respectively.

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In the screening of new plants for biofuel production it is important not to rule out a particular natural ecosystem because of low productivity since the biomass productivity of natural stands provides little insight into productivity possible for managed food or fuel production systems. The productivity of wild oats growing along a highway or of wild progenitors of corn such as teosinte or tripsacum growing in Mexico bear little resemblance to oat productivity on commercial South Dakota farms or to hybrid corn production on Illinois farms.

In the screening of plants for biomass production or in the evaluation of the productivity of natural stands, screening for a single process such as photosynthesis or nitrogen fixation is to be avoided. To illustrate, plant physiologists have stated the reason *P. tamarugo* survives so well in the northern Chilean rainless salars is because of its capability to extract water from the atmosphere, or from its ability to develop a moist matted root zone, or because it possesses extremely high salt tolerance. While *P. tamarugo* is more salt tolerant than its near *P. alba* relatives (Felker et al., 1981c), it possesses 20 fold less biomass productivity than many other *Prosopis* species (Felker et al., 1981a). We feel the real key to *P. tamarugo* success in the Chilean salars is its complete resistance to psyllid insects. If algarrobo (*P. alba* (?)) trees possess moderate to good psyllid resistance they will tolerate the salinity, heat and low humidity of the salar de Pintados equally as well as *P. tamarugo* (Felker mss). Algarrobo trees in this region nearly devoid of leaves exhibit high psyllid predation while healthy green algarrobo's are devoid of psyllids (Felker, mss).

With the exception of the United States wood pulp industry, which uses "scrap" bark for electrical generation and process heat, and of several Brazilian industries, wood is not used as an energy source in commercial scale operations. In the United States the primary energy use of wood probably has been the widespread use in family dwellings (Smith, 1981).

We believe that areas such as south Texas where extensive flatlands are available at reasonable land leases (\$10 acre<sup>-1</sup> year<sup>-1</sup>), where low sulfur coal must be shipped more than 1,000 miles, where possibilities for co-generation of process heat and electricity exist, and where a need for tax shelters for biomass type investments are attractive - that woody biomass production from plantation grown trees can and will favorably compete with traditional energy sources in small commercial (20 megawatt) power generating plants. Managed even-aged, uniform small diameter stands of regularly and closely spaced trees are expected to be easier and less expensive to harvest than uneven aged stands of greatly differing size classes, that occur in random densities and spacings. The large quantities of wood or fuel required for commercial sized power plants or for chemical feedstocks and the sensitivity of transportation costs to distance, mandate rapid and renewable biofuel production close to the site of utilization. Since harvesting and transportation costs play a major role in the economics of wood biofuel production, dedicated biomass plantations of easily harvestable, even stands of highly productive selected strains offer significant advantages over some natural stands.

The work which follows is a result of U. S. Department of Energy sponsored research to develop woody biofuels for marginal semi-arid lands.

#### GERMPLASM ACQUISITION PROGRAM

In developing any new crop plant it is imperative to obtain as much genetic diversity as possible to be able to provide products of various qualities, and to be able to adapt to stress conditions such as heat, drought, insect predation, frost and salinity. Our Prosopis collection consists of: approximately 150 accessions obtained from Professor Solbrig which were used in the IBP project comparing North and South American deserts; of 150 collections of native Prosopis collected on a 3,000 mile field trip through the California desert; of 300 Peruvian collections obtained through contract with Dr. Alva of Lima, Peru; of approximately a dozen tamarugo (P. tamarugo), algarrobo (P. alba?), and chanar (Geoffrea decorticans) collections made by Felker in Chile; of several hundred second generation progeny of UCR and Imperial Valley grown trees; of miscellaneous collections from Argentina, Hawaii, the Caribbean, Senegal, Sudan and South Africa, and of a very limited number of cuttings of approximately a dozen clones.

#### NITROGEN FIXATION AND SALINITY TOLERANCE

Representatives of twelve Prosopis species were inoculated with a rhizobia strain isolated from the California desert and grown for 8 months on inert vermiculite that was watered with a nitrogen-free nutrient solution. The capability of mesquite to fix nitrogen was firmly established since all species were found to nodulate, fix nitrogen (reduce acetylene to ethylene) and accumulate dry matter on nitrogen free media (Felker and Clark, 1980). A ten fold range in mean nitrogen fixation

per accession was observed which suggests the possibility for selecting lines with high nitrogen fixing characteristics.

Having established that mesquite could fix nitrogen in a greenhouse environment an experiment was conducted to determine why mesquite had never been reported to nodulate in natural ecosystems. A phraeatophytically grown mesquite was simulated in a 3.05 m tall soil column with water or nutrient solution only being added to a soil-containing bucket beneath the soil column (Felker and Clark, mss). Sixteen months after the seedlings were planted, the top 0.5 m layer of soil was drier than 2200 kPa (22 Bars) but the bottom of the tube which received frequent irrigations never experienced water potentials more negative than -70 kPa. Acetylene reduction assays conducted through ports in the soil column observed no nitrogen fixation within 2.7 m of the surface although large quantities of nitrogen fixation (1.9 mg ethylene per hr) were fixed at the bottom. This nitrogen fixation occurred at leaf xylem water potentials of 3000 kPa (30 Bars) and air temperatures of 44°C. After the assays were conducted the tubes were disassembled and the roots examined for presence of nodules as a function of depth. No nodules were observed in the top 2.7 m although over 100 nodules were located at the bottom of the tube in the moist root zone (Felker and Clark, mss). Nodules probably have not yet been observed in nature because nodules have not been sought at deep enough depths in moist soil zones.

Species of Prosopis grow near the seacoasts in Hawaii, close to salt flats in southern California deserts, and in 0.5 m thick salt flats in northern Chile which suggests that considerable salt tolerance occurs in the genus. We measured the salinity tolerance of six species in greenhouse sand culture experiments (Felker, et al., 1981c). All species tested, P. glandulosa var torreyana from California, P. velutina from Arizona, P. articulata from Baja Mexico, P. chilensis from Argentina, P. pallida from Hawaii, and P. tamarugo from Chile all tolerated a 6,000 mg/L NaCl treatment with no reduction in growth. P. velutina was the only species that poorly tolerated the 12,000 mg/L salinity level. P. articulata, P. pallida, and P. tamarugo tolerated the 18,000 mg/L salinity level with 30-40 percent decrease in height growth and grew slightly in a salinity (36,000 mg/L NaCl) greater than seawater. As these plants were on a nitrogen free media they probably fixed nitrogen. These salinity tolerances are much greater than those of annual legumes such as peas and beans. Prosopis is the first legume we are aware of that has been reported to be able to grow at salinities equivalent to seawater.

#### FIELD SCREENING EXPERIMENTS

Selections of Prosopis were screened for response to irrigation on the University of California, Riverside experiment station (Felker et al., 1981a); for tolerance to winter freezing temperatures at 1500 m (5,000 ft) elevation in the mountains near Riverside, and for heat/drought

tolerance in the California Imperial Valley at minus 30 m (100 ft) where mean daily July maximum temperatures are 42°C.

Thirty-two collections representing North and South American and African germplasm were established on the UCR experiment station in three irrigation treatments in July 1978. Cultural management practices, origin of the germplasm and estimates of the first year's biomass productivity have appeared (Felker et al., 1981a). Twelve trees of each accession were grown in each of three basins that were irrigated when the soil water potential at the 30 cm depth reached either 60 kPa (0.6 Bars), 200 kPa (2 Bars) or 500 kPa (5 Bars). Riverside has a mediterranean type climate with no summer rainfall that makes imposition of these treatments possible. In the first season six-100 mm irrigations were applied to most of the wet (60 kPa) plots while no irrigations were made to the dry (500 kPa) plots. In the second season differences between treatments were not observed for P. chilensis which was the accession with the greatest biomass production. Consequently in the third growing season the dry (500 kPa) treatment received only winter rainfall and no irrigation to force differences between treatments.

At the end of the third season the trees were harvested, weighed, stem diameter measurements taken, and selected whole trees homogenised (chipped) to obtain subsamples for moisture content determination. Regressions of log dry biomass versus log stem diameter, which have been shown to be most satisfactory for mesquite biomass estimation (Felker et al., 1981b), were computed for dry biomass prediction. The estimated dry biomass at the end of the third growing season is presented in Table 1. Five accessions had zero biomass because they were killed during the first winter by an abnormally low -5°C freeze. Three of the accessions killed by the freeze P. juliflora (0044), P. pallida (0140) and P. pallida (0041) had substantial biomass the first year while the P. africana accessions did not. The ranked order for the biomass producers were approximately the same in the third season as for the first season as previously reported (Felker et al., 1981a) with P. chilensis (0009) having the greatest biomass productivity among all accessions. The 18 fold range in biomass productivity the first year was similar to the 20 fold range observed the third year. The accessions from the ranges of the southwest i.e. 0028 from West Texas, 0074 from New Mexico, and 0080 from Arizona were among the least productive accessions in both studies. Excluding those accessions which were killed by frost, P. tamarugo increased in order of biomass productivity from 26th to 19th.

The response of the accessions to irrigation treatments changed considerably from year one to year three, since in year one the 200 kPa treatment had the lowest overall productivity while in year three it had the highest productivity.

The biomass productivity in table 1 is expressed as dry kg/tree rather than dry kg ha<sup>-1</sup> because there were only 12 trees of each moisture treatment on a 4x3 array so that a substantial edge effect could not be avoided. Nevertheless it is useful to have an order of magnitude estimate of the biomass productivities in these plots realizing that edge effects have not been accounted for, and that these productivities could over-estimate actual productivity by 50 percent. As the trees were on a 1.22 x 1.22 m (4 ft) spacing the density was 6718 trees/hectare. The 3 season total dry matter production ranged from approximately 2500 kg ha<sup>-1</sup> for P. kuntzei to 50,000 kg ha<sup>-1</sup> for P. chilensis or an annual productivity of approximately 800 to 16,000 kg ha<sup>-1</sup> respectively. The rangeland accession 0074 from New Mexico had a 3 season average dry matter production of 9200 kg ha<sup>-1</sup> or 3000 kg ha<sup>-1</sup> season<sup>-1</sup>. The least productive accessions did not have complete canopy closure and probably experienced less of an edge effect than the more productive accessions which achieved complete canopy closure in the second season.

A biomass screening trial under heat/drought conditions was conducted on 55 tree legumes in the California Imperial Valley where the July daily maximum temperature is 42°C (108°F) and the mean annual rainfall is 65 mm (2.5"). Total water received by the plot the first season was 400 mm (16") in three irrigations and the total the second season was 680 mm (27") in a single irrigation in January preceding the second growing season. At the end of the second season four blocks of 55 trees each were harvested and representative whole trees oven dried so that regression equations could be developed to estimate biomass on companion plots of the same age. The mean measured oven dry biomass per accession for these second season (1 3/4 year old) trees ranged from 0.23 to 36.8 kg. Individual trees ranged from 0.2 to 56.3 kg oven dry biomass. The largest trees exceed 6 m height and 16 cm basal diameter. Progeny of California ornamental Prosopis alba (?) had the greatest biomass. The California native P. glandulosa var torreyana exhibited a wide range in biomass. The least productive accessions were P. tamarugo from Chile and Olneya tesota from California deserts. Parkinsonia aculeata and Leucaena leucocephala (Hawaii Giant K-8) ranked 4th and 14th in mean biomass per accession respectively. Trees in three accessions had a 45 kg oven dry biomass that have been cloned. Since this biomass was obtained in two seasons on a 1.5 x 3.6 m (5 x 12 ft) spacing we project a 45 kg tree average should be possible over large areas from clonally propagated trees in 3 seasons. At a 3 x 3 m spacing this would yield 50 metric tons per hectare for a 3 season annual production of 16 metric tons (7 dry english tons acre<sup>-1</sup> year<sup>-1</sup>). This production level is assumed in economic section that follows later.

Table 1

## Predicted UCR Third Season Dry Biomass Per Tree

Species	Accession Number	Biomass per tree (Kg)			
		Irrigation treatment			Average
		60kPa	200kPa	500 kPa	
<i>P. chilensis</i>	0009	6.96	8.15	7.34	7.49
<i>P. alba</i>	0039	7.44	5.55	5.85	6.29
<i>P. alba</i>	0098	4.08	6.73	6.44	5.58
<i>P. articulata</i>	0016	5.40	6.22	4.70	5.44
<i>P. alba</i>	0137	5.54	6.18	4.18	5.33
<i>P. alba</i>	0013	5.33	5.61	4.51	5.11
<i>P. nigra</i>	0133	3.71	5.55	4.02	4.45
<i>P. alba</i>	0132	4.24	7.00	2.07	4.44
<i>P. alba</i>	0138	5.28	4.24	3.43	4.32
<i>P. spp</i>	0108	5.48	5.60	1.79	4.26
<i>P. alba</i>	0037	4.04	4.76	3.98	4.25
<i>P. glandulosa</i> var <i>torreyana</i>	0001	3.24	4.21	5.11	4.19
<i>P. velutina</i>	0025	3.08	3.82	3.46	3.45
<i>P. alba</i>	0134	2.98	4.08	3.28	3.45
<i>P. nigra</i>	0038	3.32	3.70	2.89	3.30
<i>P. velutina</i>	0020	3.94	2.25	2.83	3.00
<i>P. spp</i>	0116	2.15	3.18	3.72	3.00
<i>P. laevigata</i>	0114	2.03	4.07	2.40	2.87
<i>P. nigra</i>	0036	2.99	2.89	1.95	2.64
<i>P. velutina</i>	0032	2.38	4.09	1.44	2.64
<i>P. spp</i>	0028	1.42	2.22	1.39	1.69
<i>P. tamarugo</i>	0042	1.66	1.43	1.88	1.66
<i>P. spp</i>	0074	1.06	1.82	1.24	1.37
<i>P. spp</i>	0080	1.31	1.69	1.03	1.34
<i>P. nigra</i>	0034	0.83	1.36	0.95	1.05
<i>P. ruscifolia</i>	0131	1.01	1.80	0.39	1.05
<i>P. kuntzei</i>	0130	0.23	0.50	0.39	0.37
<i>P. juliflora</i>	0044	0.00	0.00	0.00	0.00
<i>P. pallida</i>	0140	0.00	0.00	0.00	0.00
<i>P. pallida</i>	0041	0.00	0.00	0.00	0.00
<i>P. africana</i>	0045	0.00	0.00	0.00	0.00
<i>P. africana</i>	0040	0.00	0.00	0.00	0.00
Mean		3.40y	4.03x	3.05y	3.49

Values followed by the same letter are not significantly different at 5% level as judged by "Student Newman-Keuls Procedure". The regression equation used for prediction of the dry biomass,  $\log_{10}$  dry matter (Kg) = 2.247  $\log_{10}$  basal stem diameter (cm) - 0.7538, had an  $r^2$  of 0.84 for 1352 observations.

## COLD/FROST SCREENING

A field planting at 1500 m (5,000 ft) elevation in the mountains 60 km from Riverside California was used to screen *Prosopis* accessions for winter hardiness (Felker et al mss.). Thirty accessions were evaluated as single tree replicates in 21 randomized blocks. A freeze on the UCR experiment station prior to this experiment indicated that the Hawaiian *P. pallida*, the West African *P. juliflora*, and the African *P. africana* could tolerate short duration -1.5°C freezes but not a short duration -5°C freeze. Accordingly these selections were not included in the mountain cold screening trial. At the 1500 m elevation site South American *P. alba*, *P. chilensis*, *P. nigra* and the Baja

Mexico *P. articulata* species tolerated a -5° freeze but not a 12 hr freeze that included a -5° freeze. The longest duration freeze was tolerated by the North American species *P. glandulosa* var *glandulosa*, *P. glandulosa* var *torreyana*, and *P. velutina* with only moderate damage. In general biomass production, predicted from regression equations, was greater for cold sensitive South American accessions than slower growing cold-hardy N. American accessions. However, a few cold hardy N. American accessions were fast growers and a few fast growing S. American accessions were cold hardy. Individual trees from these latter categories were dug up for future germ-plasm breeding studies.

Table 2. Energy Costs for Coal, Natural Gas, Oil & Wood

Commodity	Unit Price	Price
		10 <sup>6</sup> Btus
Natural gas	\$3.0 MCF	\$3.00
Crude oil	\$35 BBL	\$6.00
Western Coal	\$25 ton	\$1.48
Mesquite chips*	\$23 dry-ton	\$1.35

\* Plantation grown Mesquite averaged over 9 years (3 harvests).

ETHANOL PRODUCTION FROM MESQUITE PODS

The proximate analysis for mesquite pods shows a range of 11-17 percent crude protein, 20-30 percent fiber, and 13-44 percent sucrose (Felker et al., 1980; Avgerinos and Wang, 1980; Becker and Grosjean, 1980). Fermentation of high sugar content *Prosopis* pods to alcohol for use in the transportation sector is attractive because unlike high moisture content sorghum and sugar cane, the pod sugar is dry and non-perishable and at 44 percent sucrose is considerably higher than most plant sources. Perhaps even more important, unselected mesquite strains presently occur on 30 million hectares of semi-arid marginal land in southwestern United States. This large land resource base is crucial to development of energy or chemical feedstock crops because of the enormous quantities of fuel or chemical feedstocks (10-100 tons/hr) consumed by commercial scale chemical manufacturing or power plants.

A recent workshop sponsored by the Solar Energy Research Institute (SERI) on energy from tree crops contracted with MIT for the fermentation of 2 mesquite pod varieties and one honey locust (*Gleditsia triacanthos*) pod selection. A *P. alba* x *P. velutina* hybrid mesquite tree which produced 73 kg of 40 percent sugar pods identified by Felker et al. (1980) was included in these fermentation trials. According to the MIT analyses the second season hybrid mesquite pods were 43.5 percent sugar. The hybrid mesquite pods had the highest yield and rate of ethanol production of the 3 substrates examined with an ethanol yield of 0.23 g ethanol/g substrate fed, at a rate of 0.44 g ethanol/L - hr (Avgerinos and Wang, 1980). The resulting enriched protein residue can be sold as livestock food with a considerable by-product credit. Another substantial by-product credit can be derived from galactomannan gums which constitute approximately 25 percent of the seed weight and 3 percent of the pod weight, and are similar in chemical composition to high value (\$0.5 kg<sup>-1</sup>) industrial carob and guar gums.

ECONOMICS OF PLANTATION GROWN PROSOPIS BIOMASS PRODUCTION

The recent rapid escalation in fossil fuel prices and associated transportation costs have made the economics of biomass production appear more favorable. Table 2 lists 1980 natural gas prices in south Texas, current world prices for new crude oil, and prices for western coal delivered by rail to a San Antonio Texas utility.

This \$25 per ton price is the subject of current litigation between the railroad and the utility. If the utility loses the litigation, its price for delivered western coal will rise to \$33 per ton. Another south Texas utility, Central Power and Light, pays \$45 per ton for 8,200 Btu/lb western coal that is of the same energy density as mesquite wood (Wiley and Manwiler, 1976). Plantation grown mesquite wood at \$23.00 per dry english ton is the cheapest energy source, the only renewable energy source, and the least likely of all to escalate in price.

Table 3 outlines plantation grown mesquite wood chip production cost estimates. A land lease of \$10 per acre per year is approximately double the return for south Texas cattle ranching (Herbel, 1975). Site preparation costs of \$178 assume the site has moderate brush which must be bulldozed, stacked, burned, and the resulting field disced into a normal seedbed. No credits are assumed

Table 3. Mesquite Wood Chip Production Cost Estimates.

Item	Costs per Harvest per Acre		
	Initial Planting	Stump Resprout	Stump Resprout
Land lease 3 yrs at \$10/yr	\$30	\$30	\$30
Site preparation Bulldozing, discing, etc.	178	--	--
Seedling costs 436 @ \$0.10 each	44	--	--
Planting costs	14	--	--
Herbicides	20	--	--
Fertilizer (P, K, S)	67	67	67
Total Production Cost	\$353	\$97	\$97
Product (7 tons acre <sup>-1</sup> yr <sup>-1</sup> x 3 yr)	21 tons	21	21 tons
Production cost per dry ton	\$16.80	\$ 4.60	\$ 4.60
Harvesting cost per ton	14.00	14.00	14.00
Total Cost per ton	\$30.80	\$18.60	\$18.60
Average cost per ton averaged over 9 years	\$22.70/ton=\$1.33/10 <sup>6</sup> Btu		

for harvesting existing brush for boiler fuel, cordwood, or mesquite lumber which sells for luxury prices of \$4-5 per board foot (Mouat pers. comm.). Seedling costs assume the trees are planted on a 10 ft x 10 ft spacing for 436 trees/acre at a cost of \$0.10 each which is slightly under our current production cost of \$0.12 per seedling. Planting costs assume use of mechanical transplanter capable of planting 1,000 trees per hour with a three man crew. Herbicide costs assume a 1.5 quart application of trifluralin per acre prior to transplant and a 2 lb/acre simazine application 4 months after transplant. Fertilizer costs are calculated to replace nutrients removed in biomass and assume 220 lbs of triple superphosphate, 300 lbs of muriate of potash (60 percent K<sub>2</sub>O), and 50 lbs of granulated sulfur in a single application at transplant. No nitrogen is required since *Prosopis* can fix its own nitrogen (Felker and Clark, 1980). The total production cost for the first 3 year rotation is \$353 per acre. *Prosopis* coppices or resprouts from the stump so that subsequent rotations will avoid site preparation costs, seedling costs, planting costs, and herbicide costs. Total production costs for subsequent coppice rotations are projected to be \$97 per acre.

As discussed earlier, we project a 7 dry ton acre<sup>-1</sup> year<sup>-1</sup> aboveground biomass production for *Prosopis* in south Texas. We have not measured the biomass production of the coppice regrowth but visual estimates of regrowth of Imperial Valley plantings appear larger than from first year seedling production. Due to large carbohydrate root reserves, coppice regrowth is often more productive than initial seedling production.

Harvesting costs assume use of the mesquite combine developed by Dr. Ulich at Texas Tech University. This combine is a modified 130 hp diesel Massey Ferguson tractor which can harvest 4 tons per hour in light stands at a cost of \$14.00 per dry ton (Ulich, 1980). Total harvested costs are \$30.80 for the first rotation and \$18.60 for subsequent rotations or an average of \$22.70 over 9 years (3 rotations). As the number of coppice rotations increases, the average cost per ton would approach \$18.60 per ton (\$1.09 per million Btu's). This crude economic analyses does not include a profit, or return on the investment but it does include a significant return to the landowner in the form of land lease.

Some inexpensive energy sources do not readily lend themselves to deliver the huge quantities of energy currently used in the United States. Figure 1 graphically expresses the size biomass farms required to power commercial sized power plants assuming a 33 percent Btu to Kwh conversion efficiency.

This graph 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 size of biomass farm

required for electrical generation. At our projected yield of 7 dry tons acre<sup>-1</sup> year<sup>-1</sup> a circle of radius of 1.38, 4.35, 6.15, and 13.75 miles would be required for 5, 50, 100 and 500 MW power plants respectively. A 50 MW plant provides enough electricity for approximately 50,000 people.

The land/water resource base in south Texas has sufficiently high rainfall (20-27" annually) and land area (55 million acres in Texas are currently occupied by mesquite) to appear feasible to support biomass plantations large enough for commercial size electrical generating facilities.

Land/water resources in California are more limited but use of saline irrigation drainage water in San Joaquin and Imperial Valleys, and use of shallow (1-4 ft) saline groundwater in San Joaquin Valley might support commercial sized electrical generating facilities.

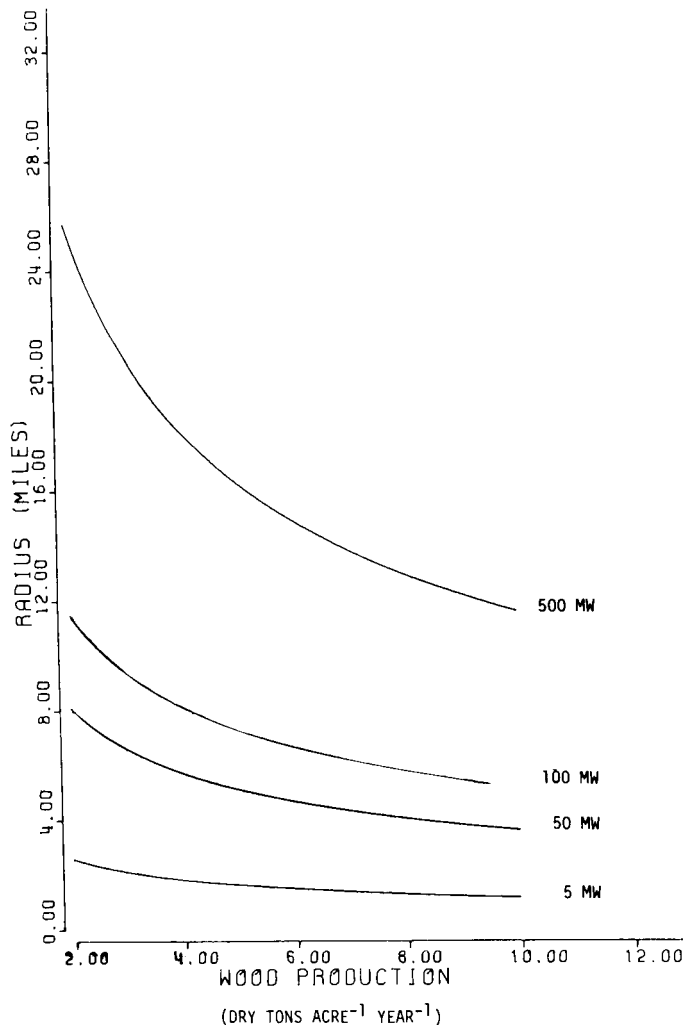


Figure 1- BIOMASS FARM RADIUS AND PRODUCTION LEVELS  
REQUIRED FOR ELECTRICAL GENERATION  
AT 33%  $\frac{\text{KWH}}{\text{BTU}}$  CONVERSION EFFICIENCY

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