ORNL/TM-11791

ornl

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

Biomass Energy Development in Yunnan Province, China

Preliminary Evaluation

R. D. Perlack
J. W. Ranney
M. Russell

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-11791

BIOMASS ENERGY DEVELOPMENT IN YUNNAN PROVINCE, CHINA PRELIMINARY EVALUATION

R. D. Perlack
J. W. Ranney*
M. Russell

Energy Division

---

* Environmental Sciences Division, ORNL

Prepared for the
Committee on Renewable Energy Commerce and Trade
and the
Biofuels Systems Division
U.S. Department of Energy

DATE PUBLISHED: June 1991

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract No. DE-AC05-84OR21400

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

BIOMASS ENERGY DEVELOPMENT IN YUNNAN PROVINCE, CHINA PRELIMINARY EVALUATION

ABSTRACT

A preliminary feasibility study of generating electricity from energy plantations in Central Yunnan Province identified sites with a biomass resource potential of 24,000 to 45,000 dry Mg per year within an effective transportation range. Average annual productivity rates of about 8 dry Mg per hectare are feasible. This level of feedstock production would be sufficient to fuel a 20 MW conversion plant operating with a margin of safety sufficient to cover all but catastrophic failures. Cost of electricity generation was estimated to be about 0.24 yuan/kwh ($0.05/kWh), which may be competitive with alternative generation sources. The ancillary economic development benefits are substantial because of the shortages of electricity so the value of electricity exceeds its cost of production. Environmental effects are positive. Neither of these benefits are included in this preliminary analysis. In assessing the biomass resource potential, it was concluded that further research (tree crop improvement, site-species trials, and soil stabilization methods) is necessary before large scale deployment to avoid major cost and supply risks and to improve long-run results. This research will require another 5 to 7 years of effort. Nonetheless, a demonstration project to prove the concept and to gain information required for scale-up appears sufficiently promising to warrant immediate follow-up and a second stage detailed investigation. A reasonable target would be an operating facility in 7 years. The commitment of support (labor and land) and leadership at all levels to this project by the Chinese is overwhelming, exceeding all pre-site visit expectations. A limited amount of technical assistance would be helpful in augmenting an already sophisticated and dedicated forestry technical base. It appears that external expertise will be required in biomass electricity conversion processes and that much of the most appropriate conversion technology is available only from the U.S. A relatively minor investment in further investigation at this time could open a potentially large market for U.S. technology, the deployment of which would have substantial local and global environmental benefits as well as improve economic conditions.

1. INTRODUCTION

The purpose of this site visit was to evaluate the potential of an integrated biomass energy system, including the growing and handling of biomass feedstocks and conversion to electricity, that would be beneficial to China's energy development and environmental needs. ORNL also wished to determine whether U.S. technologies could be technically, economically, and institutionally adapted and deployed in rural Yunnan Province. If successful, this project could lead to more widespread dissemination of these technologies in other areas of China and in other developing countries. In turn, this project would encourage energy use and production patterns that would lessen the severity of global climate change. Yunnan Province was selected as a place in which to investigate the advantages of growing and using biomass crops to generate electricity because it has a wide range of climatic, environmental, and socioeconomic conditions as well as available technical expertise.

The results of this report are based on a site visit to Beijing and Yunnan Province during the latter half of September 1990. The first four days of the visit were spent in Beijing where high level meetings were held with governmental Ministries (Agriculture, Energy, Forestry) and agencies (Environmental Protection Agency, Energy Research Institute of the State Planning Council). Eight days were then spent in Kunming and rural Central Yunnan Province to gather data on the energy sector, to assess potential sites for the production of biomass, and to evaluate the capabilities of local institutions.

The site visit had four specific objectives: evaluate the organizational leadership and commitment at the national, provincial, prefecture, and county levels; assess the economic and energy sector conditions; evaluate the resource and technology conditions to produce biomass economically for electricity generation; and assess the general technical expertise locally available for biomass-fired electricity generation. The short duration of the site visit required a pragmatic and quick approach. "Show stopper" questions were structured to determine if the assessment as a whole would be negative. These questions were a) unwillingness of the Chinese to pay their share of costs, b) no Chinese agency able or willing to lead, c) lack of biological resources, d) lack of sufficient technical and intellectual resources, e) lack of income generating activities and a market for power, f) insufficient data for conducting an assessment, and g) insufficient labor. The assessment team found no obvious negative answers to these questions.

The next section of this report provides project background information and is followed by a section that briefly describes the economic setting and energy sector in Yunnan Province. The fourth section of this report discusses various aspects of biomass energy production (sites, existing resources, plantation practices, land, biomass productivity potential). The evaluation of the costs of biomass production and its conversion to electricity then follows. The final section of this report outlines findings and recommendations.

2. PROJECT BACKGROUND

Yunnan is in the Southwest region of China bordering Myanmar (Burma), Laos, and Viet Nam. Yunnan is variable in climate, topography (100 to over 6700 m in elevation), and soils. In the more inaccessible parts of the Province there are large forest areas of low quality. However, in the populated areas forests have been extensively cleared for agriculture, grazing, excessive harvesting, and failed large-scale industrial movements, such as during the Great Leap Forward of the 1950s. Environmental degradation in the form of soil erosion and siltation, with its concomitant impacts on agricultural productivity, is a major problem and concern in Yunnan.

Like most areas in China, Yunnan is suffering from a critical shortage of energy.[1] Rural energy problems in Yunnan have resulted in pervasive environmental degradation from biomass fuel collection. In the household sector, the labor and effort required in the collection of fuelwood has prompted many of the rural poor to use inferior fuels (e.g., crop residues) and to cut back on basic energy needs. The unavailability and unreliability of electric power during the dry season has idled industrial production and has constrained the development of new rural industry. For these commercial energy users, there are shortages and no economically viable substitutes. Coal is in limited supply in Yunnan, and, if available, is expensive because it must be transported over severely constrained roads. There is considerable hydroelectric potential in Yunnan, but low-head projects have highly seasonal output (monsoon conditions) and there is competition for water between energy production and irrigation. The prospects for developing large hydro projects with dry season water storage are poor at the Provincial level for a number of economic and institutional reasons.

The recent concern about global warming has raised awareness that biomass crops can reduce the rate of increase in carbon releases by sequestering carbon and by substituting for fossil fuels

[1]Markets for energy moving through commercial channels, such as electricity, do not clear; that is, the supply is allocated partly by price and partly by simple unavailability. Therefore, the true loss to the economy from inadequate supply is greater that the observed loss measured on the basis of price.

(primarily coal). When grown renewably, biomass fuels create little, if any, buildup of atmospheric carbon as the carbon released during combustion is extracted from the atmosphere during photosynthesis. Biomass fuel production can also help to offset deforestation and thereby reduce soil erosion and its concomitant impacts.

In sum, biomass production can be both environmentally and economically attractive for lands considered marginal for annual cultivation. Biomass is an indigenous energy supply, particularly well suited to small-scale and decentralized energy applications, and represents an alternative to coal. The demand for biomass energy to supplement existing household fuel supplies and as a feedstock for electricity generation can serve to stimulate its production as an alternative cash crop. Biomass used for energy, when matched with appropriate technologies, can reduce environmental degradation, increase the sustainability of agriculture, and stimulate local township industries.

3. ECONOMIC SETTING AND THE ENERGY SECTOR

The three Yunnan counties (Yuanmou, Maoding, and Yaoan) visited are primarily dependent on agriculture. In each county agriculture employs about 90% of the workforce. The main cash crop is tobacco, accounting for about 70% of income in each county (per capita income is about 400 yuan per year or less than $100). Other important crops are rice, corn, sugar cane, vegetables, and fruits. There are also some small rice mills and paper mills in each county. In addition, local officials believe that there is considerable potential to develop Central Yunnan's mineral resources, such as iron, copper, and clay.

In this area of Yunnan Province there is a serious lack of electricity, especially during the latter months of the dry season (March and April). The electric lines are energized during some seasons only a few hours per day -- primarily early evening. The unavailability of power is constraining the further development of local agricultural processing and mineral industries. Current annual electricity consumption in Maoding and Yaoan Counties is about 12.6 million kWh and 9.3 million kWh, respectively. Local officials estimate that they will need over three times more power by the year 2000 if their plans for the development of agricultural processing and small township industries are to be achieved. Both counties rely on electricity allocations from the regional grid. Electricity tariffs are currently set at 0.08 yuan/kWh ($0.017/kWh) for rural households and irrigation and 0.16 to 0.18 yuan/kWh ($0.034 to $0.038/kWh) for township industries; electricity is heavily subsidized throughout China.[2]

Other than a small hydro project (350 kW) under construction in Yaoan, there is virtually no potential for hydropower in these counties. There are no local coal resources to exploit and coal brought in from the outside is expensive, because of high transport costs, when it is available at all.

---

[2]At the time of this assessment the exchange rate was 4.71 yuan to one U.S. dollar.

Byproduct biomass wastes generated at rice and sugar mills are already being exploited and field wastes are used for compost and household needs (cooking).

The economic and amenity benefits from access to more power are large and obvious, and they would flow mostly to local citizens because of the institutional structure in place. There are strong incentives to develop local power generation. Most decisions regarding the allocation and distribution of power from the regional grid are made at the local level. Further, power from a small local generating facility would be controlled, distributed, and used locally for whatever purposes county officials saw fit. In addition, the regulations are that any locally produced power can be sold to the Provincial grid and that, in turn, the locality has a right to receive an equal amount of power from the grid -- presumably on demand. Thus, local supply need not be meshed in time to local demand, providing valuable flexibility in both production and consumption decisions.

4. BIOMASS ENERGY PRODUCTION

4.1 DESCRIPTION OF BIOMASS PRODUCTION SITES

The potential project sites fall within the three county (Yuanmou, Maoding, and Yaoan) Upper Yangtze Treatment Project, Chuxiong Prefecture, West-Central Yunnan Province in Southwest China. Soil stabilization through reforestation is a high priority in this area. Nearly 70,000 hectares have been planted in trees with current plans calling for an additional 50,000 hectares to be planted over the next five years. The long-range goal of the Prefecture is to reestablish the natural ecological status of the region by increasing forest cover to 35% of the land area by the year 2000. Average success rates of tree plantings appear to be about 60% (40% mortality) primarily using one species (Eucalyptus globulus) on mountain slopes to about 2000m elevation.[3] In this area, it is common to observe plantations established on 20 to 30% slopes.

Terrain in Chuxiong Prefecture is hilly to mountainous with elevations running generally from 1400m to over 3000m. Soils of steeper rounded hilltops over 2400m are often comprised of stony, excessively drained, highly leached soils. Soils of more gently sloped hilltops and sideslopes are comprised of deeply weathered red clays interspersed with poorer, sandier, highly erodible soils. Rainfall varies from 700mm in Maoding County to over 900mm in Yaoan County. Only 500mm of rainfall may occur during occasional dry years. Moisture availability and tree productivity are more favorable than precipitation and latitude would indicate due to the moderating effects of high altitudes. A distinct 6-month dry season occurs from November to April. Climate at these locations is subtropical but moderated again by the coolness of the high elevations. The region is in a middle elevation tension zone between tropical and temperate ecosystems as well as between forest and grassland systems.

---

[3]This 60% establishment success rate was inferred from inspection of numerous planting sites in Chuxiong Prefecture.

Severe site and climate limitations on biomass productivity would significantly confine areas appropriate for short-rotation plantation management in spite of large available land areas. Annual productivity of E. globulus varied between 4 and 15 dry Mg per hectare, where plantations were considered successfully established. All of these plantings were below 2000m elevation or on relatively level agricultural soils. Although long rotation pine (Pinus yunnanensis) plantations show promise on some sites above 2000m, no operational short-rotation plantations demonstrated success in productivity above this elevation.

A recently completed inventory of site quality in the Chuxiong Prefecture indicated that 2.7% was considered "good," 10.6% was "medium," 54.3% was "poor," and 32.4% was "very poor" for plantations. Average productivities should not be expected to surpass 8 dry Mg per hectare per year. Even with these limitations, significant areas appear available and suitable to supply a biomass-fired electric generating facility. However, risks of plantation failure remain significant as a result of inadequate tree screening research and because of the severe site limitations.

4.2 EXISTING RESOURCE SUPPLIES

The current availability of biomass for central electricity generating facilities is negligible. Existing forests, more correctly described as shrubland, are significantly over-harvested for firewood, timber, fodder, herbal medicinal products, and other forest products. Between 1950 and 1989, Chuxiong Prefecture went from 36% forest cover to 24%. In Yaoan County alone, 151,000 cubic meters of wood is harvested annually, which is 50,000 cubic meters above forest growth. Individual private woodlots are now being encouraged for firewood and timber production. Generally bark and leaves from these woodlots are the property of the individual with the timber bought by the government at about 0.33 yuan/kg ($0.07/kg). Abundant rice straw and corn fodder are utilized completely in composting with manure for organic fertilizers, for other home and farm uses, and for paper production. Biomass demand for paper production is not large -- paper mills produce about 1000 Mg each year.

Plantation planting is occurring at a rate of about 3,000 hectares per year per county (10 counties in the Chuxiong Prefecture). About 60% of these plantations are successful by U.S. standards. Very few plantations over 5 years old were observed, because it was only in the last (7th) five year plan, or 1984 - 1989 that these plantings were initiated. The Prefecture forest cover is scheduled to increase by 10% as a result of plantation planting. Objectives are to thin and/or harvest some of these stands and permit them to resprout into second rotation plantations completing a single rotation in about 10 years. Most of this wood is designated for classical uses not including electricity generation. In the three project counties (Yaoan, Maoding, and Yuanmou) there are no underutilized biomass resources that could be used for electricity generation. The recent tree plantings offer some limited alternative wood supplies within the next 5 years. However, sufficient information was not available to determine the extent of this resource.

Another alternative, apparently not considered in past 5 year plans, is the development of herbaceous energy crops above 2000m elevation. Although annual productivity would likely be in the 4 to 6 dry Mg per hectare range, substantial land could be placed into active production while maintaining excellent erosion control. Such a source of biomass at these elevations could add perhaps 50% more biomass to annual supplies. The constraint, however, is that annual harvesting is required and that there are higher losses to storage. Also, the compatibility of herbaceous material with wood as an energy feedstock is not well tested.

4.3 BIOMASS PLANTATION PRACTICES

Plantation establishment is planned by the county Forestry Bureau under the direction of the Prefecture Bureau which supplies expertise and some resources. Areas, species, number of seedlings, schedules, materials, labor, establishment techniques, and financial requirements are determined for each district. The districts work with township forestry staff and in turn with village leaders to implement plans. All propagation, planting, tending, and harvesting is based on hand labor at extremely low cost. The low cost of establishment enables use of slopes up to 30% and terracing of tree rows.

The Chinese nursery systems are well prepared for large operational planting with a 6 to 9 month start-up period. Plants are propagated either by farmers (about 10,000 to 30,000 plantlets each) or at state-run propagation facilities (hundreds of thousands to millions of plantlets). Seedlings costs are approximately 0.10 yuan/seedling. The local farm system used for producing seedlings is of concern since seedling quality and appropriate numbers of given species is hard to control. There is also concern about the small size of trees planted -- 30cm height and 3 months old. (For successful hardwood plantations, plantlet height should be 50 to 70cm.) Survival is generally about 60 to 80% the first year. Those plantlets surviving the first year have an 85 to 90% chance of surviving to harvest age. Successful plantations should have a survival of 80% or better for all seedlings planted under U.S. factor cost conditions. These constraints are relaxed in China because manual labor and seedlings are cheap and seedling mortality replacement is easily done, but evenness of height growth requires early establishment success. Further technical exchange is believed to be required on these points.

For seedling establishment, holes 30cm square and 80cm deep are dug by hand for each seedling. Compost is dropped into the pit of each hole at a rate of about 7.5 Mg per hectare. Some weed control is practiced the first year. Harvesting by hand and hauling to roadside restricts maximum tree size to 10 to 14 cm diameter at 1.5m height. This dictates 4 to 10 year rotations on a 1x1 m^2 or 1x2 m^2 spacing, with perhaps one thinning anticipated in the longer rotations.

The use of Eucalyptus requires nutrient amendments. Options are compost, which is limited in supply, and commercial fertilizers that are available locally as 25-15-15, urea nitrogen, or phosphate. Investigations of interplanting with nitrogen fixing Acacia in a 2:1 mix favoring Eucalyptus are looking extremely promising.

Only recently have alternative tree species received any attention. These include Acacia and Eucalyptus species, all essentially in first rotations and some under mixed planting tests. Serious seed source studies of E. globulus were initiated this past July in a joint venture with Australia. Performance and production trials are extremely limited and quite insufficient as a base for such wide plantation plantings as are already underway. The arboretum at the Yunnan Forest Sciences Institute contains many hundreds of species, including over 30 Eucalyptus species. These plantings are comprised of 2 to 6 individual trees, some now reaching 10 years of age, arranged in wide spacings. However, references to successes at the arboretum should not serve to surplant or replace the need for operational tests in potential planting areas -- site differences can yield dramatically different results. The Chinese have obviously judged, however, that the risks from moving ahead without further tests are acceptable under the circumstances because the need for wood, the potential benefits from erosion control, and other aspects of getting some cover on the land are so high as to offset the risks. Even so, such tests should continue and be expanded in order to support future plantings. At present, only three or four locations of 2 to 10 ha each form the research base from which all plantations are being established. Herbaceous species trials exist only at mine spoil reclamation projects.

An assured biomass supply for an array of conversion facilities in different locations will require careful consideration of a wide variety of species, some tolerant of infrequent frosts, some tolerant to drought, others matched to particular soil types, and all resistant to (or tolerant of) major diseases. Although a claim was made that 20 species are being screened in block tests, there is evidence of only 5 receiving significant attention. Potential species are Pinus yunnanensis on which considerable study has been conducted for long rotation silviculture, some southern pines, Keterleeria evelyniana, Pinus armandi, Eucalyptus camaldulensis, E. robusta, E. maidenei, Acacia dealbata, A. mearnsis, Robinia pseudoacacia, Alnus nepalensis, Populus yunnanensis, Populus hybrids, Sesbania spp. and Acer species. A vast resource of 1500 native woody species remains essentially unscreened for plantation success. A few of the native species show promise at the Yunnan Forest Sciences Institute in Kunming, but on-site field trials are needed. It is recommended that such screening begin at once, and be added to ongoing exotic species trials. The staff in Yunnan need added support and perhaps additional expertise to go along with their own knowledge of native plants to achieve correct, accurate and timely screening of native species.

It appears that screening trees for pest/disease resistance or tolerance has been totally neglected in Yunnan Province. Diseases of Phomes and Septoria have caused problems while leaf miners, aphids, and leaf defoliators are ever-present. No plants of Pinus yunnanensis or Populus nepalensis were observed to be free of disease damage. Eucalyptus were generally visually free of disease. The oversight of these risks is of significant concern in tree improvement and species diversity and is a major point in assigning a "maybe" to the adequacy of biomass resources. Since no biomass is available from other sources, investment in a conversion facility requires that future risks be reduced through research to reduce biological and climate related hazards.

4.4 ESTIMATES OF AVAILABLE LAND AND BIOMASS PRODUCTIVITY

Approximately 20% of the land area in Yaoan, Maoding, and Yuanmou Counties designated by officials as available for plantation planting in support of an electricity project falls at appropriate elevations for successful levels of productivity. Of this 20%, about 30 to 40% is too steep and of too poor a soil. These restrictions leave approximately 14% of the designated area suitable for plantations. From this estimate, 20% is deducted to allow for expansion of alternative uses such as agriculture and firewood production. These reductions leave about 11% of the designated available area for plantation production under the constraint that the land yield an average 8 dry Mg per hectare per year. These estimates and the constraints on which they are based were discussed with the Chinese, who thought this approach too conservative.[4] In Yaoan County, about 8000 hectares could be planted for energy in 10 to 200 hectare blocks less than 1 km from existing 4-wheel drive roads. It is estimated that some new, low grade roads will be needed to permit access.[5] It appears that with a central generation location, average hauling distances of about 5 km on rough roads and 25 km on improved roads will be required for access to those 8000 hectares. In drier Maoding County, 20,000 hectares in one township and 26,000 hectares in another township yield a net usable 5000 to 6000 hectares (total) of viable energy plantation land having similar access and delivery parameters. Use of herbaceous plants could expand usable areas.

Experimental plots in Yaoan, Maoding, and other counties suggests that the "good" land would support 12 to 16 dry Mg per hectare annual productivity and "medium" land would probably support 6 to 12 Mg per hectare per year. The "poor" land is comprised primarily of red soils indicating poorer productivity potential. The lack of plantation success on other sites suggests that "poor" land may produce 2 to 6 dry Mg per hectare annually and the "very poor" less than 2 Mg per hectare. These figures represent the most that can be expected from these sites after the best species and optimum silviculture conditions have been identified. Irrigation, mulching, and heavy fertilization could increase these estimates but the expense of doing so make such efforts unlikely. The six month dry season (November through April) is also a major growth-limiting factor. Given elevation

---

[4]The basis for these judgements are that alternative or multiple land use possibilities impinging on plantation development are significant at lower elevations where site quality is best (up to 1900m). These include fruit orchards, tobacco as the mainstay cash crop, corn, Eucalyptus leaf harvest for oils, and firewood. Rural population increases will likely place heavy pressure on these sites over the next decade. Between 10% and 25% of land lying below 2000m elevation should be excluded from the calculated land resource for energy crops and that includes "good" sites, and much of the area designated "medium." Appropriate energy plantation land is effectively restricted to a narrow elevation band (1900m to 2150m) comprised of mostly medium to poor sites. Use of herbaceous crops above 2000m should be seriously considered in soil stabilization and in expanding biomass supplies.

[5]A poor access system now exists, and erosion from these roads is significant. The lowest class roads cost 20,000 yuan/km to construct. Biomass transport costs are 0.35 yuan/tonne-km, but could be lower with properly designed roads.

constraints and encroachment onto good land from agriculture, plantation land generally will occupy medium to poor land at a 3:2 ratio respectively. Average annual productivity should be about 7 to 8 dry Mg per hectare.

4.5 WOOD SUPPLY ESTIMATES

The available plantation area is estimated at 5000 to 8000 hectares in each county. If biomass productivity is assumed to average 7 to 8 dry Mg per hectare per year, then 35,000 to 64,000 dry Mg could be available for biomass conversion in each location. Losses in handling and transport could reduce these estimates by about 10%. Most of the wood supply would have to be harvested in the dry season to enable successful stump resprouting. Fortunately, this is the same time the electricity produced would have the greatest value as an offset to reduced hydroelectric output.[6] Storage losses of 3% per month and the requirement of maintaining a 30 day wood supply on site should yield less than a 10% loss of wood due to storage. If the smaller limbs are left on-site for conservation reasons, yields per hectare will be about 15% less. These losses leave a net 24,000 to 45,000 dry Mg per county per year of combustible wood for electricity generation. This range of supply can support a 20 MW facility operating with a 50% capacity factor. Conditions favor Yaoan County slightly over Maoding County if one county is to be selected. These supply numbers are believed conservative because stringent requirements were placed on suitable land, which might not be appropriate given the actual cost conditions in China which could justify a greater labor-to-output ratio than the one hypothesized. Also, the total land base may be somewhat larger than the figures stated, especially if herbaceous energy crops are considered.

---

[6]It appears that given current and prospective economic and regulatory conditions there is a shortage of base-load power in Yunnan, superimposed on which are demand peaks and supply shortfalls due to the monsoon-dominated hydroelectric supply. This means that any facility will be limited as to hours of output only by fuel supply and by maintenance requirements -- unless costs are above other base-load facilities. The likely demand/cost pattern in this case would call for virtual full-time operation in the dry season, and part-time operation in the wet season except for planned outages -- in the absence of fuel supply constraints.

Required start-up time to achieve this level of production is 5 to 7 years from the time of decision. This time frame is predicated on using existing Chinese and American knowledge about trees and cultivation practices, which means accepting some risks as to biomass supply and probably some extra costs of production in the interest of gaining earlier proof-of-concept and demonstration information.[7] (Research and start-up for herbaceous production could be completed in 5 years.) Plantlet development for planting stock can be accomplished relatively easily over a 9 to 12 month period. Adequate seed or propagation stock of improved material appears to be available. Labor, roads, other material, and organization appear to be available at either location to support this schedule. Consistent with potential future large scale deployment, systematic research on improved seed supplies, species screening, and handling methods should be implemented simultaneously.

[7]This trade-off seems reasonable given the large potential gain in earlier expansion of the biomass electricity programs, with concomitant benefits, and the fact that each year's delay reduces long term potential because plantings are being made of species and in cultivation patterns that may not be appropriate to what turns out to be the optimal way to use the land. This does not suggest that current information is adequate for large scale development. Effort is required in species screening and tree improvement research, experimentation with improved erosion prevention measures using herbaceous materials, installation and monitoring of cultural and species trials on a wider variety of sites, and the deployment of seed orchards or propagation beds of improved plant materials.

5. ECONOMICS OF BIOMASS ENERGY SUPPLY AND CONVERSION

5.1 BIOMASS ENERGY SUPPLY

Land that would be available for the project is, for the most part, collective land. (Land that is managed by individual farmers would not be used). Since this land would be made available to the project by the Prefecture governor and county magistrates, it would not have any direct financial cost. However, there may be a small economic opportunity cost for this land for use in grazing and in gathering of grasses and twigs for meeting household fuel needs.

Specific plantation establishment procedures were discussed with local forestry experts during the site visit. These procedures are very labor intensive and consist of the following sequence of operations. First, the land is cleared of scrub vegetation and then terraces are constructed. Second, on each terrace a pit is dug for each seedling, fertilizer (usually a compost of straw, residues and animal wastes) is added to the pit, and the seedling planted. Finally, weeds are controlled around each seedling until a canopy forms (usually within the first year of growth). No other cultural management operations are performed. If mortality is high there may also be some seedling replacement. Plantation establishment activities would take place during the early part of the dry season (November through January).

There has been no harvesting of any of the stands that have been established in the Prefecture, so direct experience of labor demands and costs is lacking. All harvest operations are assumed to be manual. Specific operations would include felling, trimming branches, cutting to a convenient handling length, forwarding to a loading area, and stacking. A 4 to 10 year old tree having a breast-high diameter of 10 to 14 cm was judged to be optimal for whole-tree manual harvest operations. For reasons of nutrient recycling and difficulty in handling small pieces, only the main trunk and larger limbs would be removed from the site for electricity production. (The smaller branches left on-site could be removed and used for firewood; eucalyptus leaves could be used for oil production.) It was estimated that average annual growth would be about 8 dry Mg per hectare. A 5 year harvest age would therefore yield about 40 dry Mg per hectare minus the smaller limbs and branches and losses due to handling and storage. These offsets leave about 30 dry Mg per hectare for electricity production. An average spacing of 1x2 m^2 would imply a planting density of 5000 trees per hectare.

Knowledge of the specific site conditions (forwarding distances to roads, slopes, etc.) would be necessary to determine the labor requirements for harvesting. However, based on discussions with local foresters, an average one hectare site was assumed to require 75 workdays to fell, trim, cut, carry, and stack at the roadside. It was further assumed that harvesting and transport of the biomass to the conversion site would take place (mostly) during the dry season when road conditions are at their best. To ensure that moisture is kept to minimum (and haulage costs reduced), the freshly cut trees would be air-dried in the field a week or two before they are transported to the conversion facility where covered storage would be made available.[8]

The estimated labor requirements for establishing and harvesting a woody biomass plantation and the factor input costs for wages and materials are summarized in Table 1. The most labor intensive establishment operations are the clearing and terracing/pitting, which only has to be done once over the life of the plantation. These combined operations are estimated to take nearly 300 workdays per hectare. The establishment of trees on relatively flat terrain would greatly reduce costs, but it is unlikely that this type of land would be available to the project. However, the high labor requirements are not deemed a constraint to the development of a biomass energy plantation as there is a plentiful supply of excess labor, especially during the dry season when most plantation operations would take place.

[8]The preliminary nature of this assessment precluded addressing biomass fuel standards and their effect on the conversion process.

It was assumed that the trees would be grown over a 5 year rotation and that 2 coppice harvests could be made after the initial cutting, with an average annual productivity of 6 dry Mg per

Table 1. Factor input assumptions for biomass energy plantations.

Plantation establishment and harvesting	
Clearing	40 days/ha
Terracing/pitting	200 days/ha
Planting	50 days/ha
Weed control	10 days/ha
Seedlings	0.10 yuan/seedling
Fertilizer	400 yuan/ha
Harvesting	0.4 Mg/day
Wage rate	
Financial	2-3 yuan/day
Economic (25% idle/yr)	1.5-2.25 yuan/day
Land rental	
Financial	0 yuan/ha
Economic	15 yuan/ha
Discount rate	10%
Plantation access roads	
Kilometers of roads	50 km
Construction cost	20,000 yuan/km
Transport	
Rate	0.35 yuan/Mg-km
Kilometers	30 km
Plantation design	
Rotation age	5 years
Planting density	5000 trees/ha
Coppicing	2 coppice harvests
Tree life	15 years

Source: Data are from site visit interviews and local published reports.

hectare (after accounting for all losses).[9] Using these base assumptions, the total costs of biomass feedstocks are estimated at approximately 45 yuan/dry Mg($9.60/dry Mg) at the plantation loading site. As with all biomass plantations, production costs are sensitive to estimates of biomass productivity. For example, halving the assumed productivity would increase costs by over 40 yuan/dry

[9]A sensitivity analysis was performed to determine an "optimal" rotation age. In general, total production costs are not very sensitive to the rotation age between 4 and 8 years. The criterion for selection of a rotation age should be more of a function of desired tree size for harvesting and handling.

Mg. In this particular case, production costs are also sensitive to the wage rate because of the high labor intensity of plantation establishment. The elimination of terracing could substantially lower production costs, but would give up the benefits from erosion control, benefits that are not included in returns to the project, however. The least sensitive input assumption is the daily harvest rate. Finally, these costs do not include expenses for major infrastructure development such as roads or fencing. Production costs would be somewhat higher if actual sites required the construction of forest access roads.

To estimate the economic (as opposed to financial) costs of biomass energy production some changes in input assumptions were made to reflect real societal costs. The wage rate was reduced by 25% to reflect unemployment during the dry season and an annual land rental rate (15 yuan/ha) was added to account for the opportunity cost of using the land for biomass production (foregone grazing and firewood collection). It was found that the effect of these changes cancel out, leaving the direct economic cost of production at about the same level as the financial cost of feedstocks to the project.

No attempt was made to assess the contribution of the stabilized slopes to agricultural production and reduced erosion and siltation because of the very preliminary nature of this evaluation. The Chinese judge these benefits to be very significant. Indeed, they have established as a national goal the complete reforestation of feasible areas in the Yangtze River Basin, of which the subject counties form a part. In one sense, then, the only costs that should be ascribed to the electricity project are the incremental costs of establishing biomass plantations as compared with the forests that would be created for other purposes, and the opportunity cost of forest products. In addition to these local and national externalities, any replacement of fossil fuel-based generation by a biomass source would lessen the global build-up of CO_2, the benefits of which are not calculated as economic offsets to costs either. Quantifying these external effects would certainly serve to lower the social and economic costs of feedstock production.

5.2 BIOMASS ENERGY CONVERSION

The production of electricity using biomass fuels is a relatively mature technology with many manufacturers offering pre-packaged systems.[10] These conventional systems involve the combustion of biomass in a boiler to generate steam, which is then used to drive a turbine and generator to produce electricity. The efficiency of these systems are however low with heat rates of perhaps 14.5 MJ/kWh. Higher efficiencies can be attained with conventional steam cycles, but the inherent logistical problems in moving and handling biomass tend to restrict units to scales well under 100 MW. At such scales higher efficiency equipment would be prohibitively expensive.

A technology that may have considerable potential in rural Yunnan is the biomass steam-injected gas turbine. Relative to conventional steam cycles, gas turbines have higher efficiencies and lower installed costs. This technology has been successfully used when fired with natural gas. Currently, the technology is being adapted in conjunction with gasifiers to use solid fuels, primarily coal. The results of recent research has demonstrated that the steam-injected gas turbine is compatible with coal gasification. The commercialization of biomass-fired systems will require modification of the gas cleaning equipment, but this modification should be relatively straightforward. Commercialized biomass-fired systems could be available in about 5 years; perhaps less if markets are assured. As noted earlier, the time required to produce biomass energy feedstocks will take 5 to 7 years, and thus this time frame would be consistent with the development of the gas turbine technology.

---

[10]There are several U.S. companies (e.g., Babcock and Wilcox, Foster Wheeler, Combustion Engineering, Zurn, and others) that offer direct combustion equipment in the under 25 MW range.

A decision on proceeding to the conversion phase of the project and selection of a specific technology need not be made before the viability of plantations is assured. For the purposes of this preliminary evaluation, a conventional steam turbine and a prototype biomass steam-injected gas turbine technology are compared. To determine the range of likely busbar electricity costs, key system parameters (e.g., installed costs and capacity factors) are parametrically varied. The basic assumptions for biomass-fired steam and gas turbine technologies are summarized in Table 2.

Given the preliminary estimate for the amount of suitable land available for biomass production, a plant size of 20 MW was chosen. The amount of biomass available for conversion should be sufficient to fuel this plant taking into consideration potential feedstock losses due to transport and storage. The installed capital costs are estimated at 8000 yuan/kW for the steam plant and 5850 yuan/kW for the gas turbine, with annual fixed maintenance of 120 yuan/kW. Variable maintenance for each plant is 0.01 yuan/kWh, with labor requirements slightly higher for the gas

Table 2. Basic assumptions for biomass-fired conversion technologies.

	Steam-turbines	Gas-turbines
Technical and financial parameters		
Overall efficiency	25%	35%
Capacity	20 MW	20 MW
Biomass consumption (Mg/hr)	19.0	12.7
Discount rate	10%	10%
Equipment life	20 yrs	20 yrs
Installed and annual operation and maintenance costs		
Capital (yuan/kW)	8000	5850
Fixed maintenance (yuan/kW)	120	120
Labor (yuan/yr)	4000	6000
Variable maintenance (yuan/kWh)	0.010	0.010

Notes: Technical parameters and costs are derived in part from Larson and Williams, *Biologue*, November 1989. Capital costs are a function of capacity -- 19,660 yuan $(MW)^{-.3}$ for steam turbines and 11,310 yuan $(MW)^{-.22}$ for gas turbines.

turbine. These estimates are very preliminary and are based on U.S. conditions. They may not adequately account for actual delivered costs in China, foreign exchange costs, the effects of local labor rates on the cost of installation, or any tariffs that may be required for imported generation technology. Capital costs for the conversion plant could be lower if local labor were used and some components of the technology were manufactured locally.[11] Costs of conventional technology could be substantially reduced if remanufactured equipment were used.

5.3 COSTS OF BIOMASS-FIRED ELECTRICITY GENERATION

The distinct wet-dry season climate of Yunnan suggests that a conversion plant would operate near full capacity during the dry season and be brought down for a two to three month period during the peak rainy season. The plant should be capable of operating at a 50% annual capacity factor, or higher if operation is extended into the wet season. It is impossible to determine the extent of plantation access roads that would be required without the identification of specific plantation sites and the conversion plant location, but for current purposes it is assumed that 50 kilometers of plantation access roads would be constructed. It is further assumed that biomass feedstocks would be transported an average distance of 30 kilometers to the conversion facility. To account for losses due to storage it is assumed that 10% of the delivered supply would be lost.

The estimated costs of biomass supply (production, transport, and storage), annual capital charges, and operation and maintenance are summarized in Table 3 for the steam turbine and the gas turbine conversion plants. In total, generation costs are estimated at 0.24 yuan/kWh and 0.31 yuan/kWh for the gas turbine and steam turbine technologies, respectively. As shown in Table 3, annual capital charges for each conversion plant account for about 70% of total electricity costs for

---

[11]China has considerable experience in manufacturing, operating, and maintaining high-pressure steam turbine technology. The Chinese have manufacturing plants and are now cooperating with private U.S. firms to produce turbines. With regards to biomass-fired steam-injected gas turbines, the Chinese now have cooperative relationships with at least two private companies to manufacture coal gasifiers. The potential to lower capital costs may well exist in China.

each plant size. Biomass supply costs are about 50% higher with the steam plant due to its lower overall thermal efficiency. However, biomass production, transport, and storage costs are less than 20% of total electricity costs. In this example, no benefits or cost offsets are ascribed to environmental and other externalities.

The estimate for electricity from the gas turbine technology is competitive with decentralized electricity from coal-fired generation. For example, assuming that coal is available in sufficient quantities in Chuxiong Prefecture, coal-fired electricity generation costs would range between 0.18 to 0.20 yuan/kWh.[12] This comparison does not take into consideration the subsidy given to coal production, emissions clean-up with coal, and the global and other environmental benefits associated with biomass production. Electricity costs from the biomass steam turbine are a little more than 0.10 yuan/kWh higher. However, this estimate is also within the range of project feasibility. Note also that the current electricity rates are subsidized and non-market allocation is used to ration supply. Still, the costs estimated are consistent with the delivered price of electricity for industrial uses (0.16 - 0.18 yuan/kWh).

These estimates of electricity generation costs are preliminary and are based on information gathered during a very brief site visit to Yunnan Province. Because of the uncertainty in much of the data and assumptions, a number of key parameters were varied to estimate their effect on total generation costs. The number of kilometers of roads and construction cost per kilometer, the cost of transport per dry Mg and distance to the conversion facility, cost of biomass supply, installed capital cost for the conversion plant, annual capacity factor, and discount rate were varied from -40

[12]A small coal-fired plant would cost about 3000 yuan/kW to construct, with annual operating and maintenance costs at 0.10 to 0.12 yuan/kWh. The 0.16 - 0.18 yuan/kWh electricity generation costs are based on a 50% capacity factor and a 10% discount rate. Estimates are from the Power and Communication Division, Planning Commission of Yunnan.

Table 3. Estimated costs for biomass-fired electricity generation.

	Steam turbines	Gas turbines
Annual capital costs (yuan/kWh)		
Conversion plant	0.215	0.157
Road construction	0.001	0.001
Operations (yuan/kWh)		
Fixed maintenance	0.027	0.027
Labor	0.001	0.002
Variable maintenance	0.010	0.010
Biomass supply costs (yuan/kWh)		
Production	0.043	0.029
Transport	0.010	0.007
Storage (10% of production)	0.004	0.003
Total cost of generation (yuan/kWh)	**0.311**	**0.236**

Note: Annual capacity factors assumed are 50% for each technology.

to +40%. Figures 1 and 2 summarize the results of this sensitivity analysis for each conversion technology.

As expected, plantation access, transport, and feedstock production do not significantly affect total electricity generation costs. For example, a 40% increase in all costs associated with biomass supply would only increase total generation costs by 0.012 yuan/kWh and 0.019 yuan/kWh for the gas turbine and steam turbine, respectively. The viability of a biomass energy project would not be dependent on the total costs of delivered feedstocks. However, electricity generation costs are sensitive to changes in parameters affecting the conversion facility. For example, a 40% reduction in the capacity factor (corresponding to an annual capacity factor of 30%) would increase generation costs by 0.12 yuan/kWh for the gas turbine technology and by 0.16 yuan/kWh for the steam turbine technology. A reduction in the planned capacity factor could result from two separate circumstances.

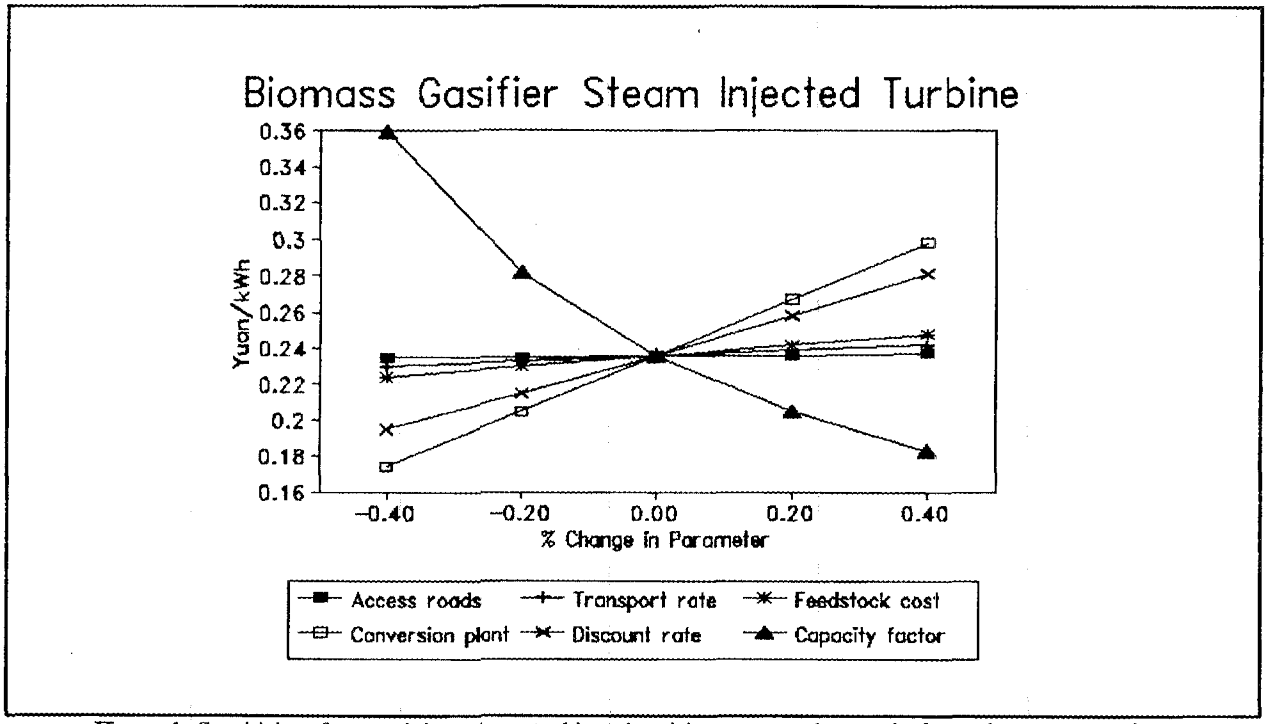

Figure 1 Sensitivity of steam injected gas turbine electricity costs to changes in factor input assumptions

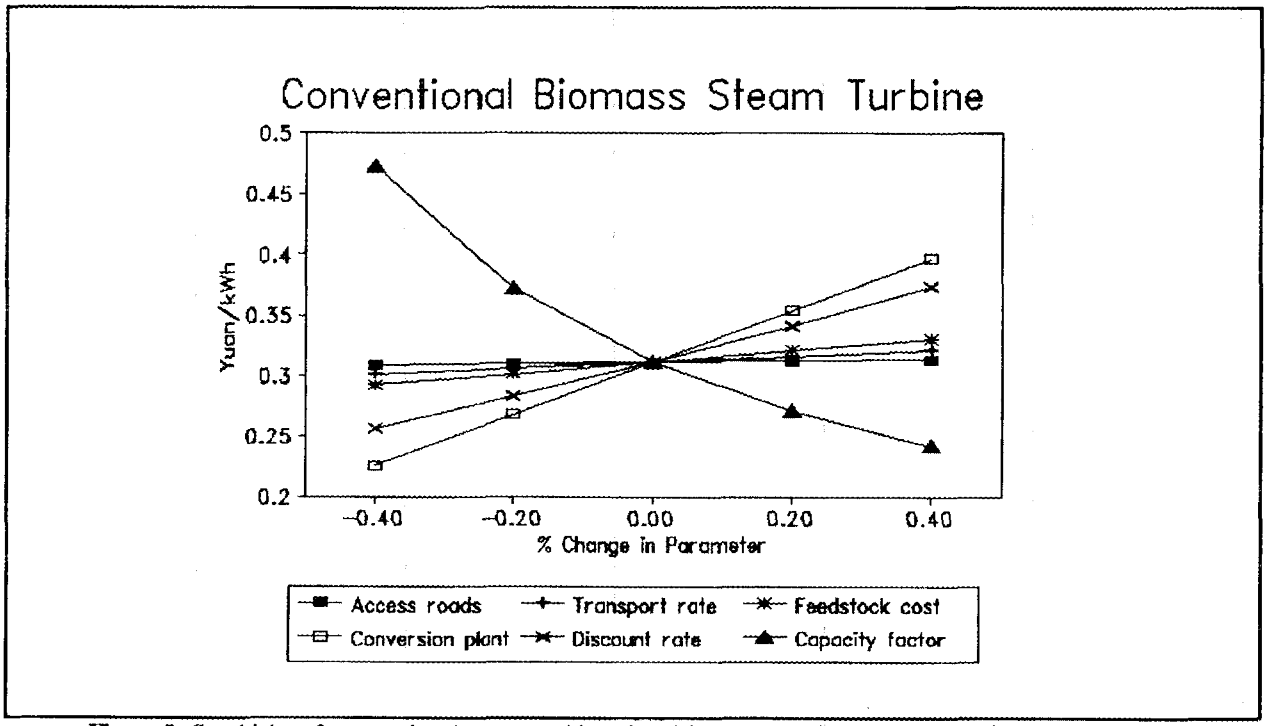

Figure 2 Sensitivity of conventional steam turbine electricity costs to changes in factor input assumptions

First, the technology may not be robust and would not operate as planned in rural Yunnan Province.[13] A much lower availability would sharply reduce the annual generation from the plant. Second, there may be a risk due to the unavailability of feedstocks. If there is unusual weather (e.g., a severe frost) or a disease outbreak that serves to increase mortality there may be insufficient feedstocks to operate the plant as planned. Electricity costs are also sensitive to changes in installed capital costs (capital accounts for about 70% of total generation costs) and any reduction (or increase) could significantly decrease (or increase) generation costs. For example, a 20% reduction in capital costs (attributable to the manufacture of some components, such as a boiler or gasifier, locally) would reduce total generation costs for the gas turbine to about 0.20 yuan/kWh and costs for the conventional steam turbine to about 0.27 yuan/kWh.

These estimates of the costs have important implications. First, the site-level characteristics with the most cost uncertainty -- biomass productivity -- are relatively unimportant; in contrast, biomass availability is extremely important because any interruption in output is very costly. This suggests that the biomass production operation should be deliberately oversized to account for uncertainty and to provide the possibility for added hours of annual operation. Further, it suggests that diversity in trees (especially to include frost-resistant species) should be pursued even in the face of lower biomass productivity and consequently higher cost. Similarly, it suggests that herbaceous crops be planned for upper slopes to yield greater potential assurance of supply during some seasons.

Second, while it may be properly conservative to project a 50% capacity factor, every effort should be made to increase hours of operation because fixed costs are such a large portion of the total. The third implication is that substantial attention should be given to efforts to reduce capital costs of the conversion equipment. For example, each 1% reduction in capital cost in a 20 MW system would allow over a 5% increase in fuel cost without affecting final electricity cost.

---

[13]These biomass-fired plants are expected to have availability factors of over 80%.

The situation in the counties examined during the site visit is representative of some, but not all, locations in Yunnan. In general, growing conditions for biomass are less favorable than in many other locations which have greater rainfall. More important, the market for power is also different, and so is the alternative costs of power with which a biomass-to-electricity project would have to compete. In the counties examined a grid exists and the economic gain from the project takes the form of additional power and enhanced reliability. The target economic value of the power produced can either be taken as the avoided production cost of additional central station power (assuming it could be produced with the invested capital) or the incremental consumer satisfaction or productive output at the marginal consumption site on the grid if power were made available. Estimating the latter depends critically on the pricing and allocation policy of the utility system absent the project. Nothing can be inferred about the value of the service based on existing price given the pricing and allocation policy in China. Obviously, though, it is greater than the price at the margin or there would not be shortages at peak times. In the case of the counties examined, it is concluded that the project is financially viable because the additional electricity can be made available at "about" the current price of industrial electricity, which in turn is below the price it could sustain, as demonstrated by existing shortages. It is economically viable because of the net positive external benefits, which would be added to the direct benefits as offsets against economic costs.

Two alternative situations exist in Yunnan, and each would suggest a different criteria for valuing output of a biomass-fired generation facility. The first of these is an area with no central grid-supplied electricity, a condition found in a number of counties in this Province. The incremental capital cost of a biomass-to-electricity project would include distribution and service lines and consumption devices, costs already borne in the counties examined in the site visit. In addition, because the biomass plant would be the only source of power, design would require maximum practical reliability, which would bring different trade-offs than optimal where a grid was in place.

Unit variable production costs would be higher because the premium to be placed on maximum availability would lead to higher conversion costs (e.g, multiple units) and higher feedstock costs (e.g., transportation and storage). The costs of failure would be greater because more capital would be at risk. On the other hand, the availability of electricity may have significant positive amenity and output values. Alternatively, it would avoid the high variable (and capital) costs associated with individual provision of power (by, for example, diesel gensets or photovoltaics) in the few locations it was available. In short, a total system economic analysis would be required to determine the expected social rate of return for a biomass-fired electricity project where no central station power existed. The first order comparison would be whether any central station service at all was justified. If biomass-fired generation passed this threshold test, the question would be to compare its costs and other characteristics with those of extending the regional grid or of using another electricity technology and fuel source.

The other situation is where the local or regional grid is served by hydropower subject to the monsoon. In this case, total supplies are greatly restricted in the dry season, demand is met either with the small amount of hydro available or with very expensive (both capital and variable cost) fossil fuel facilities. This situation is not uncommon; in these cases, dual distribution systems exist, only one of which (connected solely to lights and nonproductive uses) is energized during the dry season. A biomass-fired facility would fit perfectly as part of such a system, offering its potential for 12-month reliable base-load service and, possibly some augmentation of power during daily peak demand periods during the rainy season. The incremental capital costs would be essentially limited to the production and conversion process, as is the case a when biomass system feeds into a grid. On the demand side, the value of the biomass electricity would be determined by the avoided consumer loss.

It would appear that the situation in the three counties examined during the site visit (an existing grid with a base-load hydro and coal-fired energy source) is likely to be <u>less</u> favorable in market and economic terms than are the alternatives. The alternatives seem to be more promising. This suggests that a relatively large number of sites in Yunnan may prove feasible if the demonstration project examined here is successful.

6. FINDINGS AND RECOMMENDATIONS

6.1 FINDINGS

- The Chinese government at all levels is supportive of the concepts of this project and asserts that it is willing to provide major support to it:

  - Land will be made available free of charge.
  - Labor will be made available at going rates.
  - Infrastructure needed for the project will be given special consideration.
  - Research organizations will redirect their efforts as needed.
  - It is not clear whether the Chinese would fund a demonstration conversion facility with internal funds, but this was suggested as a possibility.

- There is an adequate infrastructure, and markets are available to use any power generated, based on assertions by local experts and casual observations.

  - Local unsatisfied electricity demand exists; more demand would develop quickly if power were available.
  - A grid adequate to move the power is in place; institutional arrangements exist whereby local production need not follow local demand, solving a major potential problem with facilities of this sort.
  - Provincial markets exist for any reasonable increase in power, certainly on a peak or shoulder basis and perhaps even for base-load.

- Local and regional electricity demand appears to be capable of supporting the project financially because uses were identified that increase income by a multiple of a cost-covering price for electricity. This conclusion was stated by local experts and is consistent with casual observations; further examination is appropriate.

- There exists in Chuxiong Prefecture a dedicated cadre of forestry professionals and technicians which can plan, create, operate and maintain a biomass tree plantation system.

- The existing knowledge about trees and cultivation practices is adequate to justify immediate initiation of plantation establishment, recognizing that significant production risk exists and that costs are likely to be higher than would be the case once further biomass production research is completed. To limit feedstock availability risk, it would be necessary to add a margin of production safety by increasing estimated required plantings by perhaps 25%, by undertaking herbaceous plantings in the area chosen (preceded by research), and by planting diverse species rather than using a single tree that appears to provide maximum growth.

- There exists a trained, dedicated cadre of forestry research professionals, which can undertake (possibly with some help) the screening, tree improvement and cultivation practices program which over the next 7 to 10 years could support a major expansion in biomass electricity operations.

- There exist two specific locations for a biomass-to-electricity plantation system where it appears all necessary conditions are met, including enthusiastic support by local officials.

- There exist substantial areas in diverse locations in Yunnan where conditions are at least suitable for a biomass-to-electricity project as they are in the sites visited. This conclusion is based on discussions with Chinese experts, on observation and on examination of published materials. If the proposed demonstration project proves successful, a major expansion to other areas would appear feasible and even likely.

- Based on relatively conservative estimates for all of the matters that could be observed, it appears that electricity produced from biomass through gasification and then steam-injected gas turbine generation would be financially competitive with the cost of the coal-fired electricity it would replace or supplement. On a full economic cost basis it would appear to be superior. Production costs from conventional steam turbine technology would be higher (but less uncertain), though local manufacturing of some components could reduce financial costs.

- The major uncertainty is that associated with the capital cost and reliability of the gasifiers and turbines. No specific experience exists with these technologies. The cost and reliability of the biomass conversion technologies are based on judgement and inference from related technologies.

- A major benefit from this project would be to prove the biomass gasifier-turbine technology under field conditions, using raw materials, labor and management consistent with other potential developing country applications.

- Potential beneficiaries of this demonstration project include a number of parties, and some equitable means of sharing specific costs may be in order among at least the following:

  - The local community, which will get the electricity and employment and the associated amenities and income.

  - The Provincial and National governments, which will obtain economic, environmental and energy benefits.

  - The developers and manufacturers of the technology, which will obtain a test bed for development and a demonstration on which market expansion can be based.

  - Other similarly placed regions and countries, which will benefit from the availability of the concept and technology.

  - Other countries, which will face fewer problems from global warming to the extent this system replaces further use of fossil fuel.

- A possible fail-safe position is that if the gasifier-turbine system does not prove satisfactory, a conventional unit can be installed quickly; the investment in establishing the biomass plantation system will not be lost.

6.2 RECOMMENDATIONS

- A program should be adopted to implement a biomass-to-electricity project in Yunnan Province. This program should be phased to allow learning and it should be understood that at the end of each phase, a positive decision to proceed is required.

- This program should be jointly negotiated with Chinese officials and with other parties, including possible equipment vendors, and a careful articulation of responsibilities and rewards should be agreed upon.

- The next step is perfecting this assessment, which will require approximately six months. This time will be used to answer questions posed above, to undertake an analysis of the actual requirements for the conversion facility, to better identify exact plantation sites so that planning can proceed, and to evaluate the potential of herbaceous energy crops to supplement woody biomass as a means to lower feedstock availability risk.

- Notwithstanding action or other recommendations, initiate enlarged biomass development and improvement activities addressing site specific species screening, pest resistance, species admixtures, environmental effects, and refined biomass handling procedures.

INTERNAL DISTRIBUTION

1. K. R. Ballew
2. F. P. Baxter
3. V. Baxter
4. D. J. Bjornstad
5. B. L. Bush
6. J. B. Cannon
7. R. S. Carlsmith
8. J. Cushman
9. M. P. Farrell
10. S. B. Floyd
11. W. Fulkerson
12. P. S. Gillis
13. F. M. Glenn
14. R. L. Graham
15. L. J. Hill
16. E. L. Hillsman
17. D. W. Jones
18. C. R. Kerley
19. R. Lee
20. P. N. Leiby
21. G. Marland

22-41. R. D. Perlack

42-61. J. W. Ranney

62. S. Rayner
63. D. Reichle

64-83. M. Russell

84. R. B. Shelton
85. Z. Shen
86. A. F. Turhollow
87. R. I. Van Hook
88. D. B. Waddle
89. E. W. Whitfield
90. T. J. Wilbanks
91. L. L. Wright
92. ORNL Patent Office
93. Central Research Library
94. Document Reference Section

95-97. Laboratory Records

98. Laboratory Records - RC

EXTERNAL DISTRIBUTION

99. M. Adler, Bruce Company, Climate Change Division, U.S. Environmental Protection Agency, 401 M Street S.W., Washington, D.C. 20460

100. K. Andresko, Office of Policy Analysis, U.S. Environmental Protection Agency, 401 M Street S.W., PM-221, Washington, D.C. 20460

101. W. F. Barron, Lecturer, Environmental Mangement Program, University of Hong Kong, Centre of Urban Studies and Urban Planning, Pokfulam Road, Hong Kong

102. R. Bower, Committee on Renewable Energy Commerce and Trade, U.S. Department of Energy, Forrestal Building, 1000 Independence Avenue, Washington, D.C. 20585

103. B. G. Buchanan, Computer Science Department, University of Pittsburgh, 206 Mineral Industries Building, Pittsburgh, PA 15260

104. J. J. Cuttica, Vice President, End Use, Research and Development, Gas Research Institute 8600 W. Bryn Mawr Avenue, Chicago, IL 60631

105. D. Dawson, 3015 S. River Road, P.O. Box 1321, Rhinelander, WI 54501

106. J. E. Ferrell, Biofuels Systems Division, U.S. Department of Energy, CE-331 Forrestal Building, 1000 Independence Avenue S.W., Washington, D.C. 20585

107. Tom Geary, USDA-FS, Forestry Support Group, Room 811-RPE, P.O. Box 2417, Washington, D.C. 20013

108. Dwight Hair, American Forestry Association, P.O. Box 2000, Washington, D.C. 20013

109. A. Hirsch, Vice President, Environmental Science and Director, Washington Operations, Midwest Research Institute, 5109 Leesburg Pike, Suite 414, Falls Church, VA 22041

110. D. Jhirad, Office of Energy, S&T/EY, U.S. Agency for International Development, SA-18, Room 508, Washington, D.C. 20523

111. J. Kadyszewski, Deputy Directory, Program in Renewable Energy and the Environment, Winrock International, 1611 N. Kent Street, Suite 600, Arlington, VA 22209

112. Stan Krugman, Room 1205 RPE, USDA Forest Service, P.O. Box 2417, Washington, D.C. 20013

113. J. Frank McCormick, Graduate Program in Ecology, 691 Dabney Hall, University of Tennessee, Knoxville, TN 37916

114. R. Moorer, Biofuels Systems Division, U.S. Department of Energy, CE-331 Forrestal Building, 1000 Independence Avenue S.W., Washington, D.C. 20585

115. D. E. Morrison, 333 Oxford Road, East Lansing, MI 48823

116. L. D. Ostlie, Energy Performance Systems, Suite 303, 4900 N. County Road 18, Minneapolis, MN 55428

117. R. Pumfrey, Office of Energy, S&T/EY, U.S. Agency for International Development, SA-18, Room 508, Washington, D.C. 20523

118. Paul Ryan, The World Bank, Room S4019, 1818 H Street N.W., Washington, D.C. 20433

119. J. Sullivan, Office of Energy, S&T/EY, U.S. Agency for International Development, SA-18, Room 508, Washington, D.C. 20523

120. Mark Trexler, World Resources Institute, 1709 New York Avenue, 7th Floor, Washington, D.C. 20006

121. M. Williams, Professor, Department of Economics, Northern Illinois University, DeKalb, IL 60115

122. R. H. Williams, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ 08544

123. R. D. White, 856 S. Ogden Street, Denver, CO 80209

124. Kathy Zoi, Environmental Protection Agency, Office of Air & Radiation, 401 M Street S.W., ANR-445, Washington, D.C. 20460

125. Office of Assistant Manager for Energy Research and Development, DOE-ORO, P.O. Box 2001, Oak Ridge, TN 37831

126-135. OSTI, U.S. Department of Energy, P.O. Box 62, Oak Ridge, TN 37831