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A SUMMARY OF THE STATUS OF BIOMASS CONVERSION TECHNOLOGIES AND OPPORTUNITIES FOR THEIR USE IN DEVELOPING COUNTRIES

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ABSTRACT

Biomass plays a significant role in energy use in developing countries; however, these resources are often used very inefficiently. Recent technology developments have made possible improved conversion efficiencies for utility scale technologies. These developments may be of interest in the wake of recent policy changes occurring in several developing countries, with respect to independent power production. Efforts are also being directed at developing biomass conversion technologies that can interface and/or compete with internal combustion engines for small, isolated loads. This paper reviews the technological status of biomass conversion technologies appropriate for commercial, industrial, and small utility applications in developing countries. Market opportunities, constraints, and technology developments are also discussed.

INTRODUCTION

Biomass energy resources are used in many forms and processes in developing countries. The largest single use is for household cooking. In Africa, for example, about 75 percent of the total energy consumption is derived from biomass fuels (8). In Latin America and Asia, the percentages are much less (42 and 30 percent, respectively) owing to a greater proportion of urban dwellers and higher incomes. Wood, bagasse, rice hull, and other agricultural wastes are all used to generate thermal energy for drying operations, steam to drive industrial and agricultural processes, electricity for on-site use at processing mills and, in some cases, for off-site power sales. In sum, biomass fuels are the single largest source of energy for households and are growing in importance in many developing countries as fuels for commercial, industrial, and small utility applications.

Much has been written regarding the potential for biomass conversion to energy, addressing technological advances, fuels and their characteristics, and, more recently, the growing concern over fuelwood use and its impact on forest resources. Deforestation and fuelwood use have been an issue of concern for over a decade, and many programs have been initiated to mitigate degradation of forest resources. These programs have included the dissemination of improved and more energy

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efficient cook stoves at the household level, the use of more efficient wood-to-charcoal conversion techniques, and the establishment of fuelwood plantations. However, the efficacy of these programs in mitigating deforestation has been called into question (13).

For non-household energy applications, research has focused on thermochemical conversion technologies, including biomass gasification and direct combustion, and biochemical conversion processes for liquid fuels production. In spite of some well-directed efforts, the success stories have generally been localized, with limited successful replication. Moreover, the degree of market penetration of commercialized conversion technologies has been limited. A recent study concludes that while there have been some successful applications of traditional (i.e., household cooking and small commercial uses) biomass conversion technologies, most projects, including those at pilot scale, demonstration scale and commercial scale, have failed to meet their stated objectives (22).

Although smaller-scale biomass technologies for decentralized power applications will remain a major market for conversion equipment, some recent technological advances in utility-scale applications suggest a growing market for larger, more advanced systems (25). The purpose of this paper is to review the technological status of biomass conversion technologies appropriate for commercial, industrial, and small utility applications, and to suggest what role biomass energy resources can play in meeting the energy needs of developing countries. The paper begins with an overview of experiences with biomass energy technologies, including some of the more important lessons learned from these projects relevant to future program design. Market opportunities are then reviewed, with a summary of perceived impediments to penetration of selected technologies, followed by the authors' views of recent technological developments. The final section of the paper provides some conclusions regarding future research and development needed to bring relevant and appropriate conversion technologies to the market.

STATUS AND EXPERIENCE WITH BIOMASS ENERGY TECHNOLOGIES

Traditionally, the private sector has played the leading role in developing and marketing biomass conversion equipment. In many developing countries, first generation power conversion devices were relegated to low efficiency, biomass-fired boilers. For example, bagasse was used to supply energy to process sugar and to provide power for other uses (e.g., lighting for sugar company employees' homes); wood wastes were used to service thermal and electrical loads at wood mills; and palm oil pulp, coconut shells and husk, and rice hulls have all been used as fuel sources.

During the 1970s and early 1980s many biomass production and conversion programs were initiated. These programs were designed during a period of historically high oil prices and, in several cases, were focused on substitution of biomass for liquid fuels in the power and transportation sectors. These activities involved traditional approaches to biomass energy use, including conversion of agricultural, industrial, and forestry wastes to energy for process steam and, to a lesser extent, electric power. The programs usually relied on low capital cost and low efficiency equipment.

During this period considerable effort was focused on the development of gasifier/internal combustion units (24), ranging from very small applications of less than one kW to larger-scale generators producing several hundred kilowatts. The most publicized case was that of the Gasifier Manufacturing Corporation (GEMCOR), a parastatal organization located in Cavite, Philippines. GEMCOR produced several hundred gasifiers, but ceased operations in 1986 because of reduced government support, declining markets for its products, and continued heavy financial losses. In a national review of over 270 gasifier/diesel systems in the Philippines, it was determined that only four systems were actually operational after only four years of system life (15). Many GEMCOR units failed because of improper operation and/or maintenance and the use of difficult fuel sources. Tars and contaminants in the producer gas condensed and accumulated within the combustion chamber, often causing severe engine damage when rigorous decarbonization schedules were followed.

In general, gasifier/internal combustion engine projects have been problematic, particularly when implementation programs have been initiated prior to establishing an acceptable level of technological reliability through laboratory and controlled field testing. Only where the cost of transporting diesel fuel is high, loads on the gasifier/engine are fairly constant, homogeneous fuels are available, and competent maintenance is applied, can a gasifier be considered reliable and cost-effective. At present, off-the-shelf gasifier/engine units do not appear to be available commercially. There are reports of gasifier/engine generator sets being produced in Thailand and Brazil, but these appear to be largely custom built units.

Gasifier systems have been designed and commercialized in the U.S. for direct heat applications, as well as power generation, using a Rankine cycle in conjunction with steam turbines and engines. PRM Energy Systems (PRME) has successfully installed two 600 kW [thermal] systems in Malaysia, which have been in operation since August 1987. In the United States, PRME has been using a rice-hull-fed gasifier system for a par-boiling operation in Arkansas since 1984 (17). This technology is simple and robust and has an overall efficiency of about 14%. Efficiency could be significantly increased in larger applications if heat recovery components were used in the steam cycle.

Most bioconversion (anaerobic digestion) systems have been custom designed to account for local water chemistry, temperature and fuel characteristics. However, in at least two cases, companies have begun to engineer and construct digesters on a fill-to-order basis. Bacardi Corporation (Puerto Rico), for example, after successfully constructing and operating an anaerobic digester for its own use, has begun to market this technology to other companies in the Caribbean region (20). The Bacardi unit was initially designed as a waste water treatment facility, but the gas produced by the process was seen as a major incentive to use the technology more widely. Maya Farms (Philippines) has often been noted for its successful experience with anaerobic digestion equipment as well. They have installed a biogas system at the Philippines' largest swine facility, and have also successfully marketed their technology to several distilleries and agri-businesses in Southeast Asia (18).

There are several U.S. companies with direct combustion equipment product lines in the 1 to 25 MW range. Babcock and Wilcox, Foster Wheeler, Combustion Engineering, Zurn, and others have produced steam boilers and component equipment for wood-waste and bagasse combustion applications, both in the United States and under license in other countries (4). One example of this application is a rice-hull-fired system operated by Agrilectric, in Lake Charles, Louisiana. This system, designed and manufactured by McBurnie/Deltac, operates at approximately 26% overall thermal efficiency, with a 10 MW capacity. A second unit of similar design with a capacity of over 25 MW has been recently commissioned in California that will use both rice hull and straw. Discussions are currently underway between principals from Agrilectric and San Miguel Corporation (Philippines) to install a 10 MW plant in the Philippines in the near future (1).

There are only a few manufacturers of smaller-scale combustion systems with commercial products for converting more exotic fuels. One of the smallest and most novel is a thermal biomass conversion system produced by Stirling Technology, a company that began manufacturing a 5 kW rice hull-fired Stirling engine in Madras, India in 1986. These engines are used primarily for micro-irrigation but there is potential for a variety of other small-scale applications. Although there were problems in performance and reliability with early versions of this design the manufacturer now claims that these problems have been solved. It is estimated that over 120 engines are in use in India today (14).

Until recently, systems were designed to convert biomass to energy at minimal project cost; in most cases without taking into consideration the use of more efficient technologies, such as waste heat recovery units, economizers, superheaters, and automated boiler control systems. More recently, there has been a trend toward introducing higher efficiency technology on a regional and even a national scale for power generation. With improved system efficiency, some direct combustion systems that utilize biomass for on-site electricity generation can also allow for the generation of additional electricity for sale to the local grid. Particularly attractive are cogeneration systems which use high pressure steam to generate electricity in a turbine and the lower pressure exhaust steam as process heat. The most prevalent cogeneration systems use bagasse, a byproduct of sugar production.

One noteworthy example is that of the Kenana Sugar Company. This facility is one of the largest sugar mills in the world, currently producing 40 MW of power for on-site and local use. The plant consists of two 10 MW back pressure turbines and two 10 MW full condensing turbines, all supplied by Fuji Electric. Power is used for plant operations and to run the irrigation systems for cane production. With the installation of transmission lines to Khartoum (Sudan), the facility will export power during the off-season to supplement power generated by the national utility. This facility was designed by and operated under a management contract with ARKEL International until recently (2).

In another private venture, Proctor and Gamble Philippine Manufacturing Corporation installed a 5 MW waste-fired power plant in Metro Manila in 1986. The system operates on a combination of wood waste and coconut shell, providing process steam and electricity for the plant. Originally, the facility was intended to sell power to MERALCO, the local distribution company. However, the failure of the two parties to come to an equitable agreement for purchase of the power led Proctor and Gamble to seek ways to use all the power generated productively on-site.

In the public arena, there have been some well intentioned but unsuccessful attempts to institutionalize biomass power production. Perhaps the most ambitious program was designed in the Philippines in the early 1980's, a program often referred to as the "Dendrothermal Program." This program's primary objective was the construction of over seventy wood-fired power plants, ranging in size from 3 to 5 MW. The wood fuel for the power plants was to be supplied by state supported wood-energy plantations established on marginal land loaned to farmer groups for the sole purpose of producing wood fuel (7). Unfortunately, this program, so ambitious and promising at its inception, failed to achieve even a minor measure of success. The forestry component suffered from mismanagement, poor silvicultural research, and some unrealistic expectations, such as requiring farmers to sell fuel to the power plants at unprofitable rates. Only three of the more than seventy power plants were built. These plants received poor maintenance and were plagued by a wide range of mechanical and management problems. In addition, the plants were owned and operated by rural electric cooperatives which lacked the technical and managerial capability to operate projects of this size.

Currently, a large number of U.S. companies are expressing interest in providing energy equipment and services for biomass conversion. Unfortunately, U.S. technologies have not been cost competitive with other suppliers, particularly in the smaller size range (less than 600 kW high efficiency equipment). For example, Mernak (a Brazilian boiler manufacturer), has a long track record of success with several biomass fuels, including wood waste, bagasse, rice hull and other fuels. These systems are extremely attractive, at costs as low as $800 per installed kilowatt. Even with these low costs, the equipment includes, as part of a standard package, superheaters and heat recovery equipment that significantly increase cycle efficiency. Mernak's low cost can be attributed to previous recovery of development costs, a well established market in the frontiers of the Amazon basin, and little current competition. Moreover, the internal Brazilian markets, such as the Amazon basin (woodfuel) and Porto Alegre (rice hull) have provided a large, steadily growing and captive market base. Penetration into similar markets could allow other manufacturers to reduce product costs, but only if tens, or even hundreds of systems could be sold.

What can be learned from the experiences described above? It seems that the success stories have most often occurred when the private sector played a leading role in developing and operating the program or project. Moreover, projects that were successful represented sound business investments to end-users, compared not only to other possible energy projects but also to other investment opportunities in general. Technologies that were not fully developed to the proven commercial stage often encountered problems.

MARKET OPPORTUNITIES AND IMPEDIMENTS

Several countries have recently begun to consider and legislate private sector participation in power production. These countries include Costa Rica, Guatemala, India, Indonesia, Sri Lanka, and Thailand. These changes have resulted from increased pressures facing electric power utilities owing to extremely high debt burdens, high rates of demand growth, and needs to meet future capacity requirements, as well as increased governmental support of private sector activities in general (23).

There currently are numerous private power projects under negotiation. In Costa Rica and Guatemala, sugar mills are negotiating with their respective power companies for power purchase agreements for bagasse projects (21). The El Viejo mill recently began selling power to the Instituto Costarricense de Electricidad (ICE) as the first step towards liberalizing independent power production in Costa Rica. Likewise, Panteleon began selling power to Empresa Electrica de Guatemala (EEGSA) this year. Although both of these facilities are quite small (500 kW and 1000 kW respectively), they represent the first critical step in the process, both for the utilities as well as the mill owners. Approximately 10 to 50 MW of bagasse-fired generation potential exists in Costa Rica, and perhaps as much as 75 MW in Guatemala if high pressure steam equipment is purchased.

In India, the Punjab State Electricity Board is negotiating the purchase of a 1.5 MW rice hull-fired power plant as the first in a series of perhaps as many as two dozen modular plants to be installed in the future. The pilot plant is being financed jointly by the State Electricity Board, Punjab Agro-Industries, and the equipment supplier. In the Philippines, several projects are under consideration. Central de Azucarera de Tarlac (a sugar mill/distillery north of Manila) is negotiating a multi-megawatt project, using excess bagasse to generate steam and electricity for sale to the National Power Corporation. San Miguel Corporation (a beverage and food conglomerate in Manila) is considering the purchase of a 10 MW rice hull-fired power plant. World wide, small entrepreneurs are considering the purchase of biomass combustion systems for power generation at capacities of 500 kW to 1.5 MW (5).

Newly established policy guidelines will greatly affect the attractiveness of projects designed in coordination with electric utilities. As Tugwell (21) has noted, the reasons for the lack of existing cane energy projects in Central America has stemmed from government policies and the absence of well-defined incentives for cogenerators. In countries where policies and incentives have been clearly established, power generation projects have been undertaken successfully. However, the absence of competitive financing arrangements has been a limiting factor in sales of U.S. technology to these markets (19).

In addition to generating power from biomass for sale to established electric utilities, opportunities are emerging for biomass conversion to satisfy on-site energy needs. Perhaps the largest potential market (e.g., several thousands of systems) exists for small to intermediate scale biomass conversion systems to displace diesel prime movers ranging in size from 5 kW to approximately 200 kW. However, penetrating this market is difficult because of the lack of adequate credit in rural areas, financial markets in most developing countries present the greatest impediment to market penetration. Interest rates may range as high as 40%+ for rural credit in many countries, and when available it may be extended for periods of less than one year. Thus, a small entrepreneur must expect an investment to pay for itself in a matter of months.

In some respects, technologies create their own markets to fill needs. Many biomass conversion technologies do not appear to be available in the quantities and sizes needed for developing country markets; however, combustion technologies for larger power applications are an exception. In general, the market outlook is encouraging, but the process of seeking out independent power opportunities can be time consuming and expensive. Moreover, utilities in developing countries can be expected to bargain hard for attractive purchase agreements and, because rate structures are at times set below their cost of production, these utilities may be extremely inflexible in offering attractive packages.

As evidenced by the absence of readily available small-scale conversion technologies (5 to 50 kW), there is a need to bring technologies in this size range to the commercial stage, and to successfully integrate these technologies into appropriate markets. Additional investments in research will be required to bring these technologies currently in development and demonstration stages to points where they are cost competitive and sufficiently reliable to compete with their conventional counterparts.

TECHNOLOGY DEVELOPMENTS

The interest in efficiency improvements and clean combustion technology in the United States has resulted in development of technologies that could revolutionize biomass conversion, leading to greater use of biomass, especially in utility-scale applications. Perhaps the most promising of these technologies are aero-derivative, steam injected gas turbines (STIGs). STIGs have been used successfully with natural gas and coal gasification applications, and if an intercooler is introduced (ISTIG), efficiencies up to 47% can be achieved (11). Table 1 summarizes expected power output and efficiencies of STIG and ISTIG technologies. As this table indicates, the modified LM 5000 gas turbine design can develop an output of 108 MW under full steam injection with the ISTIG configuration. The more likely size would be using the STIG configuration, wherein the turbine will produce up to 50 MW of power at 44% overall thermal efficiency (12).

Figure 1 illustrates the relative benefits of a biomass fired steam injected gas turbines (BSTIG) over conventional fossil fuel fired conversion technologies. This figure provides a static analysis of the technology over a range of capacity factors, assuming constant fuel costs for both fossil and biomass fuels. The biomass fuel is assumed to be bagasse, with a fuel cost of $1.57/MBtu. The distillate fuel cost was assumed to be $5.50/MBtu, in accordance with EPRI guidelines (10). As this figure illustrates, the biomass fired STIG is a very attractive technology if sufficient biomass is available to fuel the turbine for a sufficiently long period.

Further testing and demonstration of STIGs will be required to certify expected equipment life and reliability before this equipment will be ready for sale to developing country utilities. However, no great technological barriers need to be overcome to move the biomass application of STIG to commercialization. The Cool Water Integrated Gasification Combined Cycle project has demonstrated the viability of the gasification/gas turbine combination, and while a biomass gasification system will require modification of the gas cleaning equipment, this modification should be relatively straightforward (16). As Williams (25) has noted, however, in order for the technology to be commercialized, the developers will require strong positive signals, perhaps nothing short of a "launch order" of several advance units, before the final development of the technology will be completed.

For more conventional combustion technologies, higher efficiencies can certainly be reached, but the cost of Rankine cycle systems with efficiencies approaching 40% would be prohibitively high for units less than several hundred megawatts. Practically speaking, the logistical problems involved with constructing units greater than five to ten megawatts at present efficiencies (18 to 26 percent) govern

Table 1: Expected power output of STIG and ISTIG technologies.

	LM5000 Simple Cycle	Minor Modified STIG	Intercooled STIG (ISTIG)
Rating, MWe	32.7	50	108
efficiency, %	37	44	55

Source: General Electric Company, Scoping study: LM5000 steam injected gas turbine, Evandale, OH, 1984.

the use of systems with higher capacities. Transportation costs, production management, feedstock management and quality control of the biomass fuel all have to be monitored with great care if larger systems (i.e., systems in excess of 1-2 MW) are to be used cost effectively. For these reasons, unless the cost of heat recovery and high pressure equipment can be reduced through some combination of reduced production and engineering costs, Rankine cycle systems will probably remain at their current efficiency levels (1).

For smaller-scale applications, additional funding is necessary for the development of gasification/internal combustion engine technology that is cost-effective and offers equal or better reliability than conventional diesel- or gasoline-fueled engines. There is no real competitor to the internal combustion (IC) engine for variable load and speed applications and for low power requirements. The work completed in the last decade has not produced a product that has challenged IC engines except in a very few specialized applications.

The two most critical components appear to be improvement of the gas cleanup train, and the IC engine itself. Simple, inexpensive gas cleaning equipment is necessary to reduce tars and particulates entering the engine, and more rugged engine components could improve life expectancy (3). Developments in ceramic components are expected to provide significant improvements in filtration and combustion chamber components, but their development could still be several years in the future.

The Stirling engine represents a technology for the smallest scale applications. Although companies such as Stirling Technology have demonstrated that these engines can be driven with biomass fuels, they have not demonstrated the durability and cost competitiveness required to compete successfully with small IC engines. Additional research will be required to develop these engines where widespread applications are feasible.

Gas separation technology has been used since the early 1940's to enrich radioactive fuel products for military and power plant applications. This technology has received increased attention recently, as a possible means of reducing thermal losses incurred in the process of removing contaminants from flue gases, and separation of high value (e.g., hydrogen and methane) from lower value gaseous products (N_2, NOx and CO_2) in gasification processes. Ceramic membranes, chemically and thermally stable under the temperature regimes in these gasification processes, may open larger markets for these technologies. Furthermore, hot gas separation could greatly reduce the risk in using solid biomass materials to drive STIG's, through both gas clean-up and through stripping the nitrogen and NOx from the product gas. While it is unlikely that ceramic membranes could be used in the next five years for these applications, their use by the turn of the century is not out of the question (6,9).

CONCLUSIONS

While biomass fuels presently play a large and significant role in energy use world wide they are generally used very inefficiently. A move is underway to improve efficiency for commercial and industrial uses. Utility-scale applications, and perhaps to a lesser extent, use of liquid fuels and biogas digesters will play a larger role in the changing complexion of biomass energy utilization.

Closed systems, including wood energy plantations used in combination with power generation for industry and utilities, will likely have a place in power sector expansion plans in many countries.

Concurrently, there will be a need to develop substitute fuels for charcoal and firewood as a household fuel, particularly in urban areas.

The development of equipment with higher efficiencies and lower unit costs will have to occur to make these changes possible. STIG, ISTIG, improved Stirling engines and gasification/internal combustion engine sets need to be brought to the market as early as possible. More efficient bioconversion technologies are needed to bring down the cost of biomass-derived liquid and gaseous fuels.

How will this happen? The research and development funds necessary to introduce reliable, efficient, and most importantly, cost-effective technologies to the market place will require a major commitment by the United States and other industrialized countries. Benefits from these improved technologies will be accrued by the entire community associated with electric power delivery and electric power use. Returns on investments will occur not only through normal means but through reductions in degradation of the environment.

The need to provide technologies that help us live in an environmentally balanced society, and to share these technologies with our neighbors in developing countries, has never been more urgent. The systematic depletion and/or destruction of our natural resources as well as the concern over the effect this may be having on our global environment suggest a need to address this impending crisis with a multi-level effort, one part of which is certainly the development and transfer of energy efficient, cost-effective conversion technologies.

REFERENCES

1. Amin-Arsala B., M. M. Gowen, Kenda and D. B. Waddle, 1988. Potential for private sector investment in rice residue power generation, Report # 88-05, Office of Energy, A.I.D., Washington, D.C.

2. Arkel International, Inc., 1981. The Kenana Sugar Factory, Sugar y Azucar, February.

3. Beenackers and Van Swaaij, 1987. Gasification, synthesis gas production and direct liquefaction of biomass, Energy From Biomass, Commission of European Communities, Elsevier Applied Science Publishers, England.

4. Biomass Energy Research Association (BERA), 1990. A Directory of U.S. Renewable Energy Vendors, U.S. Agency for International Development, Bureau for Science and Technology, Office of Energy, Washington, D.C.

5. Chronowski, R., 1989. Personal Communication, IRG Systems, Inc., Washington D.C., September.

6. Crull, Anna, 1989. Inorganic membranes: markets, technologies, players, GB-112, Business Communications Company, Inc., Norwalk, CT., April.

7. Denton, F., 1983. Wood for Energy and Rural Development: The Philippine Experience, National Energy Administration, Manilla.

8. Dunkerley, J. and W. Ramsay, 1983. Analysis of Energy Prospects and Problems in Developing Countries, Resources for the Future, Washington, D.C.

9. Egan, B. Zane, 1989. Using inorganic membranes to separate gases: R&D status review, ORNL/TM-11345, Oak Ridge National Laboratory, Oak Ridge, TN, November.

10. Electric Power Research Institute, 1987. Technical assessment guide, volume 3: fundamentals and methods, supply-1986, P-4463-SR, Volume 3, Palo Alto, California.

11. Gas Turbine News, 1988. "New NOx and CO limits spark utility industry interest in I-STIG," December.

12. General Electric Company, 1984. Scoping study: LM5000 steam injected gas turbine, Evandale, OH.

13. Gil, J., 1987. "Improved Stoves in Developing Countries," Energy Policy, April.

14. Kinzelman, C., 1989. Stirling Technology, Personal Communication, November.

15. Kjellerstrom and Bariega, 1987. Practical application of power generation via gasification of dry biomass: world wide experience, Volume 3, Proceedings of Biennial Congress of the International Solar Energy Society, Hamburg, Germany, September.

16. Larson and Williams, 1988. Biomass-fired steam injected gas turbine cogeneration, Proceedings of the 1988 ASME Cogen-Turbo Symposium, Montreaux, Switzerland.

17. Mahin, 1985. Rice hull energy conversion, Bioenergy System Report, Office of Energy, A.I.D., Washington, D.C., April.

18. Obias, 1985. Experience of Maya Farms in biogas production, National Symposium and exhibition on renewable energy technologies, Manila, Philippines, April.

19. Steingass, 1988. Electricity and ethanol options in Southern Africa, Report # 88-21, Office of Energy, A.I.D., Washington, D.C., September.

20. Szendrey, L. M., 1989. "Cogeneration from Biogas and Ethanol in Puerto Rico," Renewable Energy in the Americas Conference, U.S. Export Council for Renewable Energy, Miami, May 30-June 3.

21. Tugwell, Gowen, Kenda and Cohen, 1988. Electric power from sugarcane in Costa Rica, Report # 88-18, Office of Energy, A.I.D., Washington, D.C., July.

22. U.S. Agency for International Development (U.S.A.I.D.), 1988. New Directions for A.I.D. Renewable Energy Activities, Bureau for Science and Technology, Office of Energy, Washington, February.

23. U.S Agency for International Development (U.S.A.I.D.), 1988. A report to Congress, Power Shortages in Developing Countries: Magnitudes, Impacts, Solutions and the Role of the Private Sector, Bureau of Science and Technology, Office of Energy, Washington, D.C., March.

24. D. B. Waddle, 1985. Experience with rural gasification applications, ASAE Paper #85-5550, Winter Meeting of ASAE, Chicago, IL, December.

25. Williams, 1989. Biomass gasifier/gas turbine power and greenhouse warming, IEA/OECD Expert Seminar on Emerging Technologies for Reducing Emissions of Greenhouse Gases, Paris.

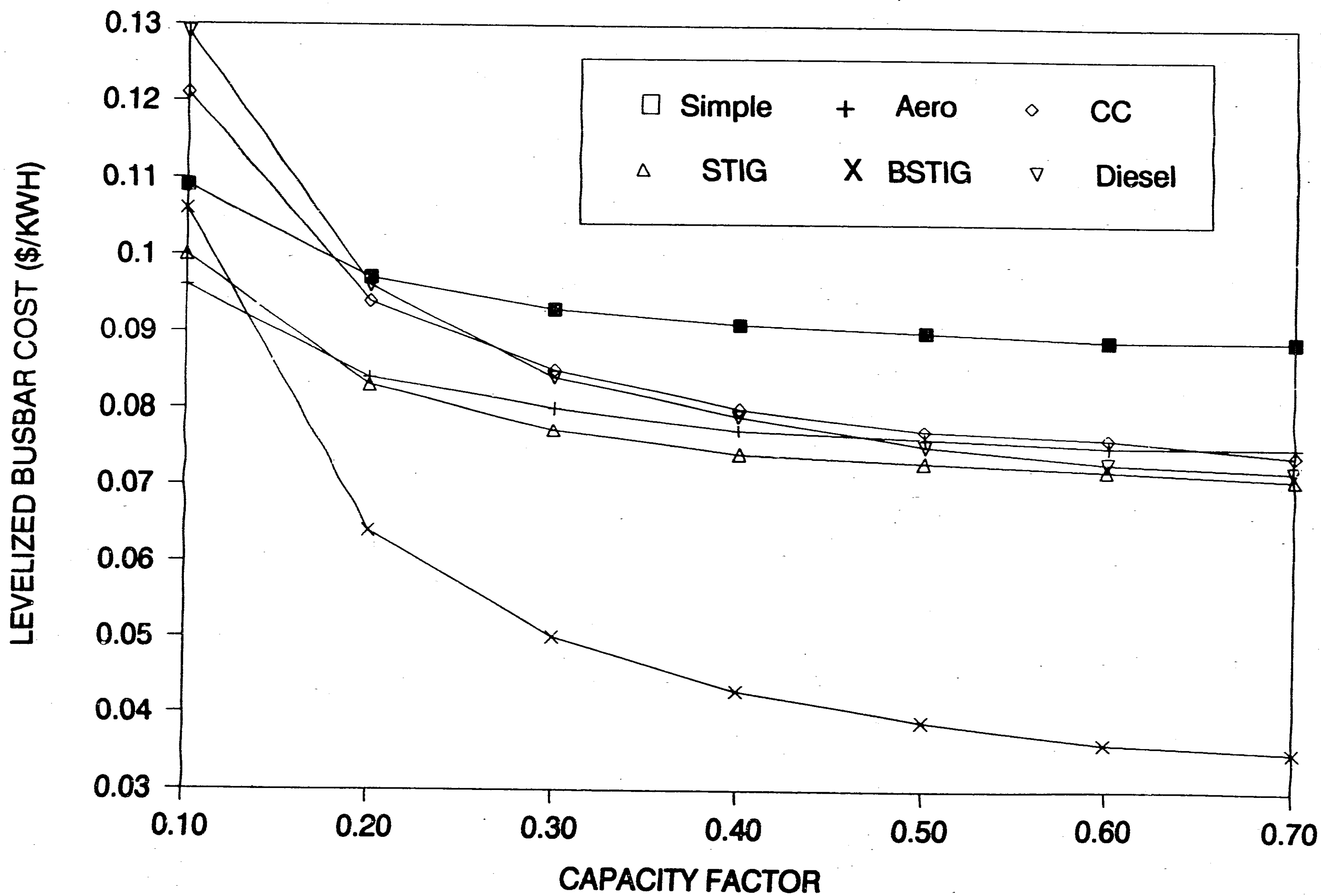

Figure 1. Prime Mover Screening Curve. 6% discount rate; $5.5/MBtu distillate; $1.73/MBtu bagasse cost; includes M&O, fuel, & capital recovery costs.

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