Biomass gasification for combined heat and power in Jilin province, People's Republic of China

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This paper describes a project that is being co-funded by the Jilin Provincial Government and the United Nations Development Program to demonstrate the technical, economic and market viability of a modern biomass gasification system to provide cooking gas, heat and electricity to village communities in China. The paper summarizes the project background, organization and approach, and provides details of the preliminary design. The project is expected to be constructed and commissioned during 2001 and to undergo operation and evaluation in 2002 and 2003. A commercialization strategy and business plan will be developed to promote project replication.

1. Introduction

The Jilin Provincial Government and the United Nations Development Program (UNDP) are co-funding a project to implement a sustainable energy, rural, combined heat and power demonstration project based on the modernized use of agricultural residues. UNDP funds are being provided through a grant from the UN Foundation [UNDP, 1999]. The long-term goal of this project is the widespread use of gasified biomass to meet the cooking, heating and electricity needs of rural communities not only in China, but also in other developing countries. Jilin province is an ideal location for launching an industry to achieve this goal because it has abundant biomass resources, the need for rural development, an emerging industrial base in this field, and the government commitment needed to ensure sustained growth of such a new industry. This project has been designed to be consistent with UNDP's corporate policy on sustainable energy, which promotes the provision of sustainable energy services as a means to address multiple social, economic, and environmental bottlenecks to human development.

Inadequate energy services are a serious impediment to local development around the world, particularly in many rural areas. Most current use of firewood and agricultural residues for heating and cooking brings with it the detrimental effects of indoor air pollution and associated adverse health effects. In addition, the time spent in the collection of biomass fuels imposes a burden on women and children, reducing the time available to them for more productive activities, such as education and gainful employment. The availability of clean, low-cost heat and power in rural areas based on the biomass resources currently available could increase living standards and would be helpful in promoting rural industrialization and the generation of employment in rural areas. In addition, since sustainable use of biomass leads to no net increase in CO_2 emissions, there would be global climate benefits arising from the widespread use of biomass for power generation. This benefit is increased further in cases where modernized biomass displaces coal for home heating and cooking, and where coal is the basis for existing electricity generation.

2. Jilin province

Jilin province is one of China's main producers of grains, especially corn. The annual grain output reached 20 million tonnes (t) in 1997, the highest among all provinces on a per capita basis. Jilin province, with 2% (26 million) of China's population, accounts for 14% of total Chinese corn production. Agricultural residues, corn stalks in particular, are the principal source of cooking and heating fuel in the rural areas. The availability of these agricultural residues exceeds the quantity needed to maintain soil quality and meet household energy needs. The residues dry out quickly in the field and decay so slowly that if kept in the field they are not easily absorbed in the soil. As a result there is widespread open-field burning of excess agricultural residues in order to promote pest control and help maintain the productivity of the land. The burning creates a significant air pollution concern for provincial officials.

An additional concern in Jilin province is that as farm

Table 1. Hechengli village data [Li, 2000]

Location	1.5 km SE of Lonqjing city, Yanbian prefecture, Jilin province
Households	224
Population	674
Per capita income	5,178 yuan
Principal crops	Corn, rice and soybeans
Main village factories	Chicken house, fertilizer plant, cold drink plant, fish farm, office block
Household fuels	Corn stalk, firewood, coal and LPG
Household energy use (1998)	Electricity: 893 kWh/year Cooking: 5.3 kg/day of stalks Heating: 43 kg/day of stalks
Factory electricity use (1998)	Total: 840,000 kWh/year

incomes rise, the pollution problems associated with cooking and heating are exacerbated. As farmers get richer, they are becoming less willing to gather biomass residues from the field and store them for cooking and heating use throughout the year. Farmers prefer coal briquettes instead if they can afford to buy them because their combustion can be controlled more easily than that of raw biomass and they can be readily purchased from itinerant merchants as needed, minimizing storage requirements. However, coal briquette stoves tend to create even more indoor air pollution than biomass stoves [Dutt and Ravindranath, 1993]. Moreover, the shift to coal is further increasing the excess of crop residue supplies, leading to increased field burning and more outdoor air pollution problems.

Biomass gasification technology has been used in Jilin and other provinces of China to provide clean cooking fuel to rural villages [Dai, Li and Overend, 1998]. While these projects have been successful in providing clean cooking fuel, they have not been economically attractive because the equipment is only utilized for about six hours a day. These cooking fuel projects have not addressed the heating demand, and they actually exacerbate the problem of disposing of the surplus agricultural residues because they provide the cooking requirements through a more efficient use of the residues [Johansson and Ni, 1998].

There is rising demand for increased electricity services in rural China for both household consumption and to support rural industrial development. The large abundance of agricultural residues in Jilin and other Chinese provinces offers the potential to combine electricity generation with the provision of cooking and heating services through a combined heat and power (CHP) application of biomass gasification technology. Co-producing heat and power enhances the economic viability of the process in comparison with separate production of these by making more extensive use of invested capital, as well as improving the overall efficiency of converting biomass into useful energy carriers. Furthermore, with continuing market reform and utility restructuring in China, power generation and distribution from decentralized plants under independent ownership will gradually become possible for economically viable technologies and approaches. The national electricity grid extends to most rural areas in China, affording the opportunity for CHP systems to supply electricity to the grid. Since over 78% of all utility-generated electricity in China comes from coal, there could be substantial positive local, regional and global environmental impacts if electricity from biomass-CHP plants could displace utility-generated electricity.

This project was developed to help create the market and institutional forces essential for wide-scale replication of CHP systems to occur. The project seeks to establish the technical and economic viability of the CHP approach, to develop a business plan and commercialization strategy for project replication, and to identify and promote policy initiatives that are necessary for market-based development of follow-on projects.

3. Project site

Hechengli village, a southeastern suburb of Longjing city in Yanbian Korea prefecture of Jilin province, was selected as the project site. Hechengli village has an annual average temperature of 2.5ºC, annual average precipitation of 525 mm, and 144 days per year without frost. The village covers an area of 217 ha and is surrounded by a planting area of over 13,000 ha containing corn, soybeans and rice. The grain yield for corn is over 4.8 t/ha, and considering that production of 1 t of corn grain yields approximately 2 t of stalks, the crop stalk resources in the area are abundant. If the radius of collection and collected fraction are taken as 10 km and 50%, respectively, the annual availability of only corn and soybean residues to the village is 8000 t, or 4200 equivalent t of standard coal [Liu and Zhao, 2000].

Table 1 provides basic information on Hechengli village, which was selected for this project on the basis of a number of factors, such as the attitude of the local government, the availability of biomass resources, the strength of the local collective economy, availability of skilled workers and accessibility. Hechengli village scored very high in all these areas. It has a well-established village industrial enterprise, started in 1976, that integrates agriculture, industry, and business. It has one of the highest per-capita incomes in Yanbian prefecture and Jilin province. It has abundant stalk resources. It has been carrying on the process of becoming an ecological village since 1994, and it is known for its scenic natural environment. In addition, the village has committed itself to invest local resources towards a portion of the project construction cost.

The leaders and the people of Hechengli village believe that implementation of the project will improve their quality of life and solve problems related to the disposal of biomass waste material. In fact, the village leadership believes the project will do more than just provide clean energy for the residents' cooking and heating needs and

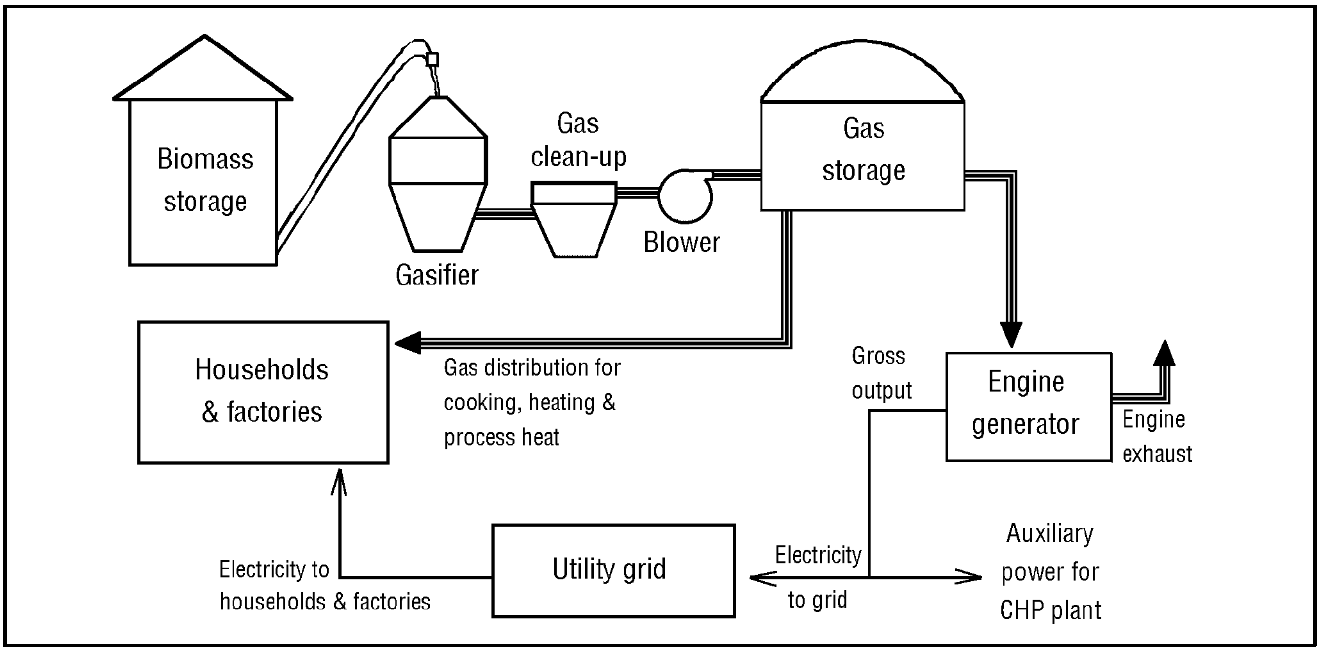

Figure 1. Schematic of the biomass gasification combined heat and power system

electricity for village households and factories. They believe it will help them expand their industrial activities, for example by providing process heat to factories in the summer or by providing heat for vegetable greenhouses in the winter.

4. System description

Figure 1 illustrates the CHP concept planned for Hechengli village. The agricultural residues (biomass) are converted into a combustible gas in a high temperature gasifier, and the gas is cleaned to remove tars and particulates before being stored in a large tank. The gas, called producer gas, has a typical composition of 21% CO, 12% H_2, 2% CH_4, 14% CO_2, and 51% N_2 when generated from corn stalks, and has a heating value of about 5 MJ/Nm^3. From the storage tank, clean gas can be provided through a piping network to the individual households in the village for cooking and heating using modern gas stoves and burners. Gas is also provided to an internal combustion engine-generator to generate electricity that can be provided to the village directly or put into the electricity grid, to which the village is already connected[1].

The quantity and valuation of the electricity sold to the grid is a major issue for the project. Connecting the CHP system to the electricity grid will offer significant technical and economic advantages. The grid connection will allow the generator to be operated at a constant load rather than being cycled in response to the changing electrical needs of the village, shown in Figure 2 along with the main components of that load. This will simplify the system design and allow the system to operate with greater reliability. The increased electricity generation will not require any additional capital investment, and so the increased revenue from electricity sales will significantly improve the economic returns to the project. In fact, the project is not likely to be economic without the increased electricity revenues. There are sufficient biomass resources for the generator to be operated for up to 24 hours a day.

The technical infrastructure to connect the project to the grid is inexpensive and well understood. However, the legal and institutional issues related to gaining grid access for this project, and for similar projects to follow it, are perhaps the most significant hurdles facing the project. There are currently very few independent power producer arrangements in all of China, and the unbundling of the electric utilities into generation and distribution services has just begun. Energy price reform is still a work in progress, and while captive power is a known approach in China, there are several legal, institutional and financial issues that must be addressed before electric sales to the grid are commonplace. This is the context within which this demonstration project is being undertaken.

5. Project organization

The UN Foundation and the W. Alton Jones Foundation, through the UNDP Energy and Atmosphere Program, are sponsoring this project, which is being managed by UNDP's Beijing office. The China International Center for Technical and Economic Exchanges (CICETE) is executing the project for UNDP. The Jilin Provincial Government has established a project office within the Jilin Environmental Protection Bureau to carry out the activities of the project. One of the authors of this paper (Liu Shuying) is the National Project Director. Several international and national technical experts are assisting the project. The Jilin Leading Group on Biomass Utilization, which is a coordinating body of ministries, bureaus and other organizations within the Jilin Provincial Government, provides important guidance to the project. It is expected that the Leading Group will be instrumental in

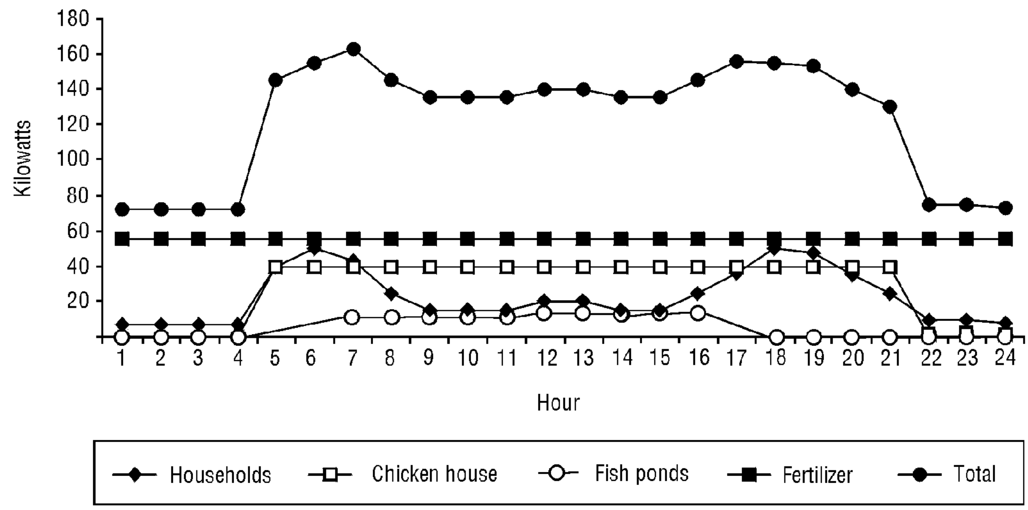

Figure 2. Typical summer-day electricity load for the village CHP system

helping to resolve the complex institutional issues faced by the project.

The overall approach to this project can be summarized as in Figure 3. The project scope includes more than the design, construction and operation of a modern biomass CHP plant. It includes important elements of training for local experts, managers, and officials, as well as elements of market assessment, business planning and information dissemination to establish the strategy and mechanisms for project replication.

6. Project status

An inception meeting was held on March 24, 2000 in Changchun, Jilin to formally initiate the project activities. A technical workshop was held in conjunction with the inception meeting in order to provide basic in-country training on gasification and CHP technologies. The workshop reviewed current technology options, best practices and national and international experiences. Following these meetings, the project office collected basic data on Hechengli village to establish baseline technical, economic and social information for the project.

A study tour of India was undertaken to enable appropriate experts from Jilin province to investigate commercial biomass gasifier systems for electricity generation that are in operation there. (Indian companies are generally acknowledged to be world leaders in small-scale gasification technology.) The study group visited several commercial gasifier systems producing high-quality low-tar gas and generating electricity or providing process heat. The technical, operational and commercial arrangements for these systems were reviewed. The one significant difference of the Indian systems is that they use diesel engines, which require continuous use of some diesel fuel to augment the producer gas (typical diesel consumption is 30% of rated full-diesel consumption). The design of the Hechengli village system envisages use of a spark-ignition engine operating with 100% producer gas.

Table 2. Energy use design data

Design parameter	Value
Household (hh) cooking demand	6 m^3/hh/day (based on a heat value of 4.6 MJ/Nm^3) 5 am to 6 am; 11 am to 12 pm; 6 pm to 7 pm
Household heating demand	58.6 m^3/hh/day (based on a heat value of 4.6 MJ/Nm^3) 5 am to 8 pm
Household electric demand	2.45 kWh/hh/day; average over 24 hrs
Factory electricity demand	2,187 kWh/day; average over 24 hrs in heating season 2,401 kWh/day; average over 24 hrs in non-heating season
Heating season	1 November to 15 April (165 days)

A project site has been selected that is midway between Hechengli village to the north and two other villages to the south. The site is located on a bluff overlooking two village factories (the chicken house and fertilizer plant). The visibility and uncluttered nature of the site make it an attractive site for a demonstration. There is an electrical substation at the fertilizer plant, which will probably be the interconnection point for providing electricity from the CHP system to the electricity grid and the village.

Preliminary design activities have been initiated, and design optimization analyses have been performed based on preliminary energy use data from the village. The most important of the design input values are given in Table 2.

In August 2000, a design workshop was held in Yanji city, Yanbian prefecture, Jilin province to tour the project site, report the results of the India study tour, and to

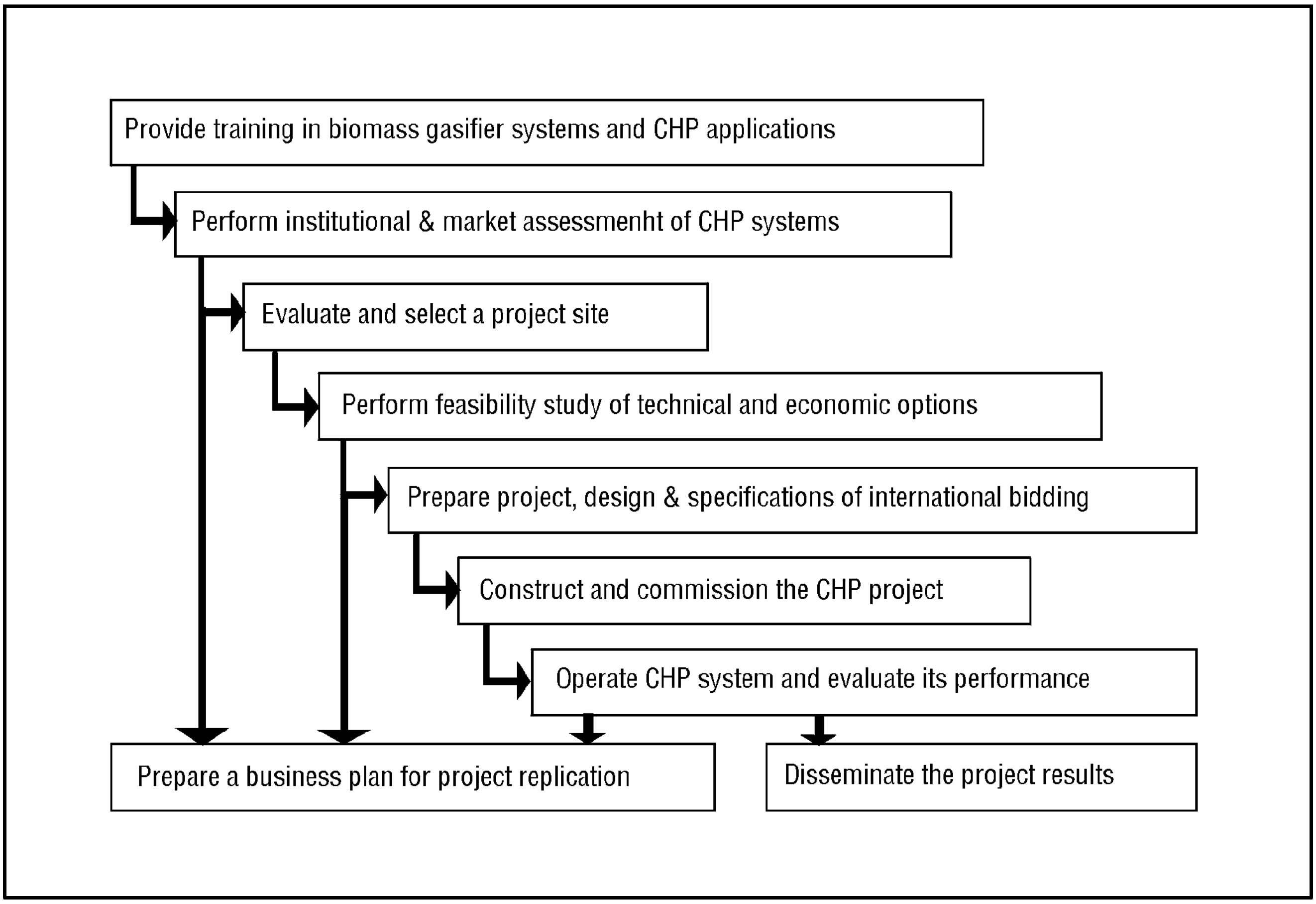

Figure 3. Overall approach to the Jilin Biomass Project

review the results of preliminary design analyses. The following conclusions for the preliminary design emerged from the workshop.

- The maximum gasifier capacity is determined by the combination of winter heating demand and engine-generator fuel gas requirements.
- The winter heating demand is over four times as large as the thermal energy available as reject heat from the engine. Therefore, a CHP system providing gas to homes for heating and cooking is more economical than one distributing gas for cooking and hot water (generated at the CHP plant) for heating. The hot water heating system would need a major supplement of hot water from a gas-fired furnace, and the efficiency loss in the furnace significantly reduces the value of using the engine reject heat.
- Given the large size of the winter heating demand, multiple gasifiers will need to be employed to avoid turndown limitations. The full gasifier capacity will be required during the winter heating season, but only about 50% of that capacity will be needed in the non-heating season. Because many gasifiers have an effective turndown of 40% at most, multiple gasifiers will allow the non-heating season demand to be met without operating any gasifiers at or near their maximum turndown limit.
- A generator size of 200 kW was tentatively selected. This size is a good match for the village electrical demand. To meet the combined household and factory electrical requirements, this size engine-generator would need to run 5780 hours per year (a 66% capacity factor) to meet this load.

On December 15, 2000, the Jilin Planning Commission approved the feasibility report for the project, and the preliminary design ratings for the major system components are given in Table 3. The expected system performance for a typical winter day is illustrated in Figure 4. Currently, electricity generation is envisaged for 17 hours per day. During periods when the plant is not operating, the villagers will revert to their previous fuels for cooking and heating, and electricity will be provided from the electricity grid.

The preliminary cost estimate for the CHP system indicates a total installed cost of 6.5 million yuan (about US$ 800,000) with annual operating costs of 820,000 yuan (US$ 100,000) and annual revenues of almost 1.5 million yuan (US$ 180,000). Just over half of the revenues are from the sale of electricity. On the basis of these preliminary figures, the project has an 8.7% internal rate of return, without including the UNDP grant as part of the capital investment.

7. Project completion and replication

The project team is currently working to complete the preliminary design and to develop the technical specifications for the major equipment. The project plans to invite

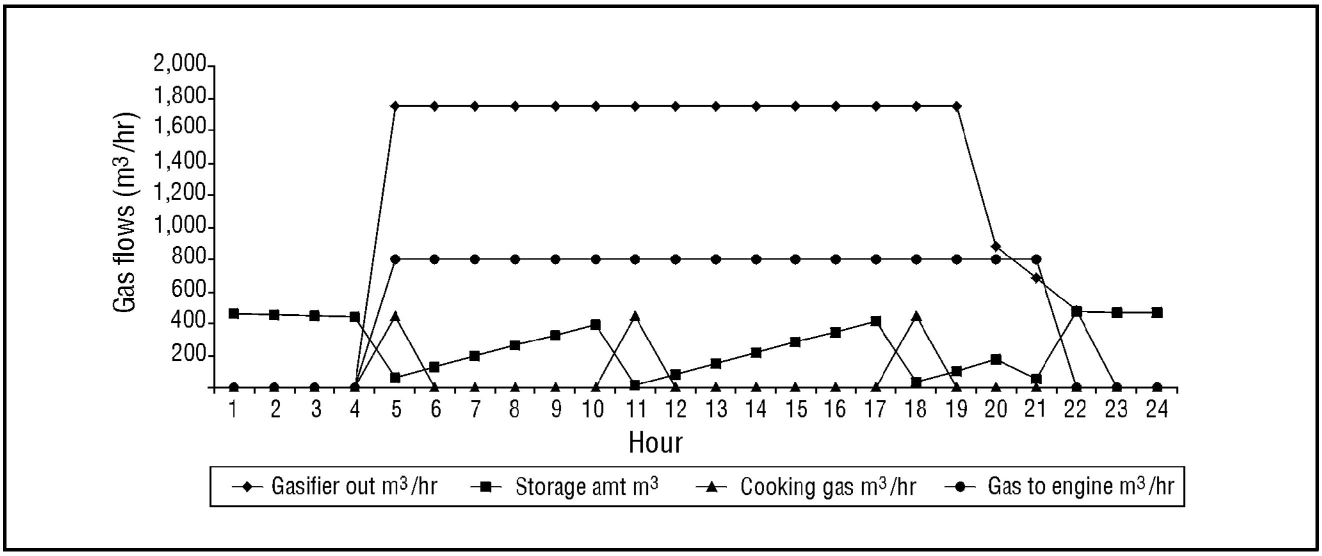

Figure 4. Typical CHP system winter day performance

Table 3. Preliminary component sizes

Component	Type	Number/ size	Rating
Gas generation	Downdraft	3	600 Nm^3/hr each
Gas storage	Dry sealing	1	575 m^3
Electric generation	Spark engine	1	200 kW
Gas distribution	Trunk lines	1200 m	219 to 89 mm dia.
	Branch lines	1000 m	38 mm dia.
	Service lines	1500 m	38 mm dia.
Biomass requirement	Chopped stalk	10 to 20 mm	700 kg/hr (15% moisture content)
Biomass storage	Covered	1	250 t
	Open	1	1000 t

international bids for all the major equipment packages in early 2001. The implementation plan calls for site construction to begin in the spring of 2001, and for the installation to be complete by that autumn. Contracts for delivery of stalks and for sale of electricity, cooking gas, and heat will be developed and put in place during the summer of 2001. Following check-out and start-up of the plant, it will be operated for an initial six months trial production period, during which adjustments may be made to the system operating parameters to optimize its performance and ensure customer satisfaction. On the basis of the evaluation of the trial production period, the operation and management of the CHP system will be continued for an extended period. System operation during this period will be similar to that of a fully commercial system. Operating and other data will be collected throughout this period. Following this approximately one-year operating period (March 2002 to March 2003), the technical, economic, social, institutional and environmental results of the project will be documented and disseminated in national and international forums with the objective of catalyzing project replication.

Development of the commercialization strategy and a business plan for replication will take place in 2001 and 2002. The challenges to project replication are significant. Important market, business and institutional issues must be addressed and mechanisms established to facilitate replication. The key technical issue is ensuring the selection of a reliable gasifier that generates low-tar, high-quality producer gas. The most important economic issue appears to be determining a fair valuation for electricity sales to the grid. As a result, the key institutional and policy issues focus on determining the best mechanism for allowing and promoting such sales to the electric utility.

These projects represent a new form of industrial activity for the villages, and their development could be promoted within the existing township and village enterprise (TVE) system in China, which encourages local communities to take the lead in industrial development. Alternatively, these projects might be developed through limited stock companies with some or no village investment. The potential market is vast, and so are the business opportunities. Jilin province generated over 40 million t of agricultural residues in 1998 [Liu, Liang and Zhao, 2000]. If 50% of these were converted to clean fuels and electricity, in a project such as this one, over 1.7 million rural households (about half the rural population) would get clean fuels and over 1,400 MW of new distributed generating capacity would be added to the grid. This compares with the current installed electric-utility generating capacity of about 4,800 MW in Jilin province.

The potential for village-scale biomass gasifier CHP systems will be even greater once technologies to replace the internal combustion engine are introduced. Second generation technologies that could be available in the next few years are the micro-turbine [Henderick and Williams, 2000] and the Stirling engine. The emergence of a village biomass CHP industry in China will only accelerate efforts to introduce these new technologies, which offer higher efficiencies and simpler operation. In the longer term, "third generation" technologies, such as a solid-oxide fuel cell and micro-turbine system [Kartha, Kreutz and Williams, 2000] would offer significantly higher efficiencies, which become important as biomass prices start to rise. ■

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Note

1. Gasifier/engine systems have been commercially successful, especially in India [Jain, 2000].

References

Dai Lin, Li Jingming and Overend, R., 1998. "Biomass energy conversion technologies in China: development and evaluation", China Environmental Science Press, Beijing.

Dutt, G.S., and Ravindranath, N.H., 1993, "Bioenergy: direct applications in cooking," Ch. 15 in *Renewable Energy: Sources for Fuels and Electricity, (*eds.) Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H., Island Press, Washington, DC.

Henderick, P., and Williams, R.H., 2000. "Trigeneration in a northern Chinese village using crop residues", *Energy for Sustainable Development*, IV(3), pp. 26-42.

Jain, B.C., 2000. "Commercializing biomass gasifiers: Indian experience", *Energy for Sustainable Development*, IV(3) pp. 72-82.

Johansson, T.B., and Ni Weidou, 1998. *Proceedings of Workshop on Small-Scale Power Generation from Biomass,* Changchun, China, January 12-13.

Kartha, S., Kreutz, T.G., and Williams, R.H., 2000, "Small-scale biomass fuel cell/gas turbine power systems for rural areas", *Energy for Sustainable Development,* IV(1), pp. 85-89.

Li Yuzong, 2000. "The advantages and guarantee of operating CHP project in Hechengli village", presented at the Design Workshop for the Modernized Biomass Energy Project, Jilin, August.

Liu Guoxi and Zhao Li, 2000. "Present situation of energy utilization in demonstration spot and supply-demand analysis of biomass gasification for cogeneration of heat and power", presented at the Design Workshop for the Modernized Biomass Energy Project, Jilin, August.

Liu Guoxi, Liang Dongmei and Zhao Li, 2000. "Peasant living energy utilization mode and rural electricity consumption in Jilin province", Project Report for Modernized Biomass Energy in China, Jilin, September.

UNDP, 1999. *Modernized Biomass Energy in China: Jilin,* United Nations Development Program Project Document CPR/99/H01/A/IV/99, October.

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