Paper for UNIDO Symposium on Development and Utilization of Biomass Energy resources in Developing Countries

Session #3 Technologies for Biomass Energy Resource Enhancement and Conversion

Paper # 0000

Biomass Energy Resource Enhancement: The move to modern secondary energy forms.

Ralph P. Overend and Kevin R. Craig
Industrial Technologies Division
National Renewable Energy Laboratory
1617 Cole Blvd, Golden, CO 80401, U.S.

Paper # 0000

Biomass Energy Resource Enhancement: The move to modern secondary energy forms.

Ralph P. Overend and Kevin R. Craig
Industrial Technologies Division
National Renewable Energy Laboratory
1617 Cole Blvd, Golden, CO 80401, U.S.

Abstract

Income growth and industrialization of the developing countries is driving their economies towards the use of secondary energy forms that deliver high efficiency energy and environmentally improved end-uses for biomass. Typical of these secondary energy forms are electricity, distributed gas systems, and liquid fuels. This trend suggests that the hitherto separate biomass energy technology development pathways followed in developing and industrialized countries will eventually share common elements. While in the U.S. and the E.U. the majority of the bioenergy applications are in medium and large-scale industrial uses of self-generated biomass residues, the characteristic use in developing countries is in rural cook-stoves. Increasing urbanization and investment in transportation infrastructure are leading to the possibility of an operational change of scale in developing countries. One factor driving this trend is diminishing individual and household biomass resource demands. This occurs as rural incomes increase and households ascend the energy ladder towards clean and efficient fuels and appliances. Scale increases and end-user separation from the biomass resource require that the biomass be converted at high efficiency into secondary energy forms which serve as energy carriers. Increasingly, in the middle-income developing country economies such as Brazil, secondary energy transmission is in the form of gas and electricity in addition to the existing transmission of liquid transportation fuels.

Unfortunately, the biomass resource is finite. Further, in the face of competing food and fiber uses and land constraints, it is difficult to substantially increase biomass availability. As a result, development must emphasize considerably increased conversion efficiency and end-use applications of bioenergy. Moreover, as a consequence of economic growth, biomass resources are increasingly to be found in the secondary and tertiary waste streams from urban and industrial operations. If not utilized for energy production, this potential resource will require disposal in some other manner on account of its negative environmental impacts.

The development cycle for biomass thus moves in a step-wise fashion. The first step is the self-use of wood and agricultural residues for cooking, heating, and lighting. Next, investments are made in anaerobic digesters (to simultaneously address energy, environment, and hygiene needs) and in efficient wood and straw fired stoves (to improve the indoor air environment and reduce the depletion of forests for fuelwood). The final stage is village-scale operation of digesters and gasifiers that provide distributed gas resource to households and enterprises that are not necessarily associated with the agricultural or forestry activities. Simultaneously, it is possible for industries that process biomass into pulp, paper, lumber, and sugar (from sugar cane) to move from being merely self-sufficient in process heat needs to becoming significant

exporters of electrical energy into the regional and national grids. The key to all of these advances is the availability of highly efficient, environmentally sound and economically viable conversion technologies.

1.0 Introduction

In the industrialized countries that are members of the OECD, the use of biomass as a direct fuel in the household has diminished considerably, while the self-use of residues generated in biomass-based industries such as pulp and paper has increased significantly. The former has resulted from the increasing urbanization of OECD societies and the latter from the pressures of economy and environment. A recent trend has been the production from biomass of electricity and liquid fuels that are marketed into the general energy economy. In the U.S. for example, there are now 9 GW of grid-connected electricity generated from a variety of biomass resources ranging from sawdust and wood residues in the lumber mills in combined heat and power (CHP or cogeneration) installations, to the use of agricultural residues and the clean fraction of the urban solid waste stream in stand-alone generating stations. Since 1980, the production of ethanol from maize in the U.S. has increased to 5.3 Mm^3 (1.4 billion US gallons per year) for use in gasoline blends to mitigate air pollution in urban areas. Around the world, CHP systems are increasingly being installed in biomass-residue-generating industries. Thus, rice husks, sugar cane bagasse, and wood and pulping residues are used to generate electricity. Animal wastes and industrial-process effluents are increasingly being used to generate methane in anaerobic digestion. The resulting secondary energy forms - electricity, methane and liquid fuels - are then marketed into end-user sectors distant from the biomass resource.

As the use of secondary energy forms increases, and more efficient, less environmentally damaging conversion technologies are developed, there is a general appreciation that **conversion technologies** are the key link in management of integrated biomass materials flow in modern economies. The biomass resources are energy crops, crop residues, process residues, and the clean, biomass-derived residue streams from mankind’s urban activities. Modern conversion technologies facilitate the production of secondary energy forms that can be used in rural, urban, and industrial end-use sectors. Such a description of an integrated biomass materials management system fits the predominantly urbanized countries in North America and Europe.

In developing countries, where the population is predominantly rural, another system of biomass materials management prevails. In these countries, the household and the village are the management unit for their own fuel needs, usually by the direct combustion of biomass in cooking and heating stoves. However, the demand for secondary energy forms in developing countries is increasing rapidly. At the same time, there is an ever-increasing need to conserve the biomass resource in the face of pressure for wood and fibre products, food, and energy.

This paper explores the application of advanced biomass conversion technologies to socio-economic development. These technologies allow production of secondary energy forms with much higher end-use efficiencies. This, in turn, enables finite biomass resources to provide improved energy services as well as serve in their traditional role as sources of food, fibre, and materials.

Several modern, efficient, and environmentally sound biomass conversion technologies are becoming available. These include advanced combustion systems, gasification and pyrolysis, and bioconversion to ethanol and to methane. For the purpose of this paper, one technology, biomass gasification, will be examined in the development context for both village and industrial scales. This will also facilitate discussion of the linkage between industrial country practice and the use of technology developments in the developing country context. The examples herein describe applications that can be foreseen in the near term. We describe in some detail the technological evolution proposed, since it is paramount, in the course of developing bioenergy, that end-use services (i.e. heat, light and power) be delivered with the maximum economically justifiable systems.

2.0 The Village Scale

In many developing countries electricity is in short supply. Peak demand deficits of 10 - 20 percent are common, and significant fractions of the population are not served with electricity at all. Recent data [World Bank Infrastructure for Development Report, 1994] show that while more than 80 percent of the urban population in developing countries have access to electricity, those in rural areas have less than 60 percent access. Even though many rural towns and villages are connected to the electricity grid or are served by stand-alone diesel generating systems, the supply of electricity is intermittent, unreliable and of poor quality. As a result, the villages still rely on dry cell batteries for radios, kerosene for lighting, and biomass fuels for cooking. In most rural areas, there is an apparent deficit of biomass; fossil fuels must be obtained to satisfy even daily living needs. However, if more advanced technologies were applied, the biomass supply in many areas (from agricultural residues and sustainable fuelwood) would be adequate not only to satisfy these daily living needs, but also to provide excess energy for labor saving appliances, telecommunications, and light industry. Unfortunately, this is not yet achievable.

2.1 Plotting a rural energy trajectory to demonstrate the potential of advanced technologies to serve all energy needs.

China and India have the world’s largest rural populations - 70 percent of their combined population of 2.2 billion. Most of these people depend on biomass for the majority of their daily living requirements. In order to show the role that advanced technologies could play in such a setting, the following section outlines a series of incremental investments that could bring a typical village from being a net energy importer with a low level of energy services to one that uses its biomass resource base to become energy self-sufficient, satisfy modern expectations of energy service, and perhaps even provide energy exports.

2.2 Jincunzhuang village: high conversion efficiencies at small scales

To illustrate both the current situation and the potential of biomass at the village scale, this section discusses a hypothetical village situated in SE China in a region of double cropping (winter wheat and summer maize) a situation typical of the provinces of Shandong and Jinan. Though the notion of an “average” village is improbable, the hypothetical village of Jincunzhuang has 97 households (about 300 - 350 population) and access to approximately 20 ha of arable land. In this highly productive region the annual straw production (wheat straw, and maize stover and cobs) is about 15 tonnes/ha, leading to an annual energy supply capability of 4.66 TJ. Today, the majority of this residue is used for cooking and some surplus fraction is burnt in the field owing to the lack of effective conversion technologies. This was not always the case. The development of the biomass energy system for Jincunzhuang will be described in terms of its evolution from 1960 to a projected future status in the year 2000.

2.2.1 **Jincunzhuang in 1960**

In 1960, the available conversion technology was essentially an open fire (the three-stone stove) or a primitive cook stove with about 10-12 percent efficiency in delivering fuel energy to the cooking pot. As a result, the daily demands for cooking energy (approximately 19 MJ per household) could not be met from the indigenous resources, and the village had to gather fuelwood, purchase coal, or do without cooked meals. This last option was common; it is estimated that many households were short of fuel for as much as three to four months per year [Smil page 103]. This can be seen in the first bar of Figure 1 which shows that, because of the low efficiency of cooking, as much as 25 percent of the annual cooking fuel demand had to be satisfied by another fuel. Though unlikely in the China of 1960, it is assumed that lighting was provided for 6 hours per day by means of 4 kerosene wick lamps consuming about 0.75 l of kerosene per household each day. This level of lighting service would provide only about 1200 lumens of total delivered output.

2.2.2 **Jincunzhuang in 1980**

The chronic fuel shortage in developing countries and the rural population’s inability to purchase fuels spurred governments and non-governmental organizations throughout the 1960s, 1970s, and 1980s to develop improved cook stoves and the social structures and systems for their rapid diffusion. Though this development was not without its set-backs, it eventually succeeded in many countries through the role of women’s groups and government and non-governmental organizations [Daniel M. Kammen, 1995]. In China, a little known stove program developed the most extensively diffused stove model of all, the Chinese Improved Cookstove, which has an efficiency of between 20 and 40 percent. This cookstove has been disseminated to over 140 million households - more than 70 percent of all rural households in China [Deng Keyun 1994]. Most of these were installed in the 1980s. This is reflected by the bar-graph line for 1980 in Figure 1, which shows that the entire annual cooking demand for Jincunzhuang could be satisfied by 50 percent of the annual straw production, thus leaving a surplus and eliminating the need to purchase fuels or take fuelwood from surrounding regions. In regions with less arable land per household or limited biomass productivity (e.g. lack of irrigation, short season), supplementary fuels would still be required.

2.2.3 **Jincunzhuang in 1995, Technology for the future**

It is well known that, as incomes rise in developing countries, the cooking fuel preference quickly changes from self gathered wood and straw to purchased charcoal or kerosene. Increasing affluence, especially among urban dwellers, leads to LPG and natural gas use, or, where electricity is ample, electric cook stoves. While this transition is very complex and poorly understood, the factors that affect a household's shift to modern stoves and clean, efficient secondary fuels include household income, fuel producing assets such as woodlots and animals (anaerobic digestion), reliability of access to modern fuels, the relative costs of not only the fuels but also of the appliances, the educational level of the household, cooking habits, division of labor, and the control of finances. Figure 2, The Energy Ladder, quantifies the anecdotal knowledge base for five medium towns studied in Kenya in the 1980s. The survey by the Surrey Energy Economics Center shows that high income households have the insurance of several different fuels and cooking appliances.

The rural user rarely has access to natural gas pipelines or LPG distribution. This makes use of these clean, efficient energy sources unlikely. This user would most benefit from more efficient straw conversion through thermochemical gasification and the production of a gas that is distributed through a local "grid" to each household. This gasification scheme has been demonstrated by the Shandong Energy Research Institute at Huntai village in Zebo County. The XRF-1 gasifier (Figure 3) furnishes gas to 97 households. The gasifier has been developed to operate on agricultural residues such as maize stover, and operates on a continuous basis with chopped stalks. Typically, the gasifier is operated for about 4.5 hours per day since the operating rate of the gasifier is high. The gas is stored in a large gas-holder so that the peak demands at the three meal times each day can be satisfied. Though in today's demonstration project straw gasification meets only the cooking demand, the third bar of Figure 1 illustrates an option in which agricultural residues are gasified to produce gas for both lighting and cooking, allowing the village to become independent of kerosene lamps.

Typically, mantle lamps operating on gas or pressurized kerosene give about 1.5 - 2 lumens per watt of energy input. Thus a mantle lamp has ten times the efficiency of a kerosene wick lamp, and for half the energy input of the kerosene wick lamps of cases 1 and 2, approximately six times the lighting service can be obtained. In this example case, Jincunzhuang would be able to use about 60 percent of the straw and eliminate the majority of the kerosene purchases.

2.2.4 **Jincunzhuang after 2000.**

The availability of distributed gas and an efficient and proven gasifier for conversion of agricultural residues such as maize stover and cereal straw could solve the problem of producing electricity at the village scale and allow very high efficiency use of the biomass resources. The bar chart of Figure 1 contains three entries for the production of electricity from the village gas system. The first of these is based only on substituting the gas fired mantle lamps by energy efficient fluorescent lamps in each household. It is estimated that fluorescent lamps would demand about 300 - 400 Wh of electricity per household per day. A six hour period of lighting demand would be satisfied by an electrical generator of 5 - 6 kW. Thus, the generator output would provide electricity to all of the households, would reduce the straw demand for lighting by about 70 percent as compared with the gas-mantle case, and provide each household with 30 percent more lighting service. The generator could, in this case, be a spark ignition engine. Such an engine has already been demonstrated on low-energy-content gas in China. The overall efficiency in going from gas to electricity has been assumed to be 20 percent. To satisfy community needs in terms of a minimal set of lighting and electrical appliances (TV, radio, and, in some instances, a refrigerator), about 30 kWh/month per household would be needed. At a gas-to-electric conversion efficiency of 20 percent, this load increases the straw demand to 2.8TJ, a level similar to the gas mantle lighting option. Increasing the level of service to 60 kWh/household per month would require a more efficient prime mover having a capacity of 30 - 40 kW at an assumed efficiency of 30 percent or better from gas to electricity.

2.3 **Prime movers for the village scale.**

The efficient conversion of low-energy-content gas to electricity must take into account the characteristics of the gas and its influence on the functioning of the engine. Despite the use of gasifiers on vehicles during periods of war-time fuel shortages, gasifier engine sets have not been very successful. A notable exception is the 160 kW Chinese system based on rice husks which, however, has not been commercially available in recent times. The majority of the gasifier engine combinations have been close-coupled and have used the engine to provide a vacuum to pull the air-gas mixture through the gasifier. In the village energy system proposed, the gas would be cleaned and cooled prior to storage and the prime mover would be coupled to the gas system after the storage. Since it would no longer be close-coupled to the gasifier, the engine could even be installed where the energy in the exhaust could be used to heat water for households and industries.

The efficiency of the prime mover will have a major effect on the biomass demand as the use of electricity grows. Systems with better than 30 percent efficiency at a small scale are desirable. If at all possible, these systems should not use fossil fuels for pilot ignition though, as an interim step, the use of modified diesel engines would allow dual fuel operation as well as efficient use of the gas.

New technology options offering high efficiency in going from a low-energy-content gas to electricity include both Stirling engines and fuel cells. At present, these technologies are both expensive and just completing their development cycles. Both would be low cost if the fixed costs of establishing manufacturing facilities could be spread over a large number of mass produced units, either for the developing country village electricity market or, in the case of fuel cells, for transportation use. This last application is close in power output to the suggested village energy system, since small passenger automobiles are often in the 30 - 40 kW power range.

3.0 Industrial-Scale Biomass Fueled Combined Heat and Power Production (CHP)

Efficient bioenergy production schemes can also be used in the major agricultural commodities and the pulp and paper sectors. In tropical and semi-tropical latitudes the sugar industries represent a significant potential source of export electricity if advanced technologies are adopted.

The Industry and Energy Department of the World Bank has supported the evolution of such a modernization in the sugar sector. Such modernization promotes diversity in the utility sector since most of the mills are in the private sector, promotes energy and material efficiencies because of the inherent efficiencies of the combined heat and power production, and, of course, it utilizes a renewable energy resource.

3.1 The sugar industry

The process of producing sugar entails crushing the sugar cane to expel and extract the sucrose-containing juices. The fiber remaining, bagasse, is typically used as a fuel for the sugar production process that requires extensive water evaporation.

Typically, cane is harvested slightly green, and when it arrives at the sugar mill, it may have about 30 percent total solids and about 70 percent water. To a first approximation, the weight of sucrose and the weight of the bagasse are in the ratio of 1:1.5. The FAO and the United Nations use as a rule of thumb that 1 tonne of cane sugar creates about 3.26 tonne of bagasse at 50 percent moisture content. This number depends significantly on the fiber content of the bagasse and the methods of preparing cane. In China, where cane is well prepared before shipping to the mill and has little extraneous trash, the ratio used is 1:1 sucrose to bagasse. Because of the vast quantities of bagasse, it is nearly all burnt to generate the power and heat for mill operation and to dispose of the bagasse. Bagasse is used very inefficiently in most developing countries because of the disposal need, and because the mill owners have minimized their capital investment. Any bagasse surplus would normally be considered for paper production, not for conversion to electricity for export from the mill. Furthermore, in many developing countries, the generation of excess electricity is not desirable because subsidized grid electricity is sold at less than its production cost.

3.2 Bagasse fueled CHP today

Typically, a sugar mill in a developing country generates about 20 kWh of electrical energy per ton of sugar produced (Figure 4). In the 1930s, the majority of sugar mills in Hawaii were similar to the mills that presently exist in developing countries, having only a small export of electricity to local communities serving the sugar mill. However, sugar mill generating capacity grew markedly in the 1970s as the sugar industry consolidated its low pressure boilers into higher pressure units and could produce more electricity for export [Kinoshita 1991]. In the U.S., passage of the 1978 Federal Public Utilities Regulatory Policies Act (PURPA) further stimulated the use of bagasse to the point where, in 1991, the Hawaiian industry supplied about 5.5 percent of the grid electricity through the burning of bagasse in conjunction with fossil fuels [DBEDT

1992]. The generation in that year was 495 TWh, down from a high of 681 TWh in 1988.

The improvements made to the mills entailed significant investments in both the boiler and power turbines, and into process improvements. Typically, the boilers were improved by increasing the operating pressure and temperature from 1.75 MPa and 250` C, to 5.9 MPa and 400` C through the use of air preheaters and superheaters. The power turbines in general use are typically back-pressure units operating at the boiler pressure and an exhaust pressure of .1 - 0.15 MPA. The exhaust steam is used to provide the process heat as shown in Figure 4. Several turbogenerator combinations may be used to modernize such mills: a topping turbogenerator that converts the high pressure steam to the pressure of the remaining prime movers; a condensing turbogenerator that has a higher efficiency (on account of the low pressure side of the turbine being at 10 Pa pressure); or, as in current Hawaii practice, an autoextraction/condensing turbogenerator that extracts 1.725 MPa steam for the direct drives and 0.15 MPa steam for the process. A typical efficient Hawaiian mill is shown in Figure 5.

This level of sophistication is now being adopted in India. A World Bank ESMAP study identified the state of Maharashtra as having the best potential for adoption of higher electricity output from the sugar mills. These mills could usefully produce electricity in the November through April period when hydroelectric input to the Maharashtra Grid is low. A key factor, however, is the acceptance of private power producers onto the Maharashtra grid, so that adequate returns have some chance of being negotiated with the State electricity board. This study has been followed by a more detailed assessment of three mills by the Winrock Foundation for USAID. A combination of steam pressure increases from 1.4 to 6.3 MPa and steam conservation measures which reduce the steam consumption from 55 percent steam-on-cane to 40 percent have been identified. These changes would be cost-effective in increasing the in-season output of the Aruna mill to 34 MW and the off-season output to 51 MW (using lignite fuel) for a total export of 295 GWh per year. At present, the mill generates only enough electricity for its own needs (6.5 MW).

3.3 Advanced bagasse CHP facilities

The deployment of more advanced technology, such as the use of Integrated Gasification Combined Cycles (IGCC), could result in a further significant gain in exportable electricity during the sugarcane processing season. Figure 6 illustrates a modification of the base-case mill to incorporate a gasifier and gas turbine combination. To maintain the high temperature and pressure steam conditions, the turbine exhaust is ducted to a modern and highly efficient HRSG (Heat Recovery Steam Generator). The bagasse would be dried with flue gas from the HRSG. The increased output also reflects the use of more advanced energy conservation techniques to reduce the steam-on-cane usage to 35 percent. The system shown is an add-in that would allow the use of the boiler steam in the traditional way. An even more radical solution, and one that would significantly reduce investment costs, would be to use a steam-injected gas turbine (STIG). Such a turbine would provide steam for the process, produce electric power for internal use and export, and be able to utilize additional steam during periods of reduced mill loads for even more power production. Preliminary calculations suggest that the efficiency of this option would be sufficiently high that there would be a surplus of bagasse that could be used for pulp and paper production.

During the sugar cane season, therefore, the mill could become a major contributor of grid and local electricity. Excess bagasse could either be used for pulp or medium-density fibreboard production or be stored for use in the power plant beyond the mill operating period. Other fuels such as fuelwood could also be stockpiled in the dry season and used in the wet season. The bagasse gasifier necessary to implement this type of scheme is under development in Hawaii under the auspices of PICHTR with the pressurized IGT RENUGAS System. In the Export Options Summary (Table 1), the comparative performance of the sugar cane systems is set out to illustrate the benefits of a move to advanced gasification technology.

Table 1
200 Tonne of Cane Processed per Hour: Electricity Export Options Summary.

Factors	Base case	Hawaii System	IGCC - Based
Available Bagasse t/h	68	61	40.5
Moisture Content (percent)	52	47.5	20
Excess Bagasse t/h @ 50 percent moisture	0.7	0.0	0.0
Power Generation MW	3.4	17	35
Electrical Output kWh/t	16.8	84.6	175
Mill Energy Use t-steam/tc as percent	58.5	45.9	35
MW export in-season	0.4	13.5	30

4.0 Economic and Environmental Benefits

Using biomass efficiently reduces the adverse environmental impact of biomass harvest and use: over-utilization of the biomass resource which may harm land and water, and the air and water pollution which can accompany such overuse. The results of an efficiency gain can be dramatic. In Jincunzhuang, the move from inefficient cooking to a system that used less than the annual straw and stalk residue production immediately eliminated the village’s over-harvest of fuelwood. The use of improved stoves also immediately reduced household air pollution.

The environmental gains described for Jincunzhuang are certainly subject to the law of diminishing returns with additional investments. However, the associated benefits of waste reduction, offset of fossil fuel consumption, and associated reduction in air and water pollution associated with extraction and conversion of those fossil fuels are also significant, especially in the context of current discussions of the role of greenhouse gases in climate change.

Economic benefits also suffer from the phenomenon of diminishing returns with increasing investments. In the case of sugarcane energy systems, there is probably little incentive to make these investments unless a rational solution to the problem of “externalities” pricing is resolved, given the current average cost of fossil fuels. In the U.S., the only monetized externality is that for sulfur oxides, for which there are tradeable emissions credits.

5.0 Potential and Barriers to Realizing this Potential

A large part of the world’s rural population depends on biomass energy for its daily living needs. It is surprising, therefore, that little attention has been paid to development of systems that would provide living conditions and quality of energy services similar to those expected by urban dwellers. In the main, it is the developing countries that have developed energy systems that fulfill basic needs for daily living while encouraging the sustainable use of biomass resources. The recent technology developments outlined above offer the technical promise of providing these quality energy services. However, for this to be done in an economically attractive fashion, the expensive prime movers that convert fuel gas to electricity will have to be manufactured using automobile-like mass production in order to reduce the unit cost. In this respect, the village bioenergy system is little different from other renewables such as PV or Wind that must achieve low system costs at low power outputs.

The economics of larger scale CHP installations, such as the example of the sugarcane processing industry outlined here, are potentially very promising; however, there is a strong need for rational pricing for the purchase of export power from the mills. In many developing countries, the purchase price offered by the utility grids and state electricity boards would not support any investment in power systems at all.

6.0 Conclusions

As the scale of operation in developing countries moves away from the individual and the family, there is a need to consider the total fuel cycle with a view to optimizing its sustainability both economically and environmentally. In this respect electrical systems seem to offer the best opportunity, at least in those developing countries that already have a significant degree of electrification and distribution grid coverage. Urban and industrial residue processing could lead to significant grid additions at the multi-MW scale. These additions would come from combined heat and power facilities providing process heat or district heating/cooling and electricity to their own facilities or to cities and towns. Advances in technology ranging from higher performance combustion cycles to gasification combined cycles, both of which increase the electricity-to-heat ratio, will increasingly benefit society while improving the environment. This is especially true for industries such as the sugarcane processing mills and the pulp and paper sector that produce significant biomass residues and concomitantly demand large amounts of thermal energy (steam).

At the village and township level, rising income generation outside of agriculture and increasing needs for clean, efficient and reliable energy sources mean that the use of biomass will move from the individual user towards either the village or large enterprise scale. However, owing to logistical constraints, it is likely that the assembly of large quantities of biomass will be very difficult in most developing countries. It will, therefore, be necessary to consider scales of conversion that are much closer to 10 tonnes per day rather than the 1100 tpd that power stations in the U.S. utilize. It is likely that between 3 and 10 tonnes per day is roughly the amount of biomass that is available in villages in China and India that have approximately 100 - 300 ha under their direct control. These villages can generate about 10 tonnes per ha per year of residues under a double cropping regime. Thus, the technology transfer challenge is to obtain high conversion efficiencies at small scales and low cost.

Fortunately, advanced technologies such as fuel cells, stirling engines and advanced turbines can, if mass produced, break the dependence of economic power generation on large scale, and can bring the benefits of high efficiency, low environmental impact and economic operation to villages and rural agricultural industries.

References:

1. Anon.Barnes, Douglas; Openshaw, Keith; Smith, Kirk R., and van der Plas, Robert. What Makes People Cook with Improved Biomass Stoves? A comparative International Review of Stove Programs. Washington, DC: The International Bank for Reconstruction and Development / TheWorld Bank; 1994; ISBN 0-8231-2800-X. (World Bank Technical Paper; No 242; 242.

2. Board on Science and Technology for International Development. Producer Gas: Another Fuel for Motor Transport. Washington, D.C.: National Academy Press; 1983.

3. CB ISTC. New and Renewable Energy -Technologies and Products in China. First ed. Chongqing, 630013, PRC: Office of New Energy of CB ISTC; 1995.

4. Croll, Elisabeth. From Heaven to Earth: Images and Experiences of Development in China. London, U.K.: Routledge; 1994; ISBN: 0-415-10187-5.

5. ESMAP. India: Maharashtra Bagasse Energy Efficiency Project. Washington DC.: World Bank; 1991 Nov; ESMAP 120/91.

6. Kammen, Daniel M. Cookstoves for the Developing World. Scientific American. 1995 Jul; 273(1):72-75.

7. Keyun, Deng. Chinese Strategies for Rational Rural Energy Utilization and its Eco-environmental Benefits. Scheer, Hermann, Editor. Solar 3. 1 ed. London, UK: James and James Science Publishers, Ltd.; 1994; pp. 143-145.

8. Office of Technology Assessment. Energy in Developing Countries. OTA-E-486 ed. Washington, DC: U.S. Government Printing Office; 1991 Jan. ISBN: 052-003-01219-7.

9. Fueling Development: Energy Technology for Developing Countries. OTA-E-516 ed. Washington, DC: U.S. Government Printing Office; 1991 Feb. ISBN: 0-16-036185-0.

10. Parurau, J. Maurice. By-Products of the Cane Sugar Industry: An Introduction to their Industrial Utilization, Sugar Seiies, 3. Amsterdam, Oxford, New York: Elsevier Scientific Publsihing Company; 1982.

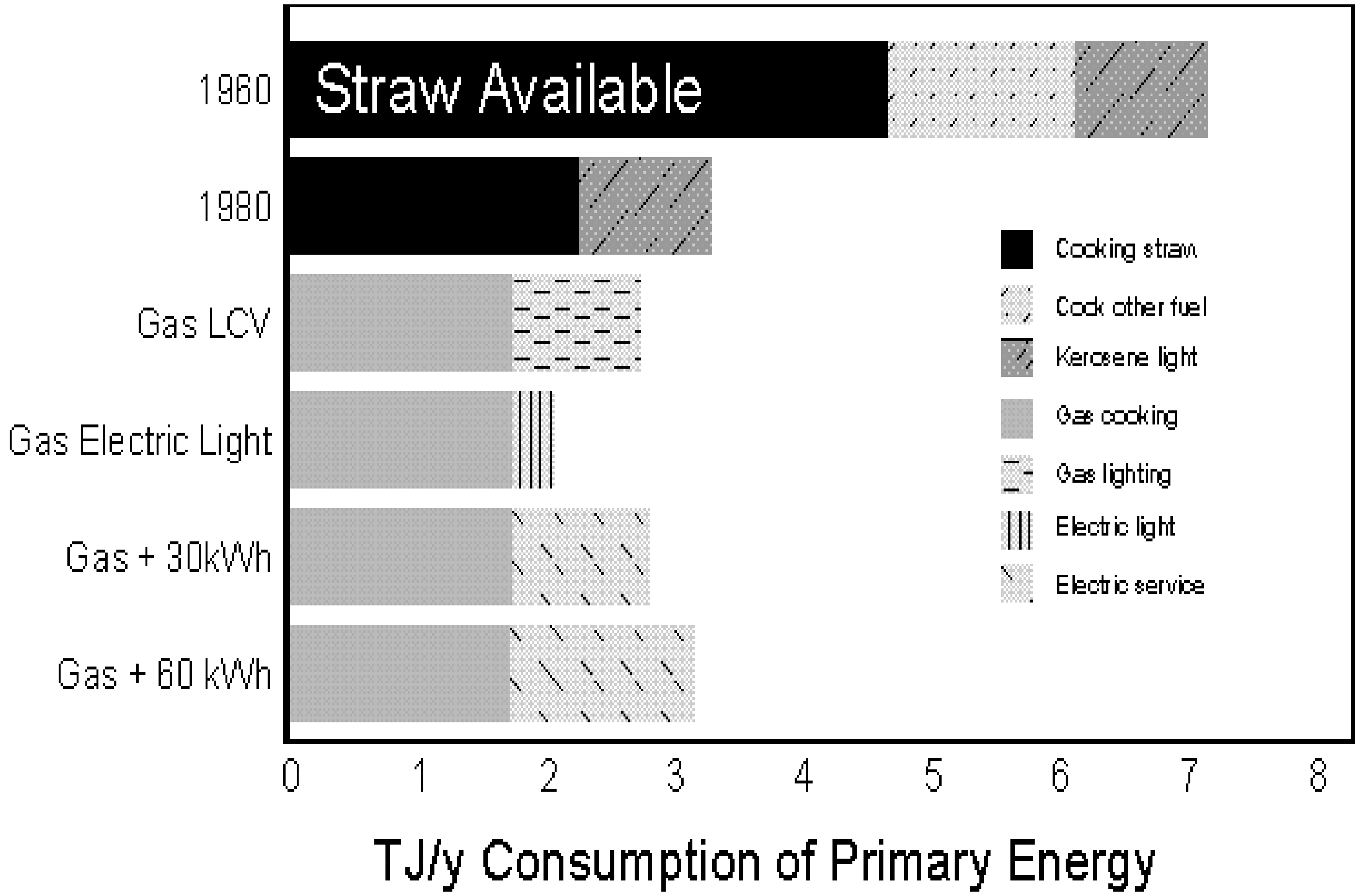
11. Payne, John Howard. Cogeneration in the Cane Sugar Industry: Sugar Series, 12. Amsterdam, Oxford, New York, Tokyo: Elsevier Science Publishers B.V.; 1991; ISBN: 0-444-88826-8.

12. Smil, Vaclav. China's Environmental Crisis: An Inquiry Into the Limits of National Development. Armonk, NY: M.E. Sharpe (an East Gate Book); 1993; ISBN: 1-56324-041-6.

13. Stasssen, Hubert E. (BTG biomass technology group). INDP./WB Small-Scale Biomass Gasifier Monitoring Report. Enschede, The Netherlands: BTG (Biomass Technology Group), University of Twente ; 1993 Sep; 1129. 54 pages.

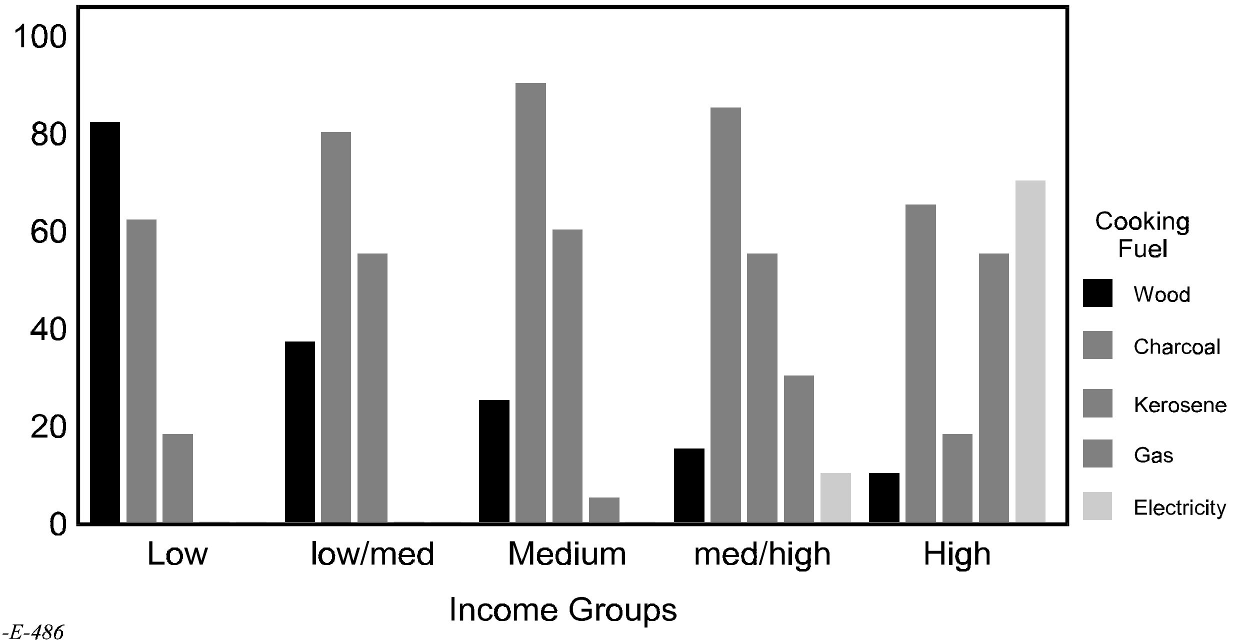
14. Winrock International and IDEA. Advancing Cogeneration in the Indian Sugar Industry: Three Mills in Tamil Nadu and Maharashtra. Washington D.C.: U.S.ID/New Delhi, and Office of Energy and Infrastructure. Bureau for Research and Development, U.S.ID; 1993 May; DHR-5737-A-00-9058-00.

15. Zhang, Zhao Jia. Rice Husk Electric Power Generation in China. Development in Southeast Asia and the Pacific. 1992; 10(2):22. ISSN: 0217-4901.



L3-CD-b070107

Figure 1 - Technology Makes for Better Energy Service — Jincunzhuang Village



Source OTA-E-486

LS-CD-b070105

Figure 2 - Ascending the Energy Ladder — Kenyan Household Fuel Use by Income

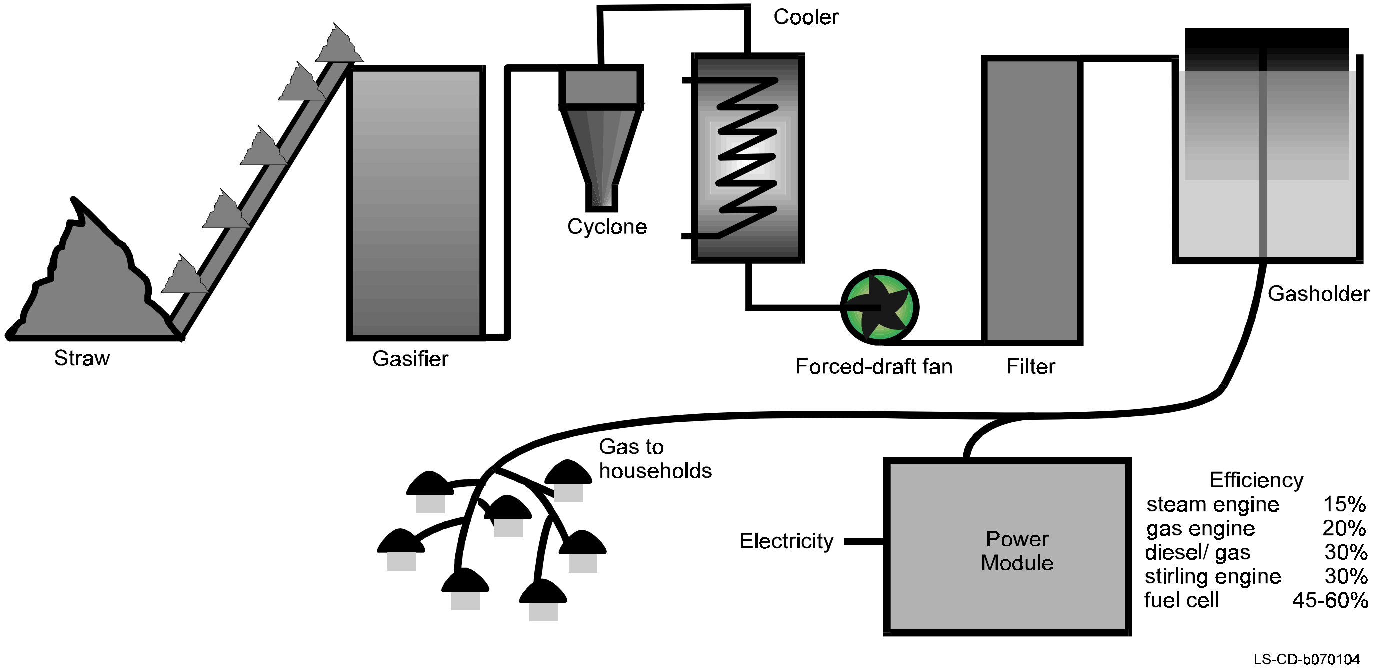


Figure 3 - Village Thermal Gasification System — Country Case

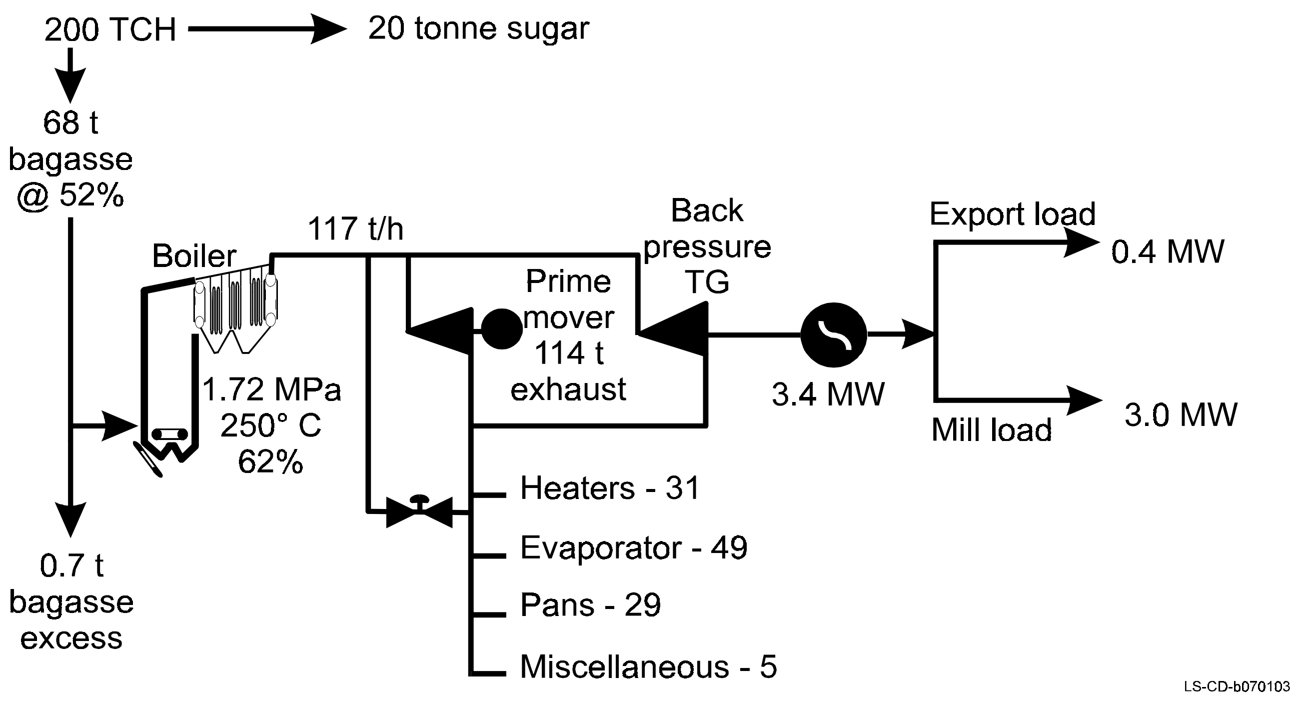


Figure 4 - Sugar Cane Energy Production Developing — Country Case

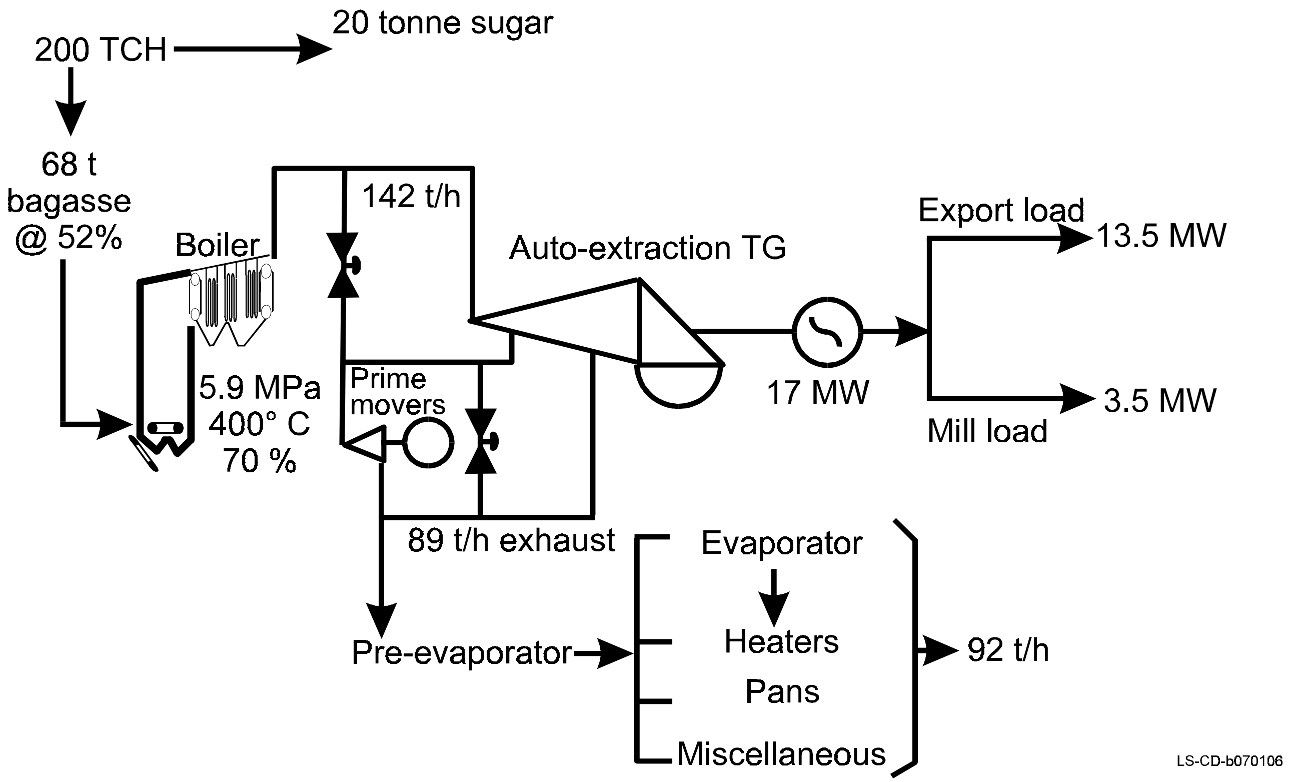
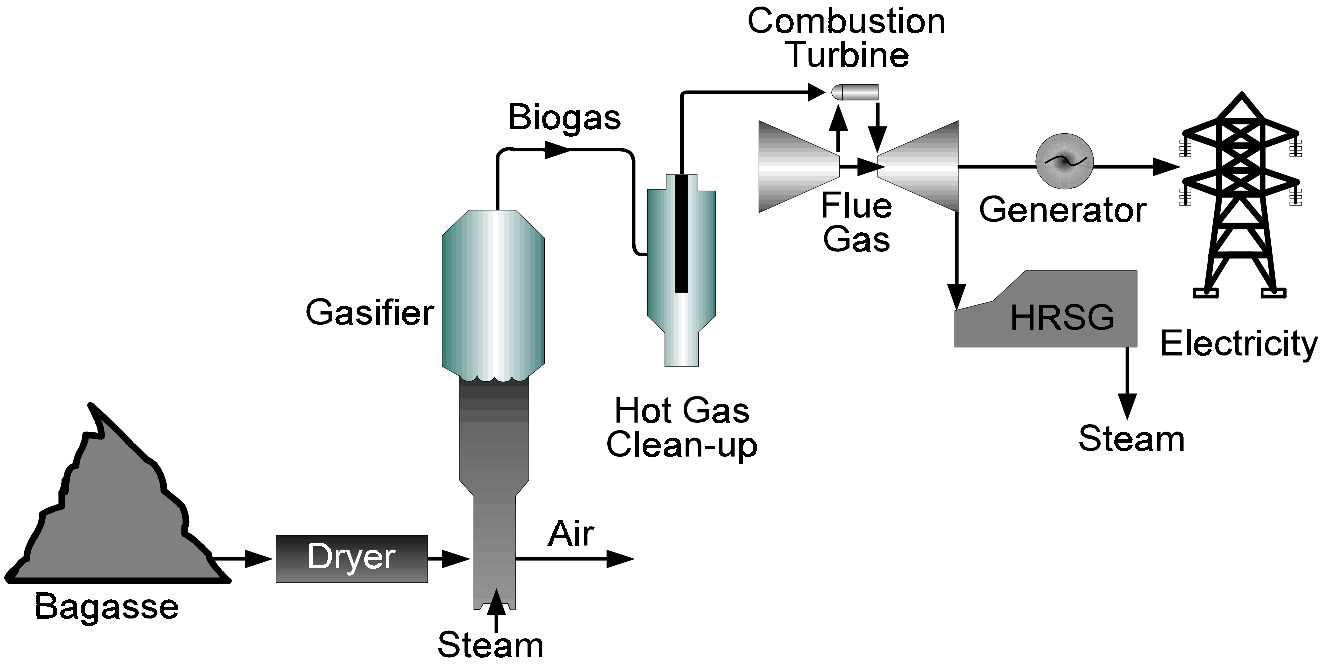


Figure 5 - Sugar Cane Energy Production — Hawaii Case



Note: See Text for Case Explanations

Figure 6 - Sugar Cane Energy Production — IGCC Case