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Prospects for Biomass-to-Electricity Projects in Yunnan Province, China

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PROSPECTS FOR BIOMASS-TO-ELECTRICITY PROJECTS IN YUNNAN PROVINCE, CHINA

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SUMMARY

Efforts have been underway since 1989 to assess the prospects for biomass-to-electricity projects in Yunnan Province. Results of prefeasibility studies for specific projects suggest that they are both financially and technically viable. Because of low labor costs and favorable climate biomass can be grown on marginal and underutilized land and converted to electricity at costs lower than other alternatives. Based on current plantation establishment rates, the potential size of the biomass resource base can easily support over 1 GW of electric generating capacity in small-sized (up to 20-40MW) cogeneration and stand-alone projects. These projects, if implemented, can ease power shortages, reduce unemployment, and help sustain the region's economic growth. Moreover, the external environmental benefits of biomass energy are also potentially significant. This report briefly summarizes the history of biomass assessment efforts in Yunnan Province and discusses in more detail twelve projects that have been identified for U.S. private sector investment. This discussion includes a feasibility analysis of the projects (plantation-grown biomass and its conversion to electricity) and an estimate of the biomass resource base in the general vicinity of each project. This data as well as information on power needs and local capabilities to manage and operate a biomass-to-electricity project are then used to rank-order the twelve projects. One cogeneration and one stand-alone facility are recommended for additional study and possible investment.

1. INTRODUCTION

1.1 BACKGROUND

The Joint Institute for Energy and Environment (JIEE) has been cooperating with Yunnan authorities since 1989 to investigate the possibility of using biomass to generate electricity. Supported by Committee on Renewable Energy Commerce and Trade (CORECT), the U.S. Department of Energy's (DOE) Biofuels Feedstock Development Program, the United Nations Development Program, the Rockefeller Foundation, and institutional funds, numerous teams of researchers have worked with Chinese experts and officials from Yunnan Province to plan, evaluate, and implement biomass-to-electricity projects. A chronology of major JIEE activities with biomass-to-electricity initiatives in Yunnan Province is summarized in Table 1.

Results of prefeasibility studies show that biomass-to-electricity projects in Yunnan Province are financially and technically viable.[1] Biomass can be grown and converted to electricity at costs lower than other alternatives and can yield favorable internal rates of return. Study teams judged that biomass energy can ease power shortages and help sustain the region's economic growth, now averaging 8-10% annually.[2] Also, the external environmental benefits of biomass-to-electricity projects are potentially large, if replicated on region-wide scale. At present, tree plantations are being established in Yunnan Province and some plans are being made to co-fire existing sugarmills with bagasse and wood for year-round power production, and to construct stand-alone biomass-fired facilities.

There are very clear energy and economic development benefits to the Chinese if these projects are realized. There are potentially important benefits to the U.S. as well. Chief among them are new opportunities for private power producers and deployment of U.S. technology in a potentially large and important market. And there is much to learn about our own biomass program regarding scale-up, logistics, and integration of dedicated production and conversion from the demonstration of a biomass energy system in Yunnan. On the general level, utilization of renewably grown biomass will result in net CO_2 fixation and in displacement of fossil fuels, with beneficial effects on climate change.[3] These magnitudes could become significant if the Yunnan experience

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[1]See Perlack, R.D., J.W. Ranney, and M. Russell, (1991); Russell, M., D. Jantzen, and Z. Shen, (1991); and Jantzen, D. and M. Russell, (1992).

[2]Yunnan has officially expressed its desire to attract foreign companies to boost its economy in several sectors, including energy (Yunnan Foreign Trade and Economic Cooperation Bureau). Yunnan, which is landlocked in a country where economic development is focused on the coast, has joined Myanmar, Thailand, Laos, Cambodia, and Viet Nam (collectively the Mekong Six) to promote greater economic cooperation and trade. The Mekong Six have plentiful and motivated cheap labor and abundant natural resources, but lack infrastructure including power.

[3]The development of biomass-to-electricity projects in Yunnan is also consistent with commitments the U.S. has made to foster sustainable development in support of both environmental and world stability goals.

Table 1. Summary of major activities in Yunnan Province, China

Date	Activity
1989	Milton Russell, sponsored by the National Environmental Protection Agency (Beijing), discussed potential collaboration with Yunnan Provincial Environmental Protection Commission. Identified opportunities to use biomass for power generation in rural Yunnan Province.
1990	ORNL team (M. Russell, R. Perlack, J. Ranney) completed prefeasibility assessment of stand-alone biomass power generating facilities. Prefeasibility assessment focused on plantation activities (site inspections) and determining whether trees could be grown for power production. The study concluded that the resource base for tree production was sufficiently large to support power plants in the 20 MW size and that power from these plants could be generated at costs competitive with alternatives. The study team also judged that the development and environmental benefits were large.
1991	A study team (M. Russell, Z. Shen, D. Jantzen-Winrock International) visited sites and collected additional information to refine the 1990 feasibility assessment. Efforts focused on the conversion technology. Identified cogeneration opportunities at sugar mills. Discussed cooperation on developing biomass projects.
1992	An international team (M. Russell, Z. Shen, D. Jantzen-Winrock, P. LaRocco-Rockefeller Foundation, J. Mullen-boiler consultant, D. Chandler-plantation forest expert) studied in detail the feasibility of converting sugar mills to cogenerate power and to sell excess power to the local grid. Biomass feedstocks would be grown and used to supplement the bagasse feedstocks for year-round power production.
1992	A study team (M. Russell, Z. Shen, D. Jantzen-Winrock International) refined the feasibility analysis of the sugar mill conversion and concluded that internal rates of return were likely to be quite favorable and potentially high enough to attract U.S. investors.
1993	A study team (M. Russell, Z. Shen, P. LaRocco-Rockefeller Foundation) visited Yunnan Province to discuss project status and to negotiate a cooperative agreement on future research. Consulted with local officials on forming an autonomous enterprise for electricity production. Consulted with the Yunnan Environmental Sciences Institute on setting up a semi-autonomous energy and environmental services enterprise.
1994	The JIEE Initiated market assessment activities to identify specific investment opportunities.
1995	Began field activities (Bill Barron, Univ. of Hong Kong) to identify specific opportunities and corroborated analysis performed by the Yunnan Institute of Environmental Science. Organized a workshop for a delegation from Yunnan Province to present specific investment opportunities to U.S. investors and private power producers.

proves transportable to other regions in China and to similarly situated countries in Southeast Asia. The projects in Yunnan could provide one of the first demonstrations of biomass-to-electricity generation relying exclusively on renewably grown plantation feedstocks.

The JIEE is currently developing private sector interest in biomass-to-electricity projects in Yunnan. Supported by DOE's Office of Policy (international Programs), a small delegation from Yunnan Province will visit U.S. facilities, utilities, and meet with prospective vendors, private power producers, and industry groups.

A workshop with representatives from the U.S. private sector will be held to discuss specific investment opportunities. Following the U.S. workshop, the Chinese delegation will use the knowledge from the U.S. site visit to arrange a workshop in Yunnan Province (Kunming) to promote joint U.S. and Chinese interests. Representatives from equipment vendors, industry groups, and U.S. government will be invited. Visits will be provided to potential biomass-to-electricity sites.

This report, which was supported by the International Fund for Renewable Energy and Energy Efficiency (IFREE), summarizes the approach and results of an assessment to identify specific biomass-to-electricity projects in Yunnan Province. This report is intended to clarify and amplify a report submitted to the JIEE by the Yunnan Institute of Environmental Science (YIES). More details related to the overall investment climate and background on specific counties within Yunnan Province can be found in that report.

1.2 ORGANIZATION OF REPORT

This report attempts to synthesize previous assessment efforts as well as to summarize the latest activities to identify specific biomass-to-electricity investment opportunities. Because it is clearly impossible to thoroughly summarize all activities, this report will frequently reference other materials. These materials are listed in the reference section to this report and are available from the authors upon request. The next section of this report will summarize the approach used to identify specific projects. This section will be followed by the prefeasibility assessment of the identified projects. The fourth section will briefly outline the rank-ordering approach and the rankings of the specific investment opportunities.

2. APPROACH USED TO DETERMINE BIOMASS INVESTMENT OPPORTUNITIES

Past assessment efforts have identified two general types of biomass-to-electricity projects. These are:

- the conversion of sugarcane mills to cogenerate heat for on-site processing needs and year-round power production for export to the local distribution grid using bagasse and plantation-grown biomass; and
- stand-alone biomass-to-electricity projects relying primarily on plantation-grown wood as a feedstock.

Because of the limited availability of financial resources, JIEE teams have not been able to work with staff of the Yunnan Institute of Environmental Science (YIES) to identify other potential biomass-to-electricity projects. For example, Yunnan produces large quantities of rice, corn (maize) and other grains, oilseeds, and timber. Additional biomass-to-electricity projects could include the conversion of rice mills and sawmills to cogeneration, as well as stand-alone facilities that might be fueled with agricultural residues and plantation-grown wood. The conversion of small coal-fired generation facilities to co-fire with plantation grown biomass (co-firing biomass and coal is under development in the U.S.) is also a possibility in Yunnan.

The limited resources available to JIEE teams and YIES to identify investment opportunities also meant that not all sugarmills or counties in the Province could be evaluated for suitability. Consequently, only a subset of all sugarmills and counties could be examined. (Appendix A to this report lists all the sugarmills in Yunnan Province.) JIEE and YIES staff therefore developed a simple and rational procedure to identify the "best" biomass-to-electricity projects. A two-step procedure was used.

The first step is what is termed the initial screening. In this step, a number of technical screens or filters were applied to eliminate projects that were deemed by YIES to be infeasible or impractical to develop at this point in time. These screens included:

- Unavailability of sufficient land located in close proximity to the mill or stand-alone site to grow trees.
- Counties where climatic and geographical conditions (e.g., low rainfall, elevation, slope, temperature, etc.) are not suitable.
- In the area surrounding the mill or stand-alone site, there is no need for power. For example, there may be inexpensive hydropower available or these areas are nearby to outside transmission grids or larger distribution grids.
- Costs are prohibitively high to develop the facility or the project is too small.
- The area is too remote and inaccessible, or there are few productive uses of electricity.
- There is a general lack of interest at the local level for biomass-to-electricity projects, or there are no capabilities at the local level to manage and operate a facility even if the project is desired.

The outcome of the first step was a list of twelve prospective projects. These projects are identified in Table 2 with their approximate locations in Yunnan Province shown in Fig. 1. For these twelve projects preliminary prefeasibility analyses were completed.

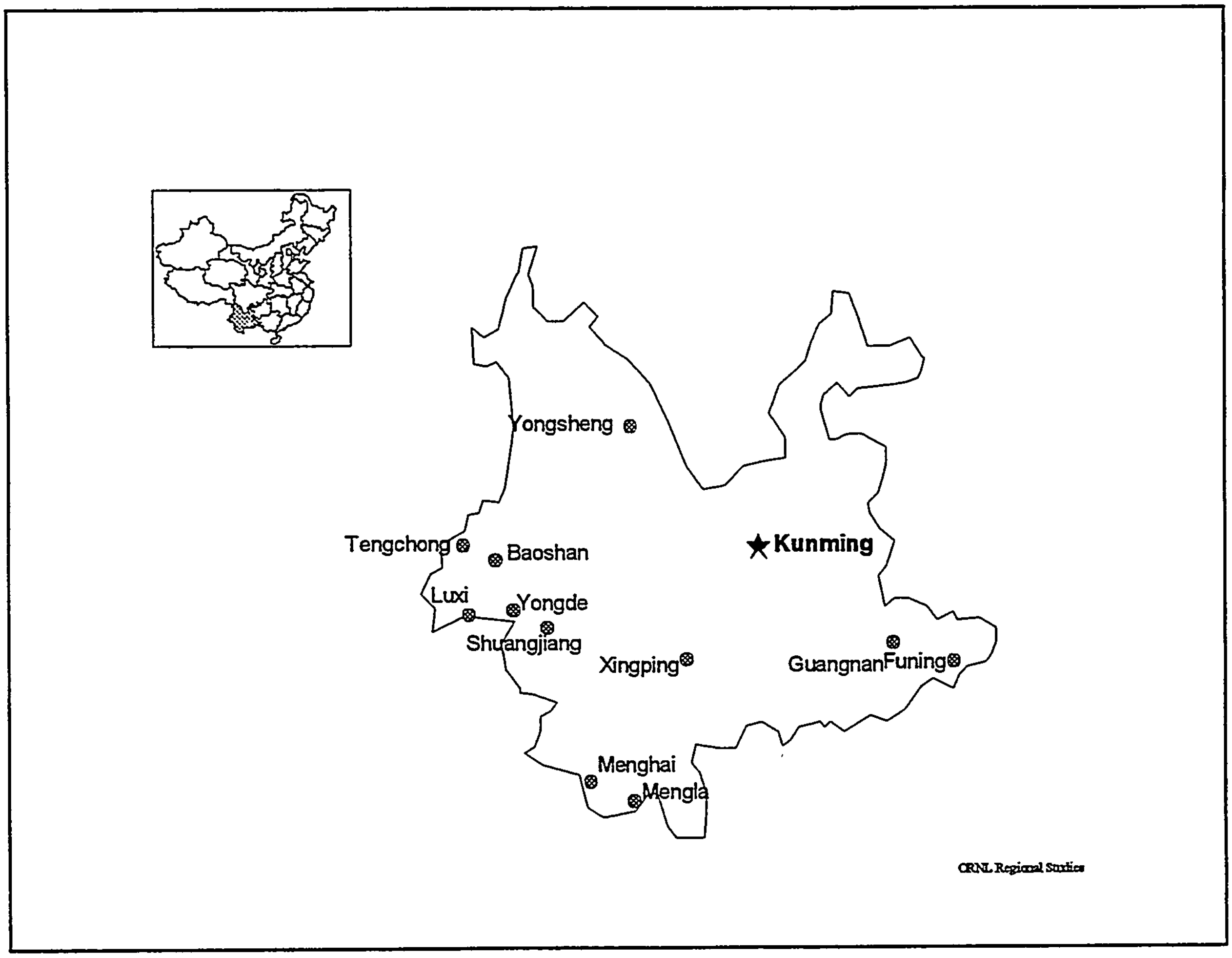

Fig. 1. Location map of identified biomass-to-electricity projects in Yunnan Province.

The second step after conducting prefeasibility analysis was to rank-order the projects to determine two projects that could be promoted as demonstration sites. For the two demonstration projects U.S. private sector involvement would then be actively solicited. The results of the prefeasibility analyses on the twelve identified projects are summarized in the following chapter. The rank-ordering of the twelve projects along with the ranking criteria that were used are summarized in Chapter Four.

Table 2. Biomass-to-electricity projects after initial screening of sugarmills and counties for stand-alone biomass-to-electricity projects

Sugarmills for cogeneration		Stand-alone facilities	
Prefecture	County or city (plant name)	Prefecture	County or city (plant name)
Baoshan	Baoshan City (Dongfeng) Tengchong (Hehua)	Lijiang	Yongsheng (Maguohe)
		Wenshan	Funing (Funing) Guangnan (Guangnan)
Dehong	Luxi City (Huanjiao)		
Lincang	Shuangjiang (Shuangjiang) Yongde (Yongkang)	Xishuangbanna	Mengla (Mengpeng)
Lijiang	Yongsheng (Qina)		
Yuxi	Xinping (Xinping)		
Xishuangbanna	Menghai (Liming)		

3. ANALYSIS OF BIOMASS-TO-ELECTRICITY PROJECTS

This chapter presents the summary results of the prefeasibility assessment of the costs of growing plantation trees, harvesting and delivering them to a power plant, and the costs of conversion.[4] This chapter also outlines the major assumptions that were used in the analysis and contains a sensitivity analysis on important determinants of project feasibility.

3.1 BIOMASS ENERGY RESOURCES AND SHORT-ROTATION FORESTRY

For each of the screened project sites estimates were made for existing biomass resources and land areas available for biomass plantations. These estimates are summarized in Table 3 for each of the eleven counties. (Yongsheng County has two projects). With the exception of Shuangjiang and to a lesser extent Luxi and Yongde the available biomass resources that could be used for power generation are relatively small. Existing forests, more correctly described as shrubland, are significantly over-harvested for firewood, timber, fodder, and miscellaneous forest products. Assuming a wood to electricity conversion rate of 1 dry kg of wood per kWh, existing wood resources are only capable of supporting a few MW of installed capacity in each county. This implies that biomass feedstocks must come from other sources, such as agricultural wastes, or plantation-grown biomass.[5]

In the early 1980s, the Chinese Government promulgated a series of policies and regulations that were aimed at promoting fuelwood energy plantations. These directives were quite successful in reforesting many areas of the countryside. It is estimated that well-over 5 million hectares have been reforested in energy plantations throughout China. In Yunnan, the establishment of wood energy plantations is occurring at a rate of about 3,000 hectares per year per county (Perlack et al., 1991). For the entire Province, plans are to plant about 270,000 hectares each year through the year 2000 (Jantzen and Russell, 1992). The size of this biomass resource is easily equal to well-over 1 GW of installed electric generating capacity. For example, sustainably harvesting only 150,000 hectares with an annual productivity rate of 10 dry tonnes cut on a 7-year cycle can support over 1 GW of installed capacity assuming only very modest wood-to-electricity conversion rates.

Table 3 shows the estimated land area available for energy plantations for each of the eleven project counties. Land areas range from about 43 km^2 in Baoshan to over 180 km^2 in Guangnan. The biomass productivity of this

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[4]The current exchange rate is US$1.00 = 8.30¥ (RMB) or 0.12$ = 1.0¥ (RMB).

[5]No estimates of the amount of agricultural wastes are available. However, given the relative shortage of household fuels and the integrated nature of most farming operations, it is likely that these residues are being fully used for animal fodder, compost, and as fuel for household cooking and heating.

Table 3. Summary of existing and plantation feedstock availability

County (city)	Existing resources (dry tonnes yr^{-1})	Plantation land area available (km^2)	Annual productivity (dry tonnes ha^{-1})	Total feedstock availability (dry tonnes yr^{-1})
Baoshan	8,500	43.8	15	74,200
Funing	3,400	69.7	15	107,900
Guangnan	3,100	183.6	25	462,100
Luxi	37,700	46.7	35	201,100
Mengla	7,500	66.7	40	266,800
Menghai	6,800	80.0	30	246,800
Shuangjiang	208,000	47.5	15	279,200
Tengchong	16,000	50.0	25	141,000
Yongde	35,900	96.0	15	179,900
Yongsheng	--	102.4	8	81,900
Xinping	13,300	44.2	8	48,600

Source: YIES, 1995.
Notes: Yongsheng County includes the Qina sugarmill and the proposed Maguohe stand-alone facility. Productivity rates in excess of 20 dry tonnes ha^{-1} should be considered as potential rates.

land is going to be quite variable considering that much of the land is hilly and degraded. However, Yunnan, for the most part, possesses quite favorable climatic conditions for growing trees (apart from high altitude locations). Productivities of at least 8 dry tonnes ha^{-1} have been observed in Yongsheng and higher rates can be easily attained in the more subtropical and tropical areas of the Province. Table 3 shows estimated productivities for each county. These rates range from a low of 8 dry tonnes ha^{-1} in Yongsheng and Xinping to a high of 40 dry tonnes ha^{-1} in tropical Mengla. For these counties average productivity is about 20 dry tonnes ha^{-1}. The product of land availability and annual productivity plus the availability of existing wood resources provides an upper bound on the amount of biomass feedstock that could become available for power production. These feedstock estimates range from a low of about 50,000 dry tonnes yr^{-1} in Xinping to over 460,000 dry tonnes yr^{-1} in Guangnan. Assuming the same wood to power conversion rate (1 dry kg kWh), estimated installed capacities range from about 10 MW in Xinping to about 90 MW in Guangnan. With the exception of Baoshan, Funing, Yongsheng, and Xinping, the selected counties can easily support well-over 20 MW of biomass-fired capacity.

Since sites for plantations are primarily degraded hillsides, establishment procedures generally include some terracing and digging of pits for each seedling, with compost added to each pit prior to planting. Clearing weeds around each seedling and replacing dead seedlings are important activities during the first growing season. Weed control is an important activity during the first year of growth. Harvesting and handling of the trees is done by hand. Beyond the first growing season the management of the plantation is not intensive. The factor input costs for plantation establishment (1st year) and annual plantation maintenance and harvesting /transport are summarized in Tables 4 and 5. Establishment costs are shown by county. The wide variation in establishment costs can be attributed to the cost of seedlings, the amount site preparation required, and the cost of fertilizers (compost). Establishment costs range from a low of about 750¥ to about 3000¥ ha^{-1}. Annual maintenance and harvest/transport costs were assumed to be the same for all locations.

The delivered (levelized) costs of plantation-grown feedstocks are summarized in Table 6. These feedstock costs range from about 20 to 80¥ dry $tonne^{-1}$. Costs were calculated over four cutting cycles (one establishment and three coppice harvests) using a real discount rate of 10%. Trees were assumed to be harvested after 7 years of growth. Fig. 2 generalizes these estimates and shows how costs are affected by productivity and establishment costs, which are assumed to range from 1000 to 3000¥ ha^{-1}. It can be seen that costs decline dramatically as productivity increases to about 15 dry tonnes ha^{-1} yr^{-1}. Productivity increases beyond 20 dry tonnes do not result in substantial reductions in feedstock costs. The sensitivity of delivered feedstock costs to changes in establishment show a similar effect.

The costs of growing, harvesting, and delivering feedstocks to power generating facilities are rather low even assuming rather conservative assumptions (U.S. - \$10-\$15 dry $tonne^{-1}$). Low costs can be explained by the following. First, daily wage rates are no more than 15¥ day^{-1}. Most plantations operations including harvesting will be done manually. Moreover, plantation operations can be timed so that they do not conflict with normal agricultural labor demands. Second, no opportunity cost of land was included in the delivered feedstock costs. Chinese officials insist that unused land is available (albeit somewhat degraded) that has no or little opportunity cost. Another factor that should be accounted for in the analysis, which was not done here, is the inclusion of both forest co- and by-products. For example, where eucalyptus is grown leaves are considered a co-product because they yield a marketable oil and small limbs and branches, a by-product of harvest operations, can be used as firewood. Finally, it should be acknowledged that in some counties the local price of firewood is reported to be much higher than the cost of growing and harvesting plantation-grown wood. Under these circumstances, provisions need to be made to ensure that wood is not diverted to non-power uses. Protection against this from happening could perhaps be met by over sizing plantation operations.

3.2 CONVERSION AND FINANCIAL ANALYSIS

Preliminary engineering studies have been performed to convert existing sugarmills to produce power during the on- and off-season as well as the construction of small stand-alone facilities. Generally, the upgrading of sugarmills for power production requires a number of modifications, which are outlined in Mullen, 1992.[6] To

[6]This report can be found as an Appendix contained in Jantzen and Russell (1992).

Table 4. Summary of plantation establishment factor costs

Establishment factor cost (¥ ha^{-1})	Funing	Guangnan	Shuang-jiang	Teng-chong	Yongde	Yong-sheng
Seedlings	600	220	486	640	810	640
Land preparation	340	57	270	360	450	380
Establishment	60	23	52	70	87	70
Nurturing	40	30	36	50	60	50
Fertilizer	670	190	540	740	1123	840
Disease control	390	150	224	270	390	360
Fire prevention	10	10	10	10	10	12
Roads	70	30	52	70	30	75
Research						46
Design	30	10	30	30	10	32
Administration	40	30	40	40	30	45
Re-planting			60	120		150
Total	2250	750	1800	2400	3000	2700

Notes: Total establishment costs for Baoshan, Luxi, Mengla, Menghai, and Xinping Counties are 3000, 2250, 1950, and 3000 ¥ ha^{-1}. Itemized costs for these Counties are not available. Yongsheng includes both sites -- Qina and Magouhe. No costs are assumed land. The land base is generally degraded land with little opportunity cost or government controlled land that is made available for plantation operations.

Table 5. Summary of annual plantation maintenance and harvest/transport factor costs

Factor cost	¥ ha^{-1}
Annual maintenance	
Weeding/tending	60
Overseeing	40
Harvesting	
Cutting	450
Handling	350
Chipping	100
Hauling	600

Notes: Annual maintenance and harvest/transport costs were assumed the same for each plantation site. Harvesting is assumed to take place after 7 years of plantation growth. Trees are assumed to regenerate for at least two additional cuttings.

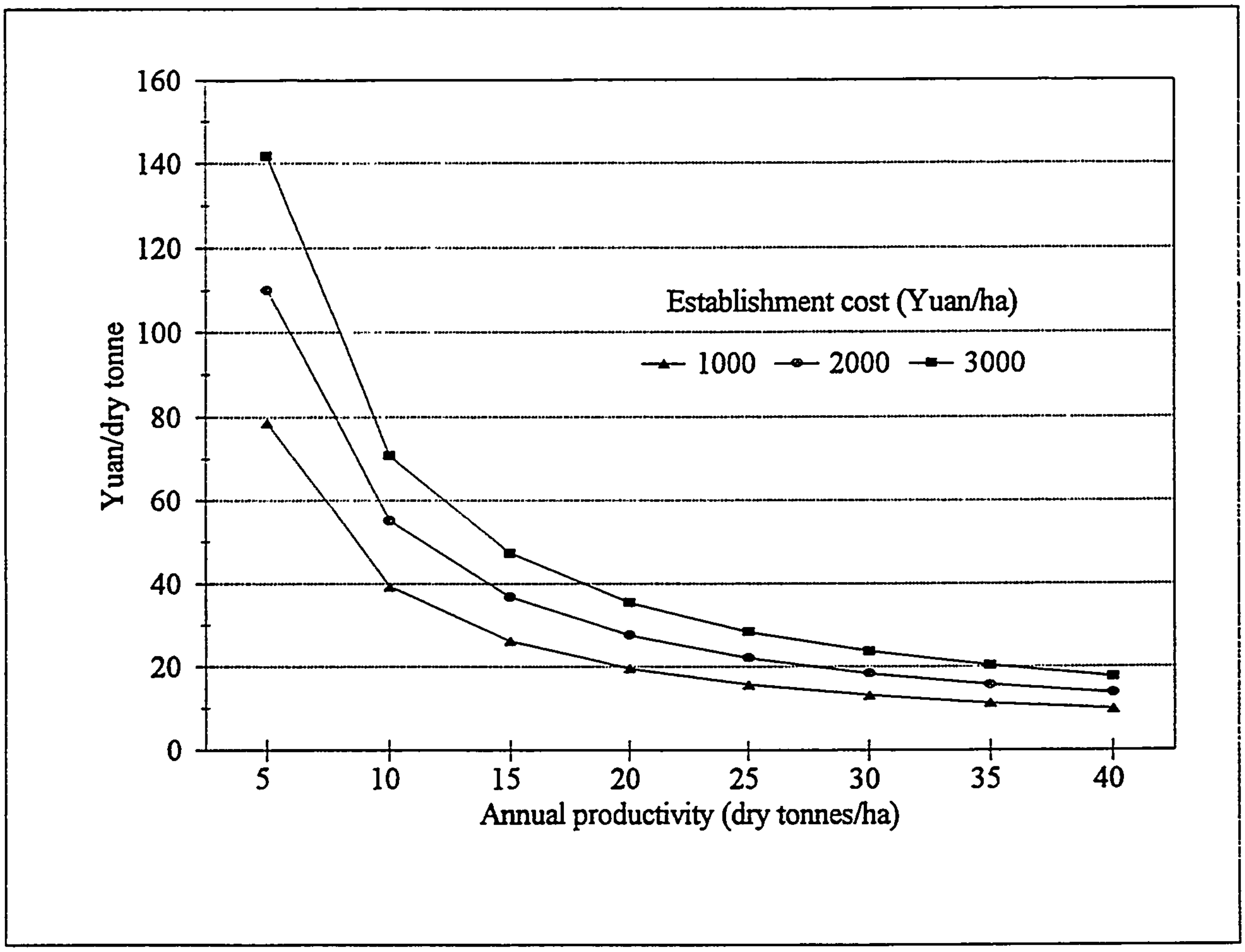

Fig. 2. Delivered feedstock costs as a function of productivity and under different assumed establishment costs.

Table 6. Delivered feedstock costs

County or city	Productivity (dry tonnes ha^{-1} yr^{-1})	Delivered cost (¥ dry $tonne^{-1}$)
Baoshan	15	47.60
Funing	15	39.70
Guangnan	15	24.00
Luxi	18	33.10
Mengla	20	27.40
Menghai	20	20.70
Shuangjiang	15	35.00
Tengchong	15	41.30
Yongde	15	47.60
Yongsheng	8	83.30
Xinping	10	71.30

Notes: Productivities for counties that were reported in excess of 20 dry tonnes were lowered to approximate actual or likely rates.

produce export power existing turbines need to be replaced with condensing-extraction turbines with appropriately matched generators, switchgear, transformers, and grid tie-in facilities. Either additional boiler capacity or new boilers will also have to be added along with wood handling and ash removal equipment. For stand-alone plants, the above equipment plus infrastructure will be required.

Table 7 summarizes the investment cost for upgrading sugarmills and for constructing new stand-alone facilities. The details of these cost estimates can be found in YIES (1995). The Chinese have conservatively configured these facilities to maximize current boiler capacity and existing facilities. Both sugarmill and stand-alone facilities are sized at either 3 or 6 MW.[7] Unit capital costs are lowest for the 3 MW sugarmills (under 2000¥/kW installed) and highest for the 6 MW stand-alone facilities. By U.S. standards costs are very low (U.S. - \$200 to \$400 kW^{-1}) and no doubt reflect the use of local manufactured equipment. Annual operation and maintenance (O&M) is about 10% of installed capital for the stand-alone plants and slightly higher for the sugarmill conversions. The low installed costs associated with the Chinese made equipment are however consistent with their assumed wood-to-electricity conversion rates. They assume a net plant efficiency of about 12.5% (27,500 BTUs kWh^{-1}). The annual wood requirements and cost of wood feedstocks assumed for each county are also summarized in Table 7.

[7]Jantzen (1992) notes that boilers and turbine-generators are produced in China, but they available in only a few standardized sizes.

Table 7. **Summary of biomass-to-electricity investment, fuel and O&M costs**

Plant type - Capacity Project	Wood fuel requirements and costs		Investment (million ¥)	Annual O&M (million ¥ yr^{-1})
	dry tonnes yr^{-1}	¥ dry $tonne^{-1}$		
Sugarmill - 3 MW				
Menghai	19,440	20.70	5.79	0.798
Yongde	21,600	47.60	4.29	0.728
Yongsheng Qina	21,600	83.30	4.29	0.758
Sugarmill - 6 MW				
Baoshan	43,200	47.60	10.50	1.314
Luxi	43,200	33.10	15.65	1.570
Shuangjiang	43,200	35.00	15.65	1.600
Tengchong	43,200	41.30	15.65	1.580
Xinping	43,200	71.30	15.65	1.709
Stand-alone - 3 MW				
Funing	17,280	39.70	8.79	0.977
Yongsheng Maguohe	21,600	83.30	8.02	1.100
Stand-alone - 6 MW				
Guangnan	34,560	23.90	18.15	1.790
Mengla	41,470	27.40	18.15	1.890

Notes: Fuel requirements based on 1.5 dry kg $kWh.^{-1}$.

In addition to installed capital costs and fuel, the feasibility of these biomass-to-electricity projects are dependent upon the number of kWh exported and sold to the local grid and the purchase price of power. Table 8 summarizes these assumptions for each of the twelve identified projects. Generally, plants are assumed to sell power to the grid for about 4500 to 5000 hours each year at prices ranging from 0.25 to 0.40¥ kWh^{-1}. The relatively low overall capacity factors reflect the fact that the plant would operate near full capacity during the cane crushing season, which is also the dry season when hydro resources are at their lowest availability, and operate at about 50% capacity during the remainder of the year.[8] Power rates appear to be somewhat flexible and are subject to local negotiation especially during the dry season (e.g., seasonal rates).

[8]The cane crushing season is relatively short lasting about 110 days.

Table 8. Summary of biomass-to-electricity generation and export power sales

Plant type - Capacity Project	Hours of operation	Export generation (MWh)	Purchase price (¥ kWh^{-1})
Sugarmill - 3 MW			
Menghai	4500	10,800	0.30
Yongde	5000	12,000	0.25
Yongsheng Qina	5000	12,000	0.35
Sugarmill - 6 MW			
Baoshan	5000	24,000	0.25
Luxi	5000	24,000	0.25
Shuangjiang	5000	24,000	0.25
Tengchong	5000	24,000	0.25
Xinping	5000	24,000	0.35
Stand-alone - 3 MW			
Funing	4000	9,600	0.30
Yongsheng Maguohe	5000	12,000	0.35
Stand-alone - 6 MW			
Guangnan	4000	19,200	0.30
Mengla	4800	23,040	0.40

Notes: Export generation based on-site needs of 10% and a 90% power factor (80% of generated power is exported to the grid). The purchase price does not include a 5% tax on power sales within the Province.

A financial summary (net present value, levelized cost of power, and internal rate of return) of the twelve identified projects is summarized in Table 9 with a ranking of projects for measure in Table 10. (The spreadsheets containing the assumptions, factor costs, and financial summary are provided in Appendix B). In calculating these measures, a number of key and often simplifying assumptions were made, and many of the assumptions are rather conservative.

- First, the net present value and levelized cost of power was calculated over a 30 year time horizon using a real discount rate of 10%.
- Conversion of sugarmills and construction of stand-alone facilities were assumed to be completed in one year. No financing was assumed (investment was charged completely in year one).
- No secondary income was assumed from plantation operations.
- Costs of wood feedstocks are from Table 6. For some projects, these costs are much lower than local firewood costs. Using market firewood prices would significantly lower financial performance measures for a number of projects.

- For the sugarmill conversions, it was assumed that sufficient bagasse was available to meet on-site steam and power needs, and all purchased wood is used for export power. Usually, excess bagasse is available to meet some of the plant's fuel needs in the off-season.
- Power plant designs are based on the availability of Chinese equipment and are probably sub-optimal. Heat rates for power plants are very low. Substantial wood fuel savings are possible especially when excess bagasse is accounted for.
- Power purchase rates reflect what small-scale industrial and domestic users are currently willing to pay. No escalation of rates was considered. A tax of 5% was levied on all power sales.
- On-site power needs were assumed to be 10% (gross to net). An additional 10% of generation was assumed to be plant losses.

The financial results in Tables 9 and 10 are highly sensitive to certain assumptions, especially those related kWh exported and power rates. However, the Mengpeng rubber farm (stand-alone plant) in Mengla County clearly outranks all other projects. The Xinping project is second on the net present value basis with Menghai and Baoshan somewhat less. These latter projects are all sugarmill conversions. Relative rankings of the projects change somewhat on the basis of the internal rate of return measure. The Yongsheng Qina sugarmill conversion is followed closely by Menghai and Mengla sugarmills. Each of these projects has an internal rate of return in excess of 30%. Finally, on the basis of levelized cost of power all plants are capable of generating power at costs ranging between 0.20 and 0.30¥ kWh^{-1} with the exception of Yongsheng Maguohe stand-alone facility.

3.3 SENSITIVITY ANALYSIS

Figures 3 and 4 summarize how changes in the sales price, wood cost, and capital cost affect the internal rate of return. Figure 3 shows the sensitivity for the Yongsheng Qina sugarmill conversion and Fig. 4 for the Mengla Mengpeng stand-alone facility. These results clearly show that changes in power price greatly influences the internal rate of return measure of viability for both projects. Small increases in sales price can increase rates of return significantly. On the cost side, similar changes were examined for cost of wood feedstocks and plant capital. These results are as expected. Because of the higher assumed cost of wood feedstocks for the Qina plant, changes in wood feedstock cost have a more pronounced effect than similar changes for the Mengla stand-alone plant. Similarly, changes in capital cost are more important for the Mengla plant.

Table 9. Financial summary of biomass-to-electricity projects

Plant type - Capacity Project	Net present value (million ¥)	Levelized cost of power (¥ kWh^{-1})	Internal rate of return (%)
Sugarmill - 3 MW			
Menghai	10.489	0.188	31.01
Yongde	5.094	0.201	23.47
Yongsheng Qina	8.019	0.273	31.08
Sugarmill - 6 MW			
Baoshan	9.782	0.203	20.95
Luxi	8.134	0.211	16.30
Shuangjiang	7.141	0.216	15.54
Tengchong	4.962	0.226	13.89
Xinping	12.276	0.291	19.36
Stand-alone - 3 MW			
Funing	0.472	0.294	10.66
Yongsheng Maguohe	1.405	0.337	12.12
Stand-alone - 6 MW			
Guangnan	7.035	0.258	14.74
Mengla	31.965	0.241	30.93

Notes: Net present value and levelized cost of power based on a 10% real discount rate and 30 year time horizon.

Table 10. Ranking of projects on basis of financial measures

Net present value million ¥	Levelized cost of power ¥ kWh^{-1}	Internal rate of return %
Mengla - 31.9	Menghai - 0.19	Yongsheng Qina - 31.0
Xinping - 12.3	Yongde - 0.20	Menghai - 31.0
Menghai - 10.5	Baoshan - 0.20	Mengla - 30.9
Baoshan - 9.8	Luxi - 0.21	Yongde - 23.5
Luxi - 8.1	Shuangjiang - 0.22	Baoshan - 21.0
Yongsheng Qina - 8.0	Tengchong - 0.23	Xinping - 19.4
Shuangjiang - 7.1	Mengla - 0.24	Luxi - 16.3
Guangnan - 7.0	Guangnan - 0.26	Shuangjiang - 15.5
Yongde - 5.1	Yongsheng Qina - 0.27	Guangnan - 14.7
Tengchong - 5.0	Xinping - 0.29	Tengchong - 13.9
Yongsheng Maguohe - 1.4	Funing - 0.29	Yongsheng Maguohe - 12.1
Funing - 0.5	Yongsheng Maguohe - 0.34	Funing - 10.7

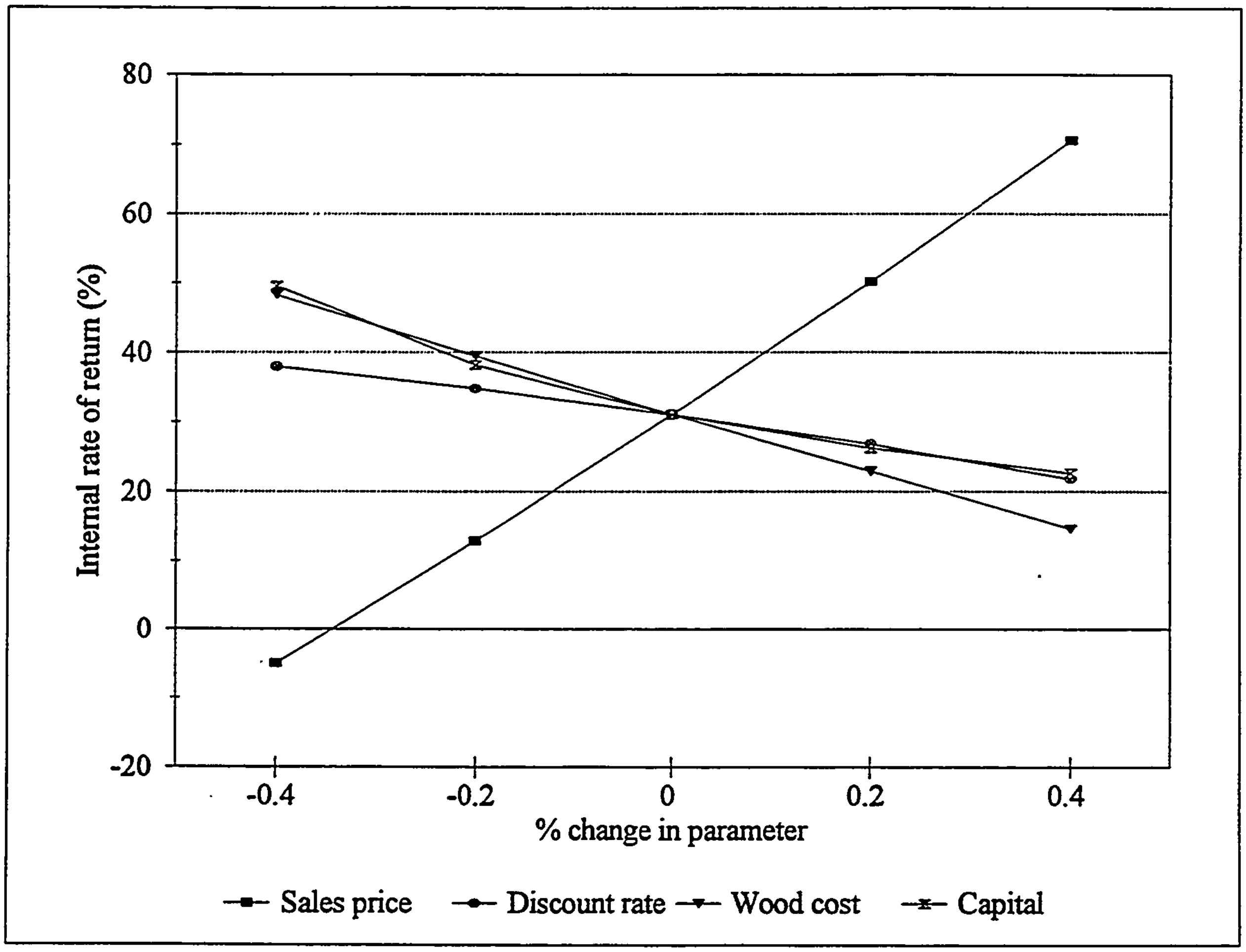

Fig. 3. Internal rate of return sensitivity of the Yongsheng Qina project to changes in important parameters.

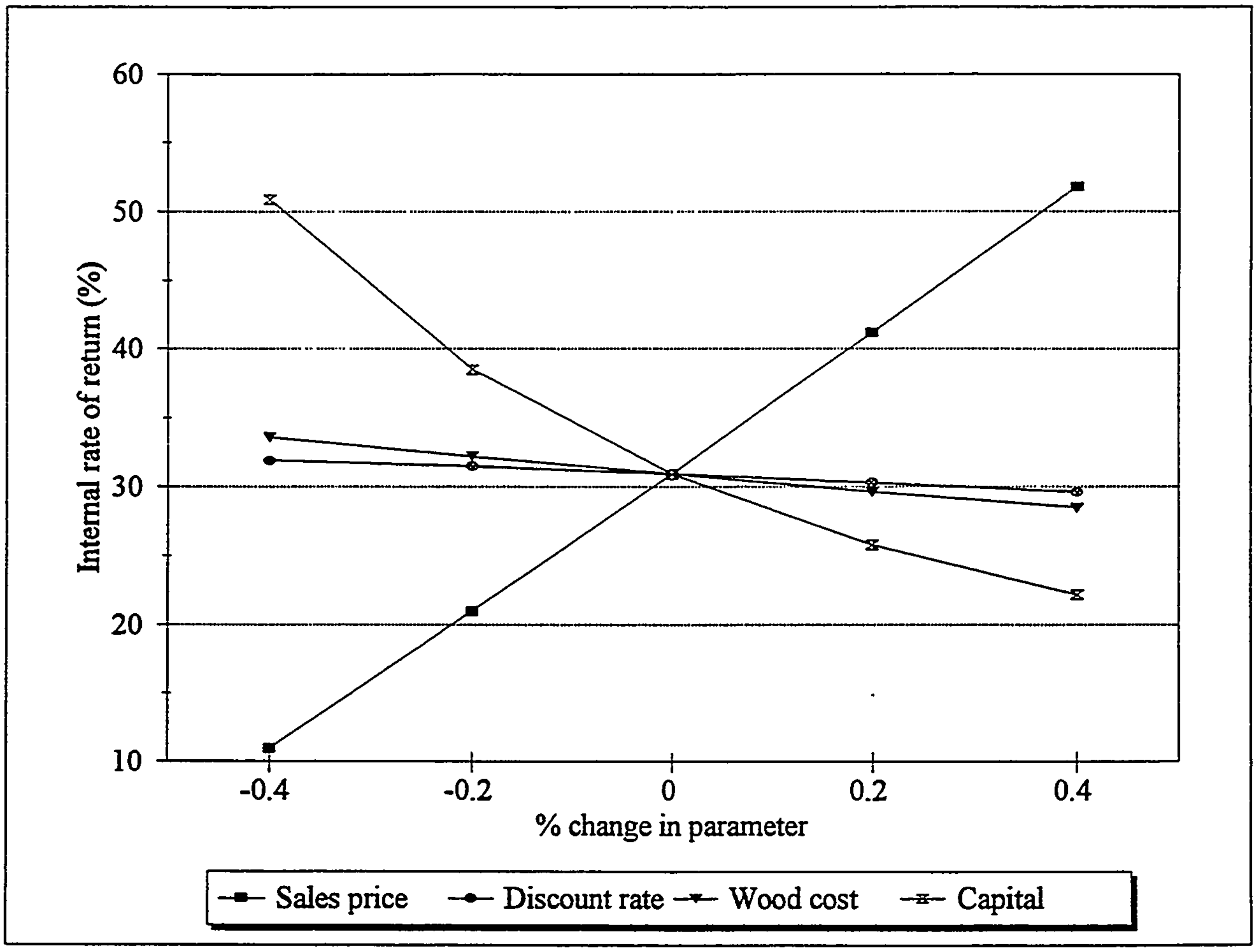

Fig. 4. Internal rate of return sensitivity of the Mengla Mengpeng project to changes in important parameters.

As noted, the designs for the sugarmill conversions and stand-alone plants are probably sub-optimal because they are based on the availability of Chinese equipment, a desire to minimize total investment cost, and, perhaps, an over caution that biomass-to-electricity plants can sell all their power output. The plants as designed are also exceedingly inefficient even for steam-turbine cycles resulting in the use of more wood feedstocks than perhaps is necessary. An obvious question is to reconsider the scale of the plants and to use more state-of-the-art technology that would more efficiently use the wood resource. Figure 5 and 6 illustrate a situation in which the scale of the plant is increased (10 MW for the Qina plant and 20 MW for the Mengpeng plant) and the efficiency of conversion is doubled. To account for equipment differences and upgrades, the x-axis of Fig. 5 and Fig. 6 represents a doubling, tripling, quadrupling, and quintupling of capital cost. The horizontal lines in both figures show the levelized cost of power for the two plants as configured in the previous sub-section. These plants annually operate 5000 hours and 4800 hours for Qina and Mengpeng, respectively. Results indicate that the same levelized cost of power could be generated at the Qina plant using equipment that is twice as efficient and over three times the installed capital. For the Mengla plant, a doubling of plant capital cost operating at twice the efficiency is equivalent to the base case discussed previously. Such a plant would produce considerably more power and use the feedstock much more efficiently.

3.4 SUMMARY

The analysis indicates that there are a number of projects that appear to be very attractive financially. These results are also somewhat consistent with the results produced by YIES (1995). Sensitivity analysis suggest that power purchase agreements are very important and affect viability greatly. Analysis also suggests that additional engineering design might be useful to find a more optimal conversion design for the sugarmills and a standard design for stand-alone plants.

Both plants are operating at relatively low capacity factors. If annual operation could be increased to 7000 hours, which is equivalent to an 80% capacity factor and is typical for biomass facilities, the same levelized cost of power could be generated at Qina with a five times increase in capital cost and over a three increase in capital cost at Mengla.

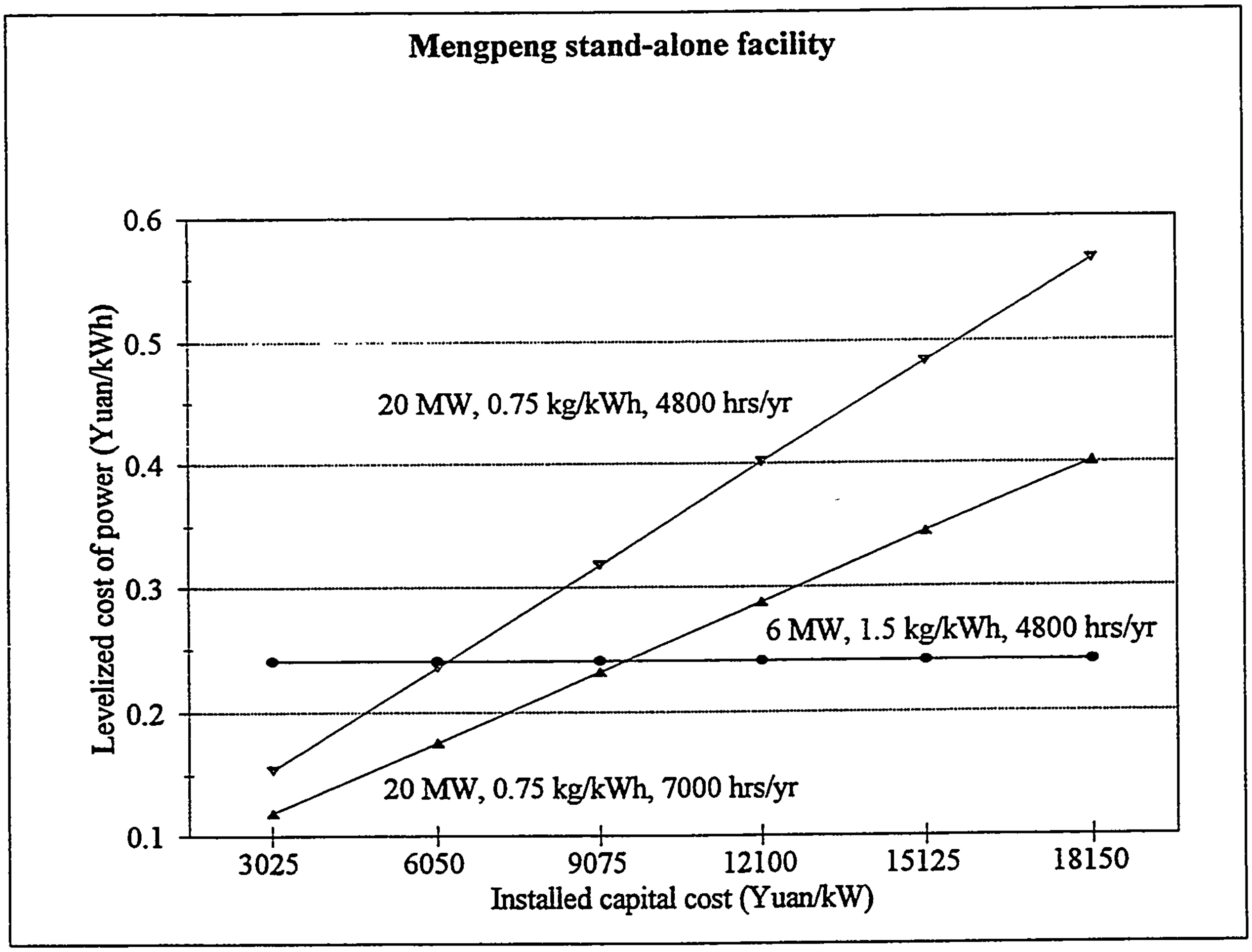

Fig. 5. Levelized cos of power as a function of plant capital cost for a larger more efficient plant operating at low and high capacity factors: Menpeng stand-alone facility

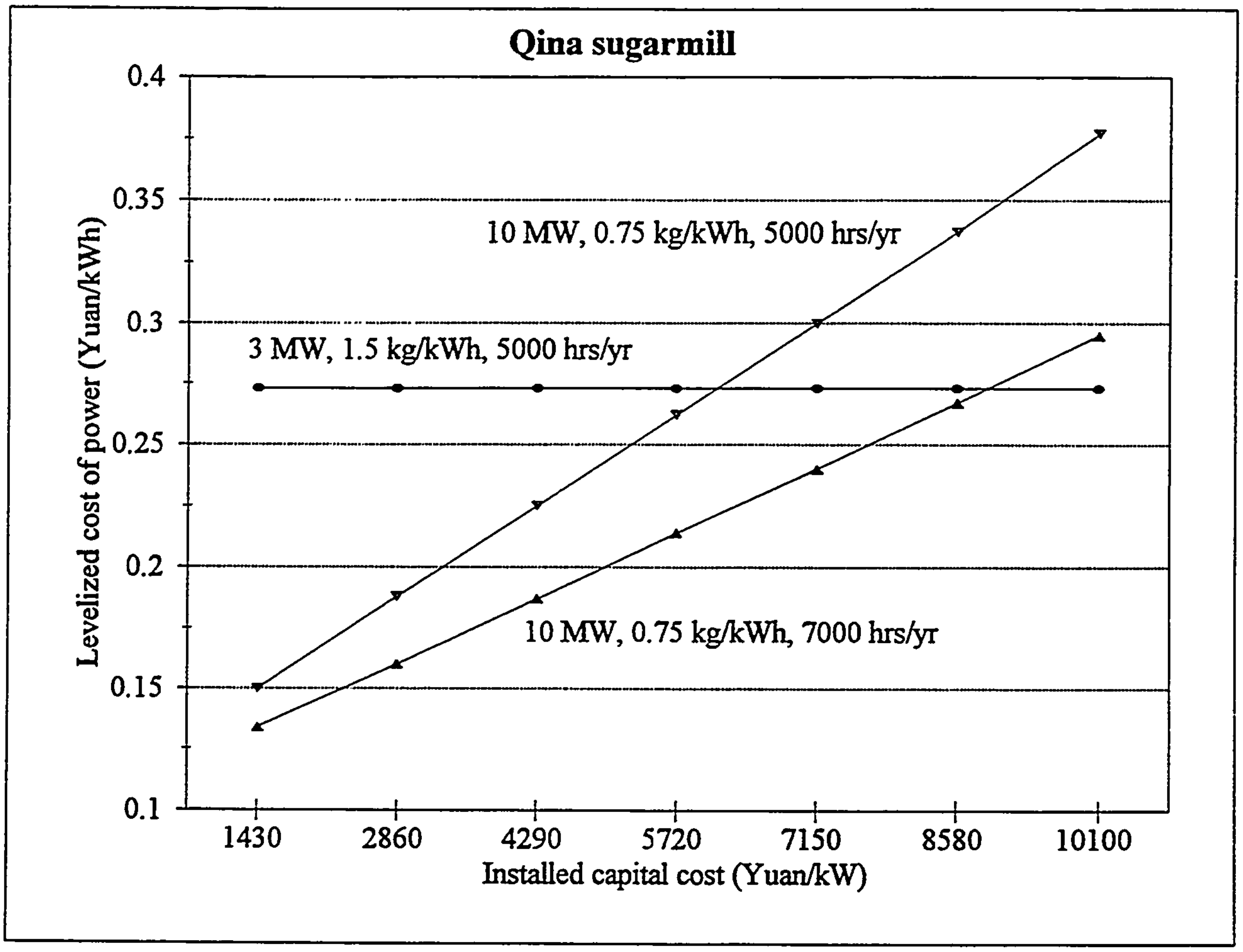

Fig. 6. Levelized cos of power as a function of plant capital cost for a larger more efficient plant operating at low and high capacity factors: qina sugarmill facility

4. RANK-ORDERING OF IDENTIFIED BIOMASS-TO-ELECTRICITY PROJECTS

The results of the feasibility analysis shows that there are a number of projects that have high net present values and offer internal rates of return in excess of 30%. However, other criteria are potentially important in determining which projects are best suited for initial investment and development. To provide a more comprehensive ranking than one on the basis of financial performance alone, additional criteria were developed. These criteria include the size of the biomass resources base, a measure of power demand, and a measure of local capabilities. A simple multicriteria method was then used to rank the individual projects.

Table 11 summarizes the four criteria that were used to rank the twelve projects. The internal rate of return and assumptions are discussed in the previous section. Biomass resources are the amount of wood feedstocks believed to be sustainably available for power production (Section 2 of this report). The power demand criterion reflects anticipated shortfalls in electricity supply or power needs that are likely to be unserved in the near future given expected economic growth. Additional discussion of power demand can be found in YIES (1995). The fourth criterion is a local capability index that was used to rate each county for quality of local people to organize and implement a project. This index was difficult to develop and given the time and resources available all that could be done to discriminate among counties was to assign higher ratings Mengla and Yongsheng counties. It was felt that these two counties have superior local capabilities relative to the other counties. No discrimination among the other counties was possible and all that could be concluded was that adequate capabilities existed at the local level.

The basic ranking model can be represented as follows:

$$V(X_j) = \sum_{i=1}^{n} w_i v_i(x_{ij})$$

where $V(X_j)$ is the overall additive value for candidate biomass-to-electricity project j, w_i is the weight assigned to criterion I, v_i is the single criterion value function for x_i, x_i is the measurement on attribute I for project j, and n is the number of criteria.

The ranking is made operational in the following sequence of steps:

- evaluate each project separately on each criterion (a 0-10 scale was used);
- assign weights to the criteria;
- aggregate the criterion weights and the single-criterion evaluations of the projects to obtain an overall measure of value or worth;
- conduct sensitivity analyses;
- and rank order projects.

Table 11. Summary criteria used to rank-order biomass-to-electricity projects

Project	Internal rate of return (%)	Biomass resources (dry tonnes yr^{-1})	Power demand (million kWh yr^{-1})	Local capabilities
Baoshan	21.0	74,200	79.38	1
Funing	10.7	107,900	11.78	1
Guangnan	14.7	462,100	38.71	1
Luxi	16.3	201,100	45.00	1
Mengla	30.9	266,800	52.50	2
Menghai	31.0	246,800	12.08	1
Shuangjiang	15.5	279,200	7.27	1
Tengchong	13.9	141,000	32.34	1
Yongde	23.5	179,900	22.38	1
Yongsheng Qina	31.0	81,900	22.50	2
Yongsheng Magh.	12.1	81,900	22.50	2
Xinping	19.4	48,600	18.45	1

Notes: Power demand and local capabilities index (2 = excellent and 1 = adequate) are explained in more detail in YIES (1995).

The results of the ranking under three alternative sets of weights is shown in Table 12. The results clearly show that the Mengla project dominates under each of the three weight sets. The Qina sugarmill conversion is second highest ranked project under the first weight set in Table 12. (This set of weights were suggested and used by the staff of YIES.) If the weight on local capability is reduced relative to the other criteria weights, the Baoshan project becomes the second highest ranked project. Other weight sets did not produce substantially different results. Of course, reducing the weight of the financial criterion relative to the other weights would change the project rankings considerably. This was not as the financial criterion was deemed to be the most important of the four criteria.

Table 12. Rankings of biomass-to-electricity projects under alternative criteria weights

Criterion - weight		
IRR - 0.4	IRR - 0.25	IRR - 0.4
Power demand - 0.3	Power demand - 0.25	Power demand - 0.4
Local capabilities - 0.2	Local capabilities - 0.25	Local capabilities - 0.1
Biomass resource- 0.1	Biomass resource- 0.25	Biomass resource- 0.1
Project - ranking value		
Mengla - 8.3	Mengla - 7.8	Mengla - 7.9
Yongsheng Qina - 6.6	Yongsheng Qina - 5.6	Baoshan - 6.1
Baoshan - 5.1	Guangnan - 4.0	Yongsheng Qina - 5.7
Menghai - 4.5	Baoshan - 3.9	Menghai - 4.5
Yongde - 3.3	Menghai - 3.7	Yongde - 3.5
Guangnan - 3.0	Yongsheng Magouhe - 3.3	Luxi - 3.4
Luxi - 2.9	Luxi - 2.8	Guangnan - 3.4
Yongsheng Magouhe - 2.8	Yongde - 2.8	Tengchong - 2.1
Xinping - 2.0	Shuangjiang - 1.8	Xinping - 2.1
Tengchong - 1.8	Tengchong - 1.7	Yongsheng Magouhe - 2.0
Shuangjiang - 1.3	Xinping - 1.3	Shuangjiang - 1.7
Funing - 0.1	Funing - 0.4	Funing - 0.1

Notes: The relative rankings of the projects change when the net present value is used in place of the internal rate of return. The Mengla project dominates as before; however, the first set of weights (column 2) would rank Baoshan ahead of Qina, the second set would place Baoshan and Guangnan ahead of Qina, and the third set would place Baoshan and five other projects ahead of Qina.

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APPENDIX A

SUGAR MILLS IN YUNNAN PROVINCE

Table A1. Locations and capacities of sugar mills in Yunnan Province, China

Prefecture	County	Mill	Capacity T/D
Dehong	Lianghe	Lianghe	1000
		Mongyang	1000
	Yingjing	Pinyan	500
		Zhanxi	500
		Nongzhan	1500
	Luxi	Mangshi	1500
		Huagqiao	500
		Zhefang	500
	Longchuan	Nongba	1000
		Jingkan	2000
	Rueili	Rueili	1500
	Baoshan	Nujing	1000
		Dongfeng	1000
		Shangjing	700
		Loming	500
		Manghe	500
	Changlin	Wangdian	750
		Kashi	800
	Shidian	Jioucheng	500
		Youwang	500
	Longlin	Mongno	500
		Longtan	500
	Tengshon	Hohua	500
Lincang	Yunxian	Yunxian	500
		Xinghu	500
	Gengma	Gengma	500
		Huaqiao	1000
	Shuangjing	Shuangjing	500
	Fengqing	Yingpang	500
	Yongde	Yongkang	500
		Yongdian	500
		Changyan	500
	Zhengkang	Mongduei	500
Honghe	Kaiyan	Kaiyan	1500
	Mile	Mile	1000
		Pongpu	1000
	Jiangshuei	Quxi	1000
		Jiangshuei	1500
	Mongzi	Yugopu	1500
		Caopa	500
	Shiping	Shiping	500

Yuxi	Yanjiang	Yanjiang	2000
		Mangling	1500
		Kangzhuan	500
		Dongwo	750
	Xingping	Xingping	1500
		Kasha	500
	Woshang	Huanian	500
	Hualin	Pangxi	1000
Lijiang	Yongshen	Yongshen	500
		Qina	500
Simao	Jindong	Wengjin	500
		Zhemong	500
	Langshang	Shangyu	1000
	Jingu	Zhongshang	500
		Yongping	1000
	Zhengyan	Mongda	500
	Monglian	Monglian	1500
Chuxiong	Yanmou	Zhuling	1000
		Yanmou	500
Dali	Houqing	Houqing	750
	Bingchuan	Bingchuan	750
Zhaotong	Qiojia	Qiojia	1000
Wenshan	Wengshan	Wengshan	500
	Maguan	Maguan	500
Dongchaun City	Dongchuan	Dongchuan	500
Xishaungbanna	Jinghong	Puweng	500
	Monghai	Jingzheng	2500
		Liming	1000
		Menga	1000
	Mengla	Mengpong	250

APPENDIX B

SAMPLE FINANCIAL ANALYSIS SREADSHEETS

Guangnan Guangnan - Stand alone

Yield		
Productivity (Mg/ha/yr)	15	25
Harvest age (yrs)	7	
Yield at harvest (MG)	105	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	15	
Net yield at harvest	105	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	6	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	4000	
Total generation (kWh/yr)	1.92E+07	
Wood needs (Mg/yr)	34560	
Total net planted area (ha)	329	
Power plant		
Capital (Y/kW)	3025	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.093229167	1790000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	750
Total	750
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)		23.93	495000	14.31
			Local price	100
Revenues				
Power sales (Y/kWh)		0.3		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.015		
Levelized feedstock cost (Y/Mg)				$23.93
NPV plantation operations (Million Yuan)				$0.000
Net present value (Million Yuan)				. $7.035
Levelized cost of power (Y/kWh)				$0.258
Internal rate of return				14.74%

Funing Funing - Stand alone

Yield		
Productivity (Mg/ha/yr)	15	15
Harvest age (yrs)	7	
Yield at harvest (MG)	105	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	15	
Net yield at harvest	105	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	3	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	4000	
Total generation (kWh/yr)	9.60E+06	
Wood needs (Mg/yr)	17280	
Total net planted area (ha)	165	
Power plant		
Capital (Y/kW)	2990	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.101770833	977000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	2250
Total	2250
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)		39.68	660000	38.19
			Local price	150
Revenues				
Power sales (Y/kWh)		0.3		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.015		
Levelized feedstock cost (Y/Mg)				$39.68
NPV plantation operations (Million Yuan)				$0.000
Net present value (Million Yuan)				$0.472
Levelized cost of power (Y/kWh)				$0.294
Internal rate of return				10.66%

Menghai Liming - Sugarmill

Yield		
Productivity (Mg/ha/yr)	20	30
Harvest age (yrs)	7	
Yield at harvest (MG)	140	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	20	
Net yield at harvest	140	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	3	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	4500	
Total generation (kWh/yr)	1.08E+07	
Wood needs (Mg/yr)	19440	
Total net planted area (ha)	139	
Power plant		
Capital (Y/kW)	1930	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.073888889	799000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	1100
Total	1100
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)	20.71	1170000	60.19
		Local price	30
Revenues			
Power sales (Y/kWh)	0.3		
By-/co-products (Y/ha)	0		
Taxes (% of product value)			
Wood 0%			
Y/Mg	0		
By-/co-produ 0%			
Y/ha	0		
Power sales 5%			
Y/kWh	0.015		
Levelized feedstock cost (Y/Mg)			$20.71
NPV plantation operations (Million Yuan)			$0.000
Net present value (Million Yuan)			$10.489
Levelized cost of power (Y/kWh)			$0.188
Internal rate of return			31.01%

Yongsheng Maguohe - Stand alone

Yield		
Productivity (Mg/ha/yr)	8	
Harvest age (yrs)	7	
Yield at harvest (MG)	56	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	8	
Net yield at harvest	56	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	3	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	5000	
Total generation (kWh/yr)	1.20E+07	
Wood needs (Mg/yr)	21600	
Total net planted area (ha)	386	
Power plant		
Capital (Y/kW)	2673	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.091666667	1100000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	70
Seedlings	640
Fertilizer	840
Labor	0
Protection	372
Research	30
Management	45
Miscellaneous	703
Total	2700
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)	83.27	1720000	79.63
		Local price	120
Revenues			
Power sales (Y/kWh)	0.35		
By-/co-products (Y/ha)	0		
Taxes (% of product value)			
Wood 0%			
Y/Mg	0		
By-/co-produ 0%			
Y/ha	0		
Power sales 5%			
Y/kWh	0.0175		
Levelized feedstock cost (Y/Mg)			$83.27
NPV plantation operations (Million Yuan)			$0.000
Net present value (Million Yuan)			$1.405
Levelized cost of power (Y/kWh)			$0.337
Internal rate of return			12.12%

Yongde Yongkang - Sugarmill

Yield		
Productivity (Mg/ha/yr)	15	15
Harvest age (yrs)	7	
Yield at harvest (MG)	105	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	15	
Net yield at harvest	105	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	3	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	5000	
Total generation (kWh/yr)	1.20E+07	
Wood needs (Mg/yr)	21600	
Total net planted area (ha)	206	
Power plant		
Capital (Y/kW)	1430	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.060666667	720000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	3000
Total	3000
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price)			
at harvest (Y/Mg)	47.56	980000	45.37
		Local price	40
Revenues			
Power sales (Y/kWh)	0.25		
By-/co-products (Y/ha)	0		
Taxes (% of product value)			
Wood 0%			
Y/Mg	0		
By-/co-produ 0%			
Y/ha	0		
Power sales 5%			
Y/kWh	0.0125		

Levelized feedstock cost (Y/Mg)	$47.56
NPV plantation operations (Million Yuan)	$0.000
Net present value (Million Yuan)	$5.094
Levelized cost of power (Y/kWh)	$0.201
Internal rate of return	23.47%

Shuangjiang Shuangjiang - Sugarmi

Yield		
Productivity (Mg/ha/yr)	15	15
Harvest age (yrs)	7	
Yield at harvest (MG)	105	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	15	
Net yield at harvest	105	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	6	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	5000	
Total generation (kWh/yr)	2.40E+07	
Wood needs (Mg/yr)	43200	
Total net planted area (ha)	411	
Power plant		
Capital (Y/kW)	2608	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.066666667	1600000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	1800
Total	1800
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price)			
at harvest (Y/Mg)	34.96	1460000	33.80
		Local price	50
Revenues			
Power sales (Y/kWh)	0.25		
By-/co-products (Y/ha)	0		
Taxes (% of product value)			
Wood 0%			
Y/Mg	0		
By-/co-produ 0%			
Y/ha	0		
Power sales 5%			
Y/kWh	0.0125		

Levelized feedstock cost (Y/Mg)	$34.96
NPV plantation operations (Million Yuan)	$0.000
Net present value (Million Yuan)	$7.141
Levelized cost of power (Y/kWh)	$0.216
Internal rate of return	15.54%

Xinping Xinping - sugarmill

Yield		
Productivity (Mg/ha/yr)	10	
Harvest age (yrs)	7	
Yield at harvest (MG)	70	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	10	
Net yield at harvest	70	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	6	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	5000	
Total generation (kWh/yr)	2.40E+07	
Wood needs (Mg/yr)	43200	
Total net planted area (ha)	617	
Power plant		
Capital (Y/kW)	2608	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.071208333	1709000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	3000
Total	3000
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)		71.34	3661000	$4.77
			Local price	n/a
Revenues				
Power sales (Y/kWh)		0.35		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.0175		
Levelized feedstock cost (Y/Mg)				$71.34
NPV plantation operations (Million Yuan)				($0.000)
Net present value (Million Yuan)				$12.276
Levelized cost of power (Y/kWh)				$0.291
Internal rate of return				19.36%

Tengchong Hehua - sugarmill

Yield		
Productivity (Mg/ha/yr)	15	25
Harvest age (yrs)	7	
Yield at harvest (MG)	105	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	15	
Net yield at harvest	105	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	6	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	1.5	12.44%
Power factor	0.90	
On-site use	0.10	
Hours	5000	
Total generation (kWh/yr)	2.40E+07	
Wood needs (Mg/yr)	43200	
Total net planted area (ha)	411	
Power plant		
Capital (Y/kW)	2608	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.065833333	1580000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	2400
Total	2400
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)		41.26	1070000	24.77
			Local price	75
Revenues				
Power sales (Y/kWh)		0.25		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.0125		
Levelized feedstock cost (Y/Mg)				$41.26
NPV plantation operations (Million Yuan)				$0.000
Net present value (Million Yuan)				$4.962
Levelized cost of power (Y/kWh)				$0.226
Internal rate of return				13.89%

Baoshan Dongfeng - sugarmill

Yield		
Productivity (Mg/ha/yr)	15	
Harvest age (yrs)	7	
Yield at harvest (MG)	105	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	15	
Net yield at harvest	105	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion			
15	Installed capacity (MW)	6	
	Energy content (GJ/Mg)	19.3	
	Efficiency (kg/kWh)	1.5	12.44%
	Power factor	0.90	
	On-site use	0.10	
	Hours	5000	
	Total generation (kWh/yr)	2.40E+07	
	Wood needs (Mg/yr)	43200	
	Total net planted area (ha)	411	
	Power plant		
	Capital (Y/kW)	1750	
	Fixed O&M (Y/kW)	0	
	Variable O&M (Y/kWh)	0.05475	1314000
	Annual management		
	Weeding/tending	50	
	Overseeing	50	
	Total	100	
	Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	3000
Total	3000
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price)				
at harvest (Y/Mg)		47.56	1960000	45.37
			Local price	150
Revenues				
Power sales (Y/kWh)		0.25		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.0125		
Levelized feedstock cost (Y/Mg)				$47.56
NPV plantation operations (Million Yuan)				$0.000
Net present value (Million Yuan)				$9.782
Levelized cost of power (Y/kWh)				$0.203
Internal rate of return				20.95%

Luxi Huanjao - sugarmill

Yield		
Productivity (Mg/ha/yr)	18	
Harvest age (yrs)	7	
Yield at harvest (MG)	126	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	18	
Net yield at harvest	126	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion			
	Installed capacity (MW)	6	
35	Energy content (GJ/Mg)	19.3	
	Efficiency (kg/kWh)	1.5	12.44%
	Power factor	0.90	
	On-site use	0.10	
	Hours	5000	
	Total generation (kWh/yr)	2.40E+07	
	Wood needs (Mg/yr)	43200	
	Total net planted area (ha)	343	
	Power plant		
	Capital (Y/kW)	2608	
	Fixed O&M (Y/kW)	0	
	Variable O&M (Y/kWh)	0.065416667	1570000
	Annual management		
	Weeding/tending	50	
	Overseeing	50	
	Total	100	
	Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	
Seedlings	
Fertilizer	
Labor	
Protection	
Research	
Management	
Miscellaneous	2250
Total	2250
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price)				
at harvest (Y/Mg)		33.07	710000	16.44
			Local price	50
Revenues				
Power sales (Y/kWh)		0.25		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.0125		
Levelized feedstock cost (Y/Mg)				$33.07
NPV plantation operations (Million Yuan)				$0.000
Net present value (Million Yuan)				$8.134
Levelized cost of power (Y/kWh)				$0.211
Internal rate of return				16.30%

Yongsheng Qina - sugarmill

Yield		
Productivity (Mg/ha/yr)	8	8
Harvest age (yrs)	7	
Yield at harvest (MG)	56	
LAC	83.27	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	8	
Net yield at harvest	56	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	10	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	0.75	24.87%
Power factor	0.90	
On-site use	0.10	
Hours	7008	
Total generation (kWh/yr)	5.61E+07	
Wood needs (Mg/yr)	50458	
Total net planted area (ha)	901	
Power plant		
Capital (Y/kW)	10100	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.013520263	758000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	70
Seedlings	640
Fertilizer	840
Labor	0
Protection	372
Research	30
Management	45
Miscellaneous	703
Total	2700
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)		83.27	1720000	34.09
			Local price	120
Revenues				
Power sales (Y/kWh)		0.35		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.0175		
Levelized feedstock cost (Y/Mg)				$83.27
NPV plantation operations (Million Yuan)				$0.000
Net present value (Million Yuan)				$26.658
Levelized cost of power (Y/kWh)				$0.295
Internal rate of return				13.49%

Mengla Mengpeng - stand-alone

Yield		
Productivity (Mg/ha/yr)	20	40
Harvest age (yrs)	7	
Yield at harvest (MG)	140	
	27.40	
Losses		
Harvest (%)	0%	
Decomposition (%/month)	0%	
Ave. storage months	4	
Storage losses	0%	
Total losses (%)	0%	
Net productivity	20	
Net yield at harvest	140	
Discount rate (%)	10.0%	
Finance rate (%)	0.0%	
Loan period (yrs)	1	

Conversion		
Installed capacity (MW)	20	
Energy content (GJ/Mg)	19.3	
Efficiency (kg/kWh)	0.75	24.87%
Power factor	0.90	
On-site use	0.10	
Hours	4800	
Total generation (kWh/yr)	7.680E+07	
Wood needs (Mg/yr)	69120	
Total net planted area (ha)	494	
Power plant		
Capital (Y/kW)	6050	
Fixed O&M (Y/kW)	0	
Variable O&M (Y/kWh)	0.024609375	1890000
Annual management		
Weeding/tending	50	
Overseeing	50	
Total	100	
Land Rent	0	

Infrastructure	0
Plantation establishment (Y/ha)	
Nursery establishment	0
Seedlings	0
Fertilizer	0
Labor	0
Protection	0
Research	0
Management	0
Miscellaneous	1950
Total	1950
Harvest/Transport	
Cutting/handling	900
Hauling	600
Total	1500
By-/co-product harvest cost	0

Wood value (price) at harvest (Y/Mg)		27.40	2790000	40.36
			Local price	60
Revenues				
Power sales (Y/kWh)		0.4		
By-/co-products (Y/ha)		0		
Taxes (% of product value)				
Wood	0%			
Y/Mg		0		
By-/co-produ	0%			
Y/ha		0		
Power sales	5%			
Y/kWh		0.02		
Levelized feedstock cost (Y/Mg)				$27.40
NPV plantation operations (Million Yuan)				$0.000
Net present value (Million Yuan)				$109.597
Levelized cost of power (Y/kWh)				$0.236
Internal rate of return				21.55%

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