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BIOMASS-GASIFIER STEAM-INJECTED GAS TURBINE COGENERATION FOR THE CANE SUGAR INDUSTRY*

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ABSTRACT

Steam injection for power and efficiency augmentation in aeroderivative gas turbines has been commercially established for natural gas-fired cogeneration since 1980. Steam-injected gas turbines fired with coal and biomass are being developed. A performance and economic assessment of biomass integrated-gasifier steam-injected gas turbine (BIG/STIG) cogeneration systems is carried out here. A detailed economic case study is presented for the second largest sugar factory in Jamaica, with cane residues as the fuel. BIG/STIG cogeneration units would be attractive investments for sugar producers, who could sell large quantities of excess electricity to the utility, or for the utility, as a low-cost generating option. Worldwide, the cane sugar industry could support some 50,000 MW of BIG/STIG electric generation capacity. The relatively modest development effort required to commercialize the BIG/STIG technology is discussed in a companion paper prepared for this conference.

BIOMASS-GASIFIER STEAM-INJECTED GAS TURBINE COGENERATION FOR THE CANE SUGAR INDUSTRY

INTRODUCTION

While bagasse is widely used in the world's cane sugar industry for the cogeneration of steam and electricity, few factories generate excess electricity for export to the electric utility grid. A typical factory cogeneration system produces some 20 kWh per tone of cane crushed (kWh/tc), which is just enough to meet on-site needs. Such a system also meets on-site low-pressure steam demands (400-500 kg/tc) and leaves no excess bagasse. Far more electricity could be produced by sugar factories using cane residues. For example, cogeneration based on the use of modern high-pressure, condensing-extraction steam turbine (CEST) systems, similar to those already installed at a few factories, could lead to exporting more than 100 kWh/tc, while still meeting on-site energy demands.

Cogeneration with gas turbines should in principle be more attractive than with steam turbines, in light of the higher thermodynamic efficiency of the gas turbine for cogeneration applications (27) and the low unit capital cost of gas turbines compared to steam turbines at the modest scales associated with power generation at sugar factories (29).

Because of its low efficiency for producing electricity only and its poor part load efficiency, the simple cycle gas turbine is not well matched to industries characterized by widely varying heat loads, such as the seasonal sugar industry. However, the steam-injected gas turbine (STIG) is a good candidate for such applications if the electricity produced in excess of on-site needs can be marketed, e.g. sold to the electric utility (16).

Biomass integrated-gasifier/steam-injected gas-turbine (BIG/STIG) cogeneration technology and prospects for its use at sugar factories are assessed in this paper.

NATURAL GAS-FIRED STEAM-INJECTED GAS TURBINES

Steam injection to increase power and improve efficiency, a modification of simple-cycle aeroderivative gas turbines, has been commercialized for natural gas-fired systems. In a STIG cogeneration system, steam is produced in an exhaust heat recovery steam generator (HRSG), and steam not needed to meet the process heat demand is injected into the combustor and points downstream to augment power output and the efficiency of power generation. Table 1 shows the estimated performance of three commercially available STIG systems, as well as of other systems that may become available in the next few years.

A modified STIG cycle under development, the intercooled steam-injected gas turbine (ISTIG), would offer even better performance. When the working fluid (air) is cooled between the compressor stages with an intercooler, less compressor work is required and the turbine can operate more efficiently at a higher turbine inlet temperature (TIT).[1] The combined effects of steam-injection and intercooling on performance would be dramatic: while the output and efficiency for the STIG version of the LM-5000 gas turbine are 51 MW and

[1] The turbine blades of modern aeroderivative turbines are cooled with air bled from the compressor. Thus with cooler compressor air, the blades can be maintained within the prescribed metallurgical limits at higher TIT.

Table 1. Estimated performance of natural gas-fired steam-injected gas turbines.

ENGINE CHARACTERISTICS(a)			PERFORMANCE ESTIMATES					
			COGENERATION				ELECTRICITY ONLY	
		Comp	*Electricity*		*Steam*(b)			
Model	*TIT (°C)*	*Ratio*	*MW*	*%HHV*	*kg/hr*	*%HHV*	*MW*	*%HHV*
Commercial								
M1A-13CC	1010	7.8	1.24	18.3	4,710	52.3	2.37	29.7
501KH	982	9.3	3.3	24.0	9,850	55.9	5.5	35.0
LM-2500	1211	18.5	21.2	33.0	34,500	41.9	26.3	36.0
LM-5000	1211	25.3	33.1	33.0	47,700	37.1	51.4	40.0
Projected								
LM-38	1204	23.0	3.4	30.6	5,700	40.0	5.3	37.1
LM-1600	1241	22.5	12.7	35.0	21,800	49.8	17.0	36.3
LM-8000(c)	1371	26.8	97.0	42.3	42,600	15.7	114.0	47.0

(a) The engine characteristics are for simple-cycle operation. The M1A-13CC was recently introduced by Kawasaki (8), the 501KH is made by Detroit Diesel Allison (15), and the LM series of engines is made by General Electric (15,24).

(b) Steam conditions for all but the M1A-13CC, LM-1600 and LM-8000 are 2 MPa, 316°C, and the feedwater temperature is 60°C. For the M1A-13CC the steam is saturated at 1.5 MPa, with 15°C feedwater temperature. For the LM-1600, half the steam is at 3.1 MPa, 413°C, half is at 1.2 MPa, 388°C, and the feedwater temperature is 60°C. For the LM-8000, 64% of the steam is at 4.13 MPa, 449°C, 36% is at 1.38 MPa, 370°C, and the feedwater temperature is 15°C.

(c) For an intercooled, steam-injected gas turbine (ISTIG). The LM-8000 is a more modern version of the LM-5000.

40%,[2] respectively, when producing electricity only (up from 33 MW and 33% efficiency for a simple-cycle LM-5000), the output and efficiency of the ISTIG version would be 114 MW and 47% (Table 1). Because the efficiency gain is accompanied by a large increase in output, the installed capital cost of an ISTIG is projected to be only $360 per kW[3] (10), compared to an actual cost of about $570 per kW for a STIG based on the LM-5000 (11).

COAL-GASIFIER GAS TURBINES

The inherent cost and efficiency advantages of the gas turbine over the steam turbine and uncertainties about the long-term availability and price of natural gas have prompted considerable developmental efforts worldwide to marry the gas turbine to coal through coal gasification. Technical feasibility was demonstrated at Cool Water, California (25), where gas produced from coal in an

[2] Higher (or gross) heating values (HHV) are used for fuels in this paper. For natural gas, the HHV is approximately 10% greater than the lower (or net) heating value (LHV). For coal the difference is about 3%. The HHV of biomass per kg of contained dry matter is independent of its moisture content (mc), unlike the LHV. For biomass with 0%, 15%, 30%, and 50% mc, the LHV is lower than the HHV by approximately 5%, 10%, 15%, and 20%, respectively.

[3] The US gross national product deflator has been used to express all costs in this paper in constant 1985 US dollars. The companion paper to this one (13) expresses costs in constant 1987$. To convert constant 1985 dollars into constant 1987 dollars, multiply by 1.059.

oxygen-blown gasifier is cooled and scrubbed of sulfur and then burned in a 100-MW gas-turbine/steam-turbine combined cycle power plant.

In an effort sponsored by the US Department of Energy (USDOE) to identify ways to improve the efficiency and capital cost of coal-gasifier/gas-turbine technology, the General Electric Company (GE) examined alternative gasifier/gas-turbine combinations and found that marrying an air-blown, fixed-bed, dry-ash gasifier with hot-gas clean-up for sulfur removal to STIG and ISTIG units was especially promising.[4] The coal-gasifier ISTIG unit was estimated to have an efficiency of 42.1% in a 110 MW unit costing $990/kW installed (4), compared to an efficiency of 38% for a 600 MW Cool Water-type plant costing $1500/kW (29).

BIOMASS GASIFIER/STEAM-INJECTED GAS TURBINES

Some coal-gasifier/gas turbine technology is readily transferable to biomass applications. Because of the dispersed nature of the biomass resource, the gas turbine technology selected for biomass applications should offer favorable economics at modest scales. The gas-turbine/steam-turbine combined cycle is not a promising candidate technology, because the cost of the steam turbine bottoming cycle is quite scale sensitive. STIG and ISTIG technologies are not so constrained. The commercialization of the biomass gasifier/steam-injected gas turbine (BIG/STIG) and biomass-gasifer/intercooled steam-injected gas turbine (BIG/ISTIG) would require less developmental effort than is needed for the coal versions, because biomass typically contains negligible amounts of sulfur, the efficient and cost-effective removal of which is the major technical impediment to commercialization with coal. Commercialization of the BIG/STIG, therefore, could be accomplished in less than 5 years, compared to twice this long for development of a coal-gasifier STIG (3). If efforts to demonstrate BIG/STIG are carried out in parallel with efforts to commercialize ISTIG technology for natural gas applications, subsequently the two technologies could be combined into BIG/ISTIG systems.

Here the analysis is focussed on the first generation BIG/STIG, based on the use of a fixed-bed gasifier. The issues involved in choosing the appropriate gasifier and the problems of integrating the gasifier to the STIG unit are discussed in a companion paper (13). In the present paper, the emphasis is on the performance and economics of BIG/STIG systems compared to condensing-extraction steam turbine (CEST) systems that are already commercially available for biomass applications.

Performance

Engineers at GE have made preliminary estimates of the performance of BIG/STIG systems based on wood pellet gasification data taken at a GE test facility (9) and a detailed computer model of the LM-5000 STIG fired with low-BTU gas that was used previously for coal-gasifier STIG analyses (7). The estimated system mass flows and related parameters for the BIG/STIG are shown in Fig. 1. Because only limited data were available on biomass gasification efficiency, the GE estimates were deliberately conservative.

[4] GE proposed to demonstrate hot gas clean-up at its test facility within a year's time, followed within 3 years by the startup of a 5-MW coal-gasifier/STIG pilot plant and within 6 years by the startup of a 50-MW commercial demonstration plant (3). The entire demonstration/scale-up effort was shelved, however, when the USDOE elected to fund an alternative "clean coal" project (19), which involved coupling an air-blown, fluidized-bed gasifier to a gas-turbine/steam-turbine combined cycle. After several years of effort, this latter project was terminated.

The estimated performance characteristics of the LM-5000 BIG/STIG in cogeneration and power-only modes of operation are summarized in Table 2. These results have been extrapolated to estimate the performance of smaller systems. Throughout the size range from 5 to 50 MW, the BIG/STIG systems would produce electricity far more efficiently than CEST systems (Table 2).

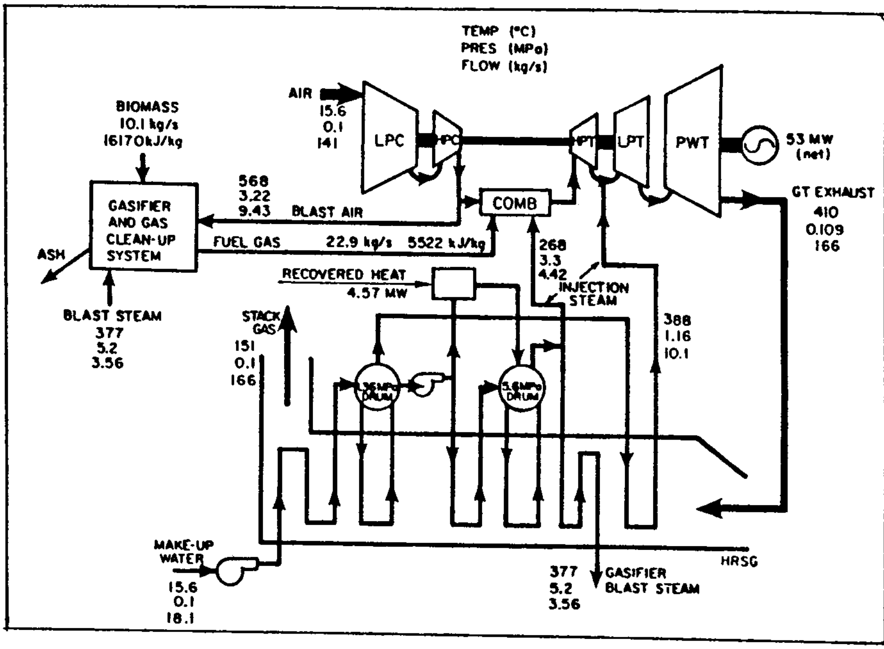

Fig. 1. Biomass-gasifier steam-injected gas turbine cycle showing preliminary mass balances and related parameters for a system based on the GE LM-5000 gas turbine (7). The energy flow marked RECOVERED HEAT accounts for feedwater preheating in the gasifier cooling jacket and in an air cooler preceding the gasifier boost compressor (not shown).

Capital Costs

An estimated installed cost of $990/kW for a 53-MW LM-5000 BIG/STIG (Table 2) was derived from a detailed cost estimate for a coal-gasifier STIG (4), by subtracting the costs associated with chemical sulfur removal, about 20% of the total. The cost estimate for a 5-MW LM-38 system, $1,650/kW (Table 2), was developed (12) based on discussions with GE engineers. The costs for intermediate-sized plants were estimated by interpolation (Fig. 2).

The estimated unit costs for BIG/STIG systems are lower than for CEST systems. Also, the scale economies for the BIG/STIG are weaker than for CEST units. Even in the larger BIG/STIG plants it is expected that shop fabrication could be utilized extensively (3), since the fuel conversion system is pressurized, making the overall system compact and readily transportable.

Maintenance

Though maintenance costs have often been high for gas turbines used in utility peaking service, they are expected to be relatively low for base-load applications of aeroderivative gas turbines. Minor on-site maintenance is facilitated by the modular nature of aeroderivative turbines, and major maintenance is done off-site, while a replacement from a lease-engine pool continues to produce power. Gas turbine availabilities in excess of 90% are typically guaranteed by vendors under such maintenance agreements (17).

ECONOMICS OF BIG/STIG FOR CANE SUGAR FACTORIES

Sugar producers are starting to seek additional products from sugar cane as part of diversification strategies (2). One strategy involves using bagasse more efficiently for energy, so as to permit excess electricity production for sale to the utility. Several CEST systems are already operating in this mode in sugar mills worldwide (21).

The economic prospects for a BIG/STIG alternative to the CEST are assessed here, through a case study of a hypothetical cane sugar factory modeled after Jamaica's second largest sugar factory, Monymusk (21). A significant database on the operation of Monymusk was available from a previous study (23) and was augmented by discussions with the chief factory engineer (1).

Table 2. Estimated performance and capital costs for BIG/STIG and CEST systems.

	PERFORMANCE						INSTALLED CAPITAL COST(c)
	COGENERATION				ELECTRICITY ONLY		
Prime	*Electricity*		*Steam*(b)				
Mover(a)	*MW*	*%HHV*	*kg/hr*	*%HHV*	*MW*	*%HHV*	*1985 US$/kW*
BIG/STIG							
LM-5000(d)	39	28.6	47,700	27.3	53	32.5	990
LM-1600(e)	15	27.1	21,800	30.7	20	30.8	1230
LM-38(e)	4	26.5	5,700	29.5	5.4	30.1	1650
CEST(f)							
Generic	17.5	13.0	65,550	35.9	27.0	20.3	1556
Generic	6.1	11.4	26,440	36.4	10.0	17.8	2096
Generic	1.8	10.1	9,010	37.2	3.0	15.7	3008

(a) For the CEST, the fuel is 50% mc biomass. for the BIG/STIG, it is 15% mc biomass. If 15% mc fuel were used in the CEST, electrical efficiencies would be improved by about 20% (12).

(b) Steam at 2 MPa, 316°C for the BIG/STIG; and 2 MPa, 250°C for the CEST.

(c) Based on the electrical capacity in the electricity-only mode. The installed cost of BIG/STIGs was estimated to vary with capacity as $2371*(MW)^{-0.22}$, where MW is the installed capacity in megawatts. The installed cost of CEST for units smaller than 35 MW was estimated to be $4182*(MW)^{-0.30}$.

(d) Based on (7).

(e) See (15) for source of estimate.

(f) The performance of the 27-MW unit is estimated based on a 6.3 MPa, 482°C system fueled by 50% mc biomass (23). For smaller systems, efficiency in the electricity-only mode is estimated as $E = 13.93*(MW)^{0.107}$, where E is in percent (12). See Appendix B in (12) for additional information.

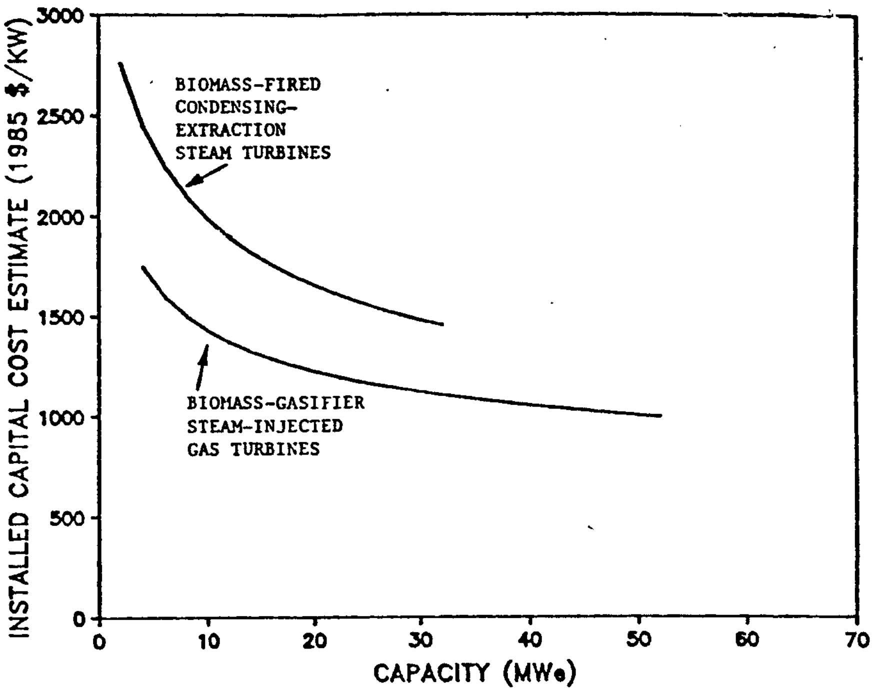

Fig. 2. Estimated unit installed capital costs for biomass-fired cogeneration plants based on BIG/STIG and CEST technology (12).

BIG/STIG systems would produce substantially more electricity than CEST units, but steam production would be limited to about 300 kg/tc (Fig. 3).[5] A detailed end-use assessment of the Monymusk factory indicates that steam demand could be cost-effectively reduced from 400 kg/tc to about 250 kg/tc by retrofitting more efficient technologies (falling-film evaporators, plate-and-gasket juice heaters, continuous vacuum pans) currently used in industries more dependent on fossil energy, e.g. beet sugar and dairy (21). Such large reductions in steam use are possible because sugar factories have traditionally been designed to be inefficient, so as to consume all the bagasse they produce and thereby avoid disposal costs.

To receive a capacity credit in the price for the electricity they would sell to a utility, sugar producers would be required to supply power year-round. Thus, some producers are also considering recovering some cane trash (tops and leaves --see Fig. 3, inset) to store for use as fuel during the non-milling season, which is about 5 months long in Jamaica. It is estimated that the tonnage of the cane

[5] The total steam production in the HRSG of the BIG/STIG would be higher than 300 kg/tc. However, the fixed-bed gasifier considered here would require about 20% of the total steam produced when operating with biomass (Fig. 1). A fluidized-bed gasifier would require much less, if any, steam (13).

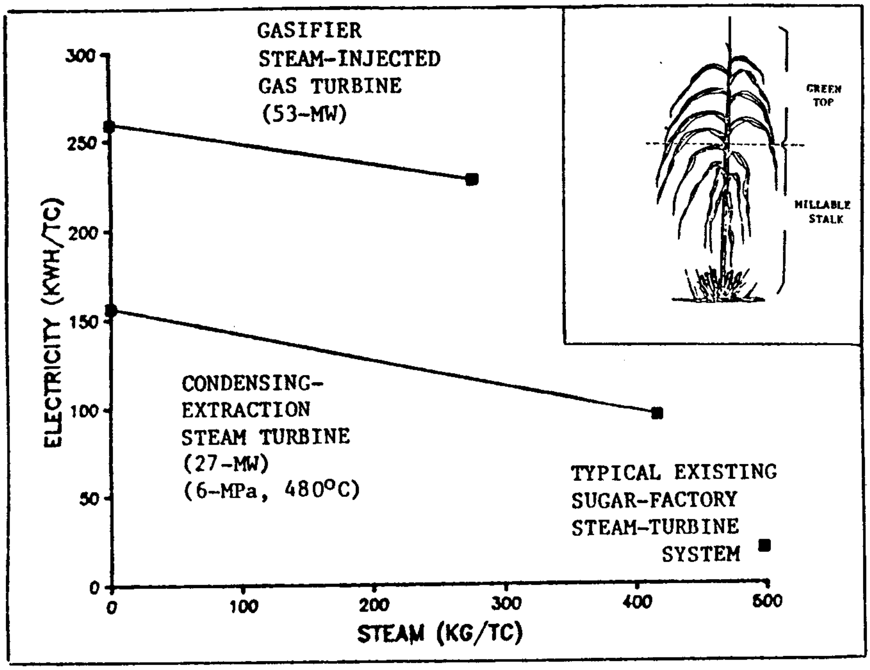

Fig. 3. Electricity and steam production estimates for alternative bagasse-fired cogeneration systems operating in a sugar factory. The inset shows a sugar cane plant, including the stalk, from which bagasse is derived, and the tops and leaves (also called cane trash after harvesting).

trash produced is about twice that of the bagasse (22).[6] Annual electricity exports would rise substantially if cane trash or an alternative fuel were used in the off-season (Fig. 4). In the best CEST case, some 240 kWh/tc would be generated, 220 kWh/tc of which would be exported. The BIG/STIG would produce over 460 kWh/tc, or more than 20 times current production.

Results for Jamaica

The internal rate of return and cost of power generation were calculated for new BIG/STIG and CEST cogeneration facilities at the hypothetical Jamaican sugar factory processing 175 tonnes of cane per hour. The bagasse available at the factory would support a 27-MW CEST or a 53-MW BIG/STIG.[7] The factory steam demand was assumed to be about 250 kg/tc, which would be achieved with an additional $3.1 million of investments in end-use equipment (21). This

[6] With the CEST, the total tonnage of cane trash used in the off-season would be about 3/4 of the bagasse tonnage consumed during the milling season. With the BIG/STIG, bagasse and cane trash consumption would be comparable.

[7] The following costs were estimated for this economic analysis of the BIG/STIG (CEST) (12): an installed capital cost of $990/kW ($1556/kW); a fixed annual maintenance cost of $1,304,000 ($664,200); a variable maintenance cost of $0.001/kWh ($0.003/kWh); and and annual labor cost of $297,000 ($129,600).

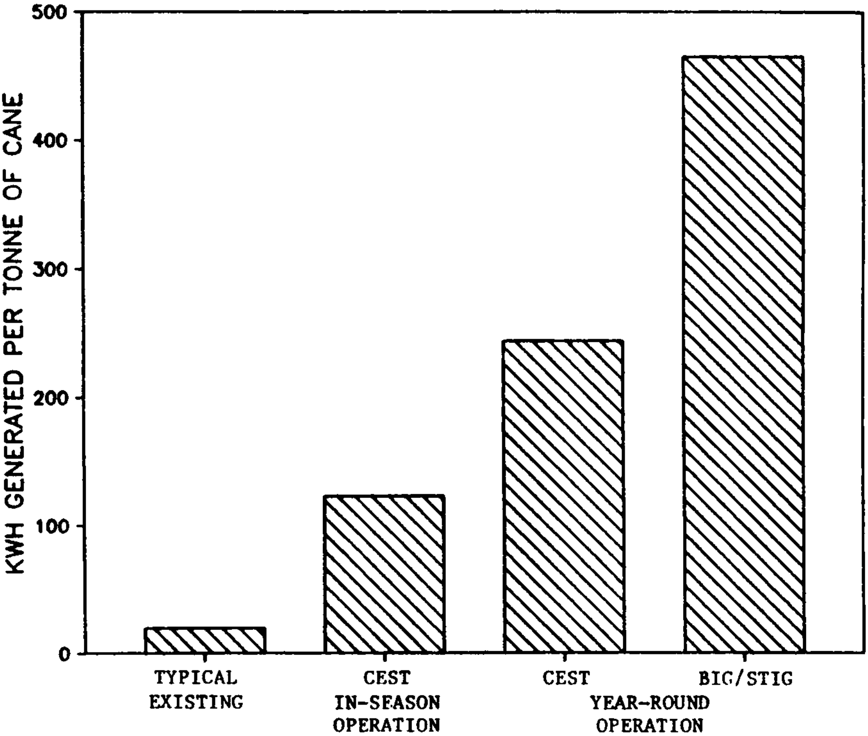

Fig. 4. Potential cogeneration of electricity using sugar cane residues. Left bar shows typical existing situation at a sugar factory during the milling season. Next bar shows CEST system operating during the milling season at a factory where steam-saving retrofits have been made. Third bar shows CEST at the steam-saving factory operating year-round. Right bar shows BIG/STIG at the steam-saving factory operating year-round.

additional capital--$115/kW for the CEST, $58/kW for the BIG/STIG--represents a small increment to the cost of the cogeneration plant. Two off-season fuel supply scenarios were considered: cane trash for the base case and oil use for a 5-year period before switching to cane trash.

Internal Rate of Return. The rate of return depends strongly on the price paid by the utility for the electricity it buys from the sugar producer. Here it was assumed that, as in the United States under the Public Utility Regulatory Policies Act, this price is equal to the cost the utility can avoid by not otherwise having to provide this electricity. The estimated avoided cost in Jamaica is 5.0-5.8 cents/kWh (12), based on the cost of power from a new 61-MW steam-electric plant burning imported coal (18).[8]

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[8] Estimated assuming an installed cost of $1316/kW, including $121/kW for a portion of the costs of building a national coal infrastructure, a 66% capacity factor, a heat rate of 12,030 kJ/kWh, labor ocsts of $358,000/yr, maintenance costs of 0.3 cents/kWh, a 12% discount rate, and a 30-year plant life (18). The electricity price range reflects a range of coal price estimates: $1.43/GJ

For the asssumed electricity price range, the ROR would be 18-23% for the BIG/STIG system with steam-conserving retrofits, compared to 13-16% for the CEST. With the BIG/STIG, exports of electricity would be almost double those with the CEST (Table 3). In the base case, assumed fuel costs are higher for the BIG/STIG (Table 3, note b), since briquetting was assumed to be necessary to use biomass in the fixed-bed gasifier. If less extensive processing were required for the BIG/STIG, the ROR would increase substantially, while if pelletizing were required, it would fall to near the base-case values for the CEST investment (Table 3).

If oil were burned during the first 5 off-seasons, the ROR for the CEST and BIG/STIG would be comparable, since the BIG/STIG would burn distillate fuel oil, while the CEST would burn less costly residual fuel oil.[9]

Levelized Cost of Electricity Generation. While the BIG/STIG would provide much more attractive rates of return to a sugar producer than would a CEST plant, the capital involved in either case would be large for a sugar producer. But from the perspective of an electric utility, the cogeneration investment would typically be less than what would be required to build a comparable amount of new central station capacity.

Cogenerated electricity would be of interest to the utility if it cost less than other utility sources. With utility financing[10] and the base-case conditions of Table 3 the BIG/STIG would produce exportable electricity for about 4.1 cents/kWh, and the CEST would produce about half as much electricity for about 4.8 cents/kWh. These cogeneration costs, and those for smaller installations, are compared in Fig. 5 to the cost of power from a new 61-MW coal-fired power plant. BIG/STIG plants larger than 20 MW would provide substantially lower-cost electricity than the coal-fired option, even with a low coal price.

The cost of exported electricity is also compared to the *operating* cost of existing Jamaican oil-fired plants, which supply over 90% of the country's electricity.[11] BIG/STIG plants larger than 20 MW would produce electricity at a comparable or lower cost, even with oil at $2.9/GJ ($19/barrel). Under these conditions, it would be economically worthwhile to scrap existing oil-fired plants and replace them with new BIG/STIG facilities.

Results for Southeast Brazil

Southeast Brazil provides an interesting contrast to Jamaica, because it is a cane-producing region that relies heavily on hydropower, historically a much less costly electricity source than most alternatives. Since most of the economical hydro resources have already been exploited in the Southeast, however, new

($40/tonne) to $2.08/GJ ($58/tonne). For comparison, costs for new electricity supplies for Jamaica estimated elsewhere (23) are: 8.3, 6.6, and 8.7 cents/kWh, for coal-fired steam electric, oil-fired steam electric, and oil-fired gas turbine power plants, respectively.

[9] In a third scenario, the cogeneration system could be undersized relative to the in-season fuel supply, and the excess bagasse stored for use during the off-season (after processing to permit long-term storage), thus avoiding the use of an auxiliary biofuel as well as oil. In this scenario about half as much electricity would be produced annually, and the RORs would be 14-18% for the BIG/STIG (using briquetted bagasse year-round) and 10-13% for the CEST (using baled, dried bagasse during the off-season) (12).

[10] A 12% discount rate, recommended for Jamaican utility sector analyses (18), has been used to calculate generation costs.

[11] The estimated operating costs for existing oil-fired plants are 4.5-6.1 cents/kWh, assuming an oil-steam plant heat rate of 14,500 kJ/kWh, and O&M costs of 0.3 cents/kWh (18), and residual oil costing $2.9/GJ to $4.0/GJ.

Table 3. Results of financial calculations (a).

Electricity Sales Price (cents/kWh)	5.0		5.8	
Cogeneration Technology	CEST	BIG/STIG	CEST	BIG/STIG
Exported Electricity (million kWh/yr)	178	360	178	360
INTERNAL RATES OF RETURN (%/yr)				
Base Case(b)	13	18	16	23
Alternative BIG/STIG fuel processing(c)				
None		24		29
Drying only		22		27
Baling and drying		21		26
Pelletizing		11		16
Alternative off-season fuels				
Oil/biomass(d)	10	11	12	13

(a) For a 206 day milling season and 90% equipment availability.

(b) During the season, the CEST burns unprocessed, 50% mc bagasse [no cost] and the BIG/STIG burns briquetted, 15% mc bagasse [$1.16/GJ (6)]. In the off-season, cane trash (baled, dried) costs $0.97/GJ for the CEST (23) and (briquetted) costs $1.35/GJ for the BIG/STIG.

(c) Fuel costs ($/GJ) on/off season are: with no processing, 0/0.97; drying only, 0.58/0.97; baling and drying, 0.78/0.97; pelletizing, 2.02/2.21.

(d) The CEST and BIG/STIG systems would burn residual fuel oil ($2.9/GJ) and distillate fuel oil ($5.4/GJ), respectively, for the first 5 years while cane trash recovery systems are developed, followed by a switch to cane trash (base case conditions).

plants would be built in the Amazon, with transmission lines connecting them to Sao Paulo (5). Electricity from such facilities, including transmission, is estimated to cost from 3.2 to 5.8 cents/kWh (Fig. 5).

Based on the calculations for Jamaica, large (53-MW) BIG/STIG cogeneration plants operating year-round on briquetted cane residues at sugar factories in Sao Paulo could supply electricity at a cost in the mid-range of costs estimated for new hydro supplies.[12] By contrast, only the larger CEST units would be competitive and then only with higher-cost hydro (Fig. 5).

GLOBAL MARKETS FOR BIG/STIGs

Extrapolating the Jamaican analysis, we estimate that the cane residues produced worldwide in 1985 would support about 50,000 MW of BIG/STIG capacity at sugar factories, over 90% of which would be in developing countries in Asia and Latin America.

The BIG/STIG capacity could make a particularly important contribution to the electrification of developing countries. Some 300 TWh of electricity could be produced annually, which is about 1/4 of the electricity generated by utilities in these countries today (Table 4) and is comparable to the level of electricity generated with oil. BIG/STIG cogeneration would also be well-suited for the

[12] Alternatively, the BIG/STIG might operate only during the milling season. The cost of cogenerated electricity would be higher, but since the milling season coincides with the dry season, the higher cost would be offset to some degree by the benefit from the filling of the hydropower dry-season "trough," which makes possible greater use of the installed hydroelectric capacity.

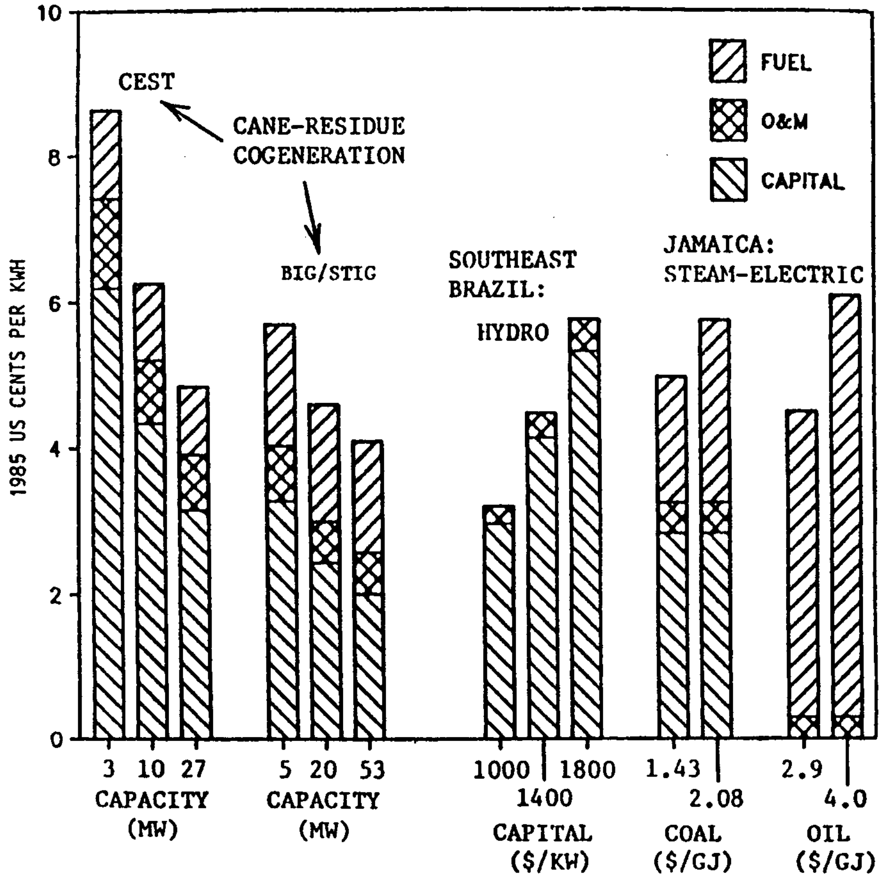

Fig. 5. Estimated levelized costs of generating exportable electricity at cane-residue-fired cogeneration plants and at least-cost central station power plants supplying electricity in Jamaica and Southeast Brazil.

production of electricity at alcohol distilleries (20). The potential electricity generation with the BIG/ISTIG would be larger still.

There are also large potential markets for gas turbines using other food and fibre residues (13,29). In the longer term, dedicated energy plantations might provide fuel for stand-alone BIG/STIG and BIG/ISTIG power plants (13,14,26).

Because biomass-gasifier/gas-turbine technologies like BIG/STIG and BIG/ISTIG would be able to provide competitive electricity supplies in rural areas, their deployment could promote rural industrialization, thereby helping alleviate problems of rural unemployment and urban migration, which are among the most formidable problems facing many developing countries.

Table 4. BIG/STIG electricity generating potential (column A) using the 1985 level of cane production, and the actual total electric utility generation in 1982 (column B), both in TWh.(a)

	A	B		A	B	A	B
TOTAL DEVELOPING COUNTRIES						**304**	**1124**
ASIA						**89**	**599**
India	31.6	129.5	Iran	0.90	17.5		
China	19.0	327.7	Vietnam	0.81	1.69		
Thailand	10.8	16.2	Burma	0.45	1.52		
Indonesia	7.6	11.9	Bangladesh	0.42	2.98		
Philippines	7.4	17.4	Malaysia	0.32	11.1		
Pakistan	6.4	14.9	Nepal	0.12	0.284		
Taiwan	3.4	45.0	Sri Lanka	0.07	2.07		
CENTRAL AMERICA						**65**	**100**
Cuba	35.5	10.8	Jamaica	0.94	1.30		
Mexico	15.7	73.2	Panama	0.72	2.71		
Dominican Rep.	4.2	2.38	Belize	0.49	0.065		
Guatemala	2.3	1.42	Barbados	0.45	0.339		
El Salvador	1.2	1.45	Trin./Tob.	0.36	2.30		
Nicaragua	1.1	0.945	Haiti	0.23	0.352		
Honduras	1.0	1.04	St. Chris.	0.12	na		
Costa Rica	1.0	2.42					
SOUTH AMERICA						**116**	**257**
Brazil	95.0	143.6	Guyana	1.1	0.255		
Colombia	6.1	21.3	Bolivia	0.78	1.40		
Argentina	5.5	36.2	Paraguay	0.36	0.569		
Peru	3.3	7.25	Uruguay	0.23	3.47		
Venezuela	2.1	39.0	Suriname	0.05	0.175		
Ecuador	1.3	3.09					
AFRICA						**32**	**167**
South Africa	11.4	109.0	Mozambique	0.26	3.25		
Egypt	3.7	17.2	Somalia	0.24	0.075		
Mauritius	3.1	0.320	Nigeria	0.23	7.45		
Zimbabwe	2.1	4.16	Angola	0.23	1.46		
Sudan	2.0	0.910	Uganda	0.15	0.569		
Swaziland	1.8	0.075	Congo	0.11	0.195		
Kenya	1.6	1.73	Mali	0.09	0.080		
Ethiopia	0.87	0.618	Gabon	0.05	0.530		
Malawi	0.69	0.410	Burk. Faso	0.05	0.123		
Zambia	0.64	10.3	Chad	0.04	0.065		
Ivory Coast	0.57	1.94	Guinea	0.02	0.143		
Tanzania	0.47	0.720	Sierra L.	0.02	0.136		
Madagascar	0.45	0.342	Benin	0.02	0.016		
Cameroon	0.32	2.15	Liberia	0.01	0.389		
Zaire	0.30	1.48	Rwanda	0.01	0.066		
Senegal	0.30	0.631					
OCEANIA						**2**	**1**
Fiji	1.6	0.241	Papua N.G.	0.13	0.441		
CANE-GROWING INDUSTRIALIZED COUNTRIES						**28**	**2409**
Australia	15.5	104.9	USA	12.7	2304		

(a) Based on Table 18 in (12). The potential BIG/STIG generation estimate for Brazil is based on all cane grown in Brazil (for sugar or ethanol production).

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