ADVANCED BAGASSE-FIRED COGENERATION TECHNOLOGIES

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Introduction

Low and falling world sugar prices and prospects of slow growth in world markets for raw sugar (FAO, 1985) provide significant motivation for sugar producers to search for alternative end-products from sugarcane. Alcohol fuel and electricity in excess of onsite needs are two attractive alternative products, particularly in countries where large quantities of expensive imported oil are used to meet domestic energy demands.

The conversion of raw sugar juice into ethanol by distillation is a relatively well-proven technology, as evidenced by the successful implementation of large-scale alcohol production in Brazil (Moreira and Goldemberg, 1982). Considerable improvements, however, could be made in the overall energy-efficiency of production, which would lead to greater availability of excess bagasse (Williams, 1985). In many cases, it appears that energy efficiency improvements are employed only to the extent that they lower plant steam requirements to match the amount of steam that can be generated with the available bagasse.

Production of large amounts of excess electricity by sugar refineries and alcohol distilleries is not widespread. The primary reason for this is the exclusive use of steam-turbines, which generate a relatively small amount of electricity for each unit of steam produced by comparison with other cogeneration technologies (Williams, 1978). Despite their relatively high capital cost compared to alternative technologies (see Fig. 1), steam turbines have been chosen because the technology for bagasse-firing is well-established and generally provides adaquate economic returns.

Even in cases where large amounts of excess electricity could be produced, prices paid by utilities to cogenerators for electricity may be economically unattractive, or the technical considerations involved in having small power producers connected to the grid (Geller, 1982) may be discouraging such connnections.

In the United States, the problem of unfair prices for cogenerated electricity has largely been solved by the passage in 1978 of the Public Utilities Regulatory Policies Act (PURPA). As a result of PURPA, electric utilities are now required to (1) purchase power from qualifying cogenerators at a price that reflects the costs the utilities would avoid by not having to provide the electricity themselves and (2) provide back-up power at rates that do not discriminate against cogenerators.

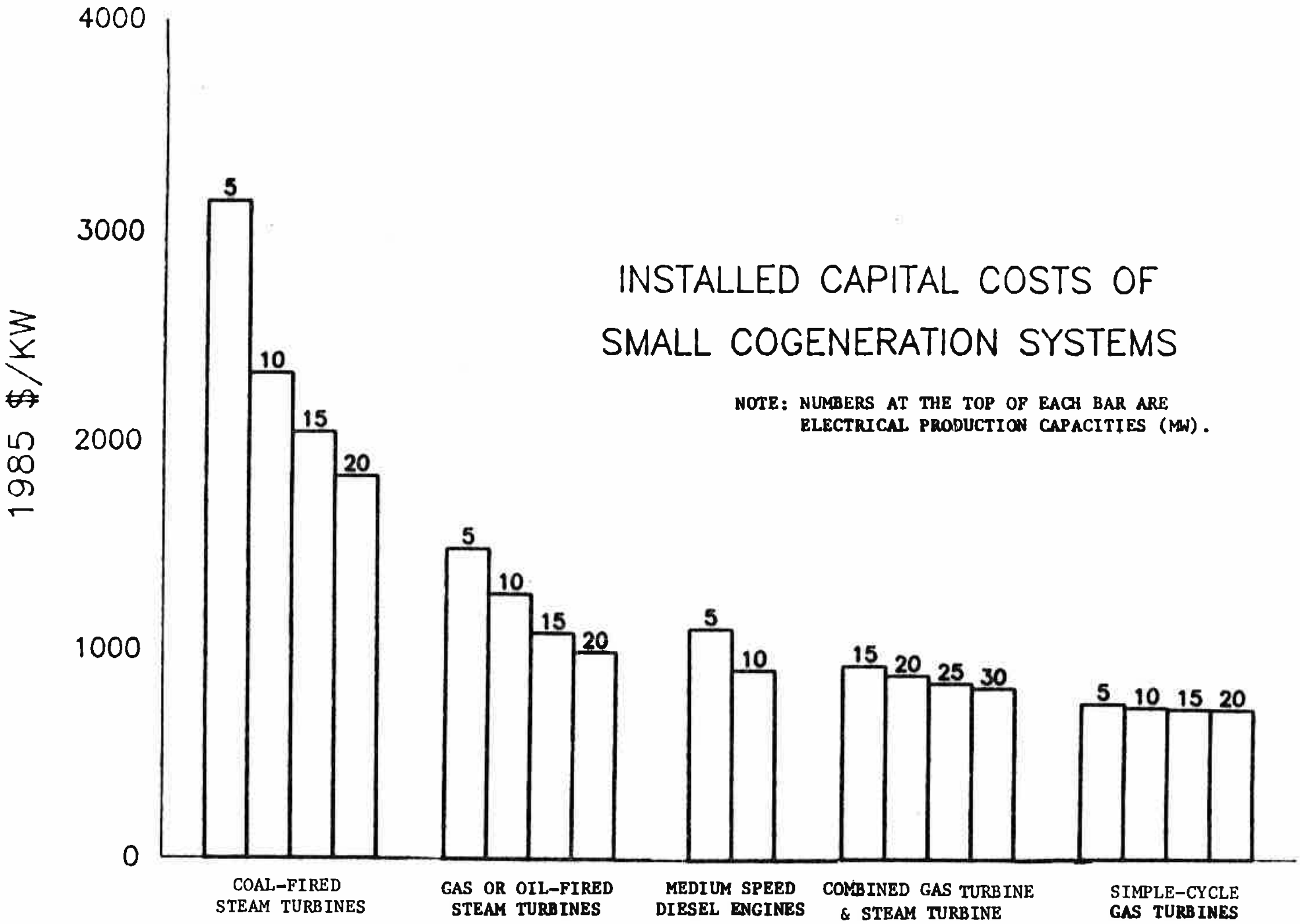


Figure 1

In the US, PURPA has led to a significant expansion in the use of cogeneration technologies characterized by high electricity-to-heat ratios, and hence the capability of producing large amounts of electricity in excess of onsite needs. These include gas turbines and diesel engines, the cogeneration technologies of high thermodynamic efficiency which are also lowest in capital cost (see Fig. 1)

Advanced Technologies

Most gas turbines and diesel engines in use today operate on liquid or gaseous fossil fuels. Rising prices for these fuels over the last decade have spawned the commercialization of innovative higher efficiency machines. In addition, advanced gas turbines are being developed to operate on lower quality fuels, including solid fuels (Makansi, 1983), and there is growing interest in firing both gas turbines and reciprocating engines with synthetic gases derived from low quality fuels (Reyaud and Gazonnet, 1981).

Preliminary calculations indicate that the availability of high-efficiency, high electricity-to-heat ratio, bagasse-fired cogeneration technologies, combined with efficiency improvements in processing technologies, would significantly increase the potential for sugar refineries and alcohol distilleries to supply large amounts of electricity to national grids (Williams, 1985).

These considerations suggest that it would be worthwhile to carry out detailed assessments of the technical and economic feasibility of using various advanced, bagasse-fired gas turbine and diesel engine cogeneration systems in existing sugar refineries, in sugar refineries converted to alcohol distilleries, and in new energy efficient alcohol distilleries.

Solid-fueled gas turbines closest to commercialization today are open-cycle, indirectly-fired units. In this cycle, the heat released by atmospheric pressure combustion of bagasse would be transferred through a high temperature heat exchanger to the cycle working fluid, air, before it expands through the turbine (Marksberry and Limdahl, 1979)). The clean hot turbine exhaust gases can be used directly for process heat or to produce steam in a heat recovery steam generator (see Fig. 2). The major advantages of this technology compared to steam turbines include a high electricity-to-heat ratio and relatively high overall thermodynamic efficiency in small sizes. Disadvantages include relatively poor performance at partial steam load, and increased capital costs (compared to conventional gas turbines) due to the heat exchanger requirements. In addition, because of current limitations of heat exchanger materials, the efficiency of the indirectly fired units are lower than directly fired systems, which can be operated at higher turbine inlet temperatures and pressures. Development work to overcome heat exchanger limitations is ongoing for fluidized bed combustor-heat exchangers (Tignac and Campbell,

Schematic of a Simple Open-Cycle Combustion Turbine in a Cogeneration Application

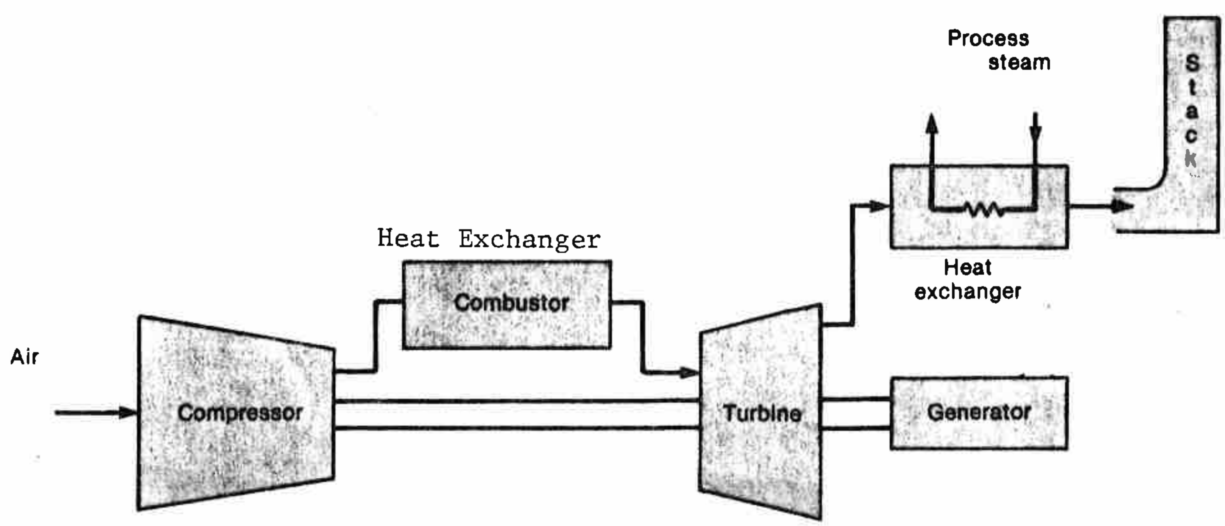
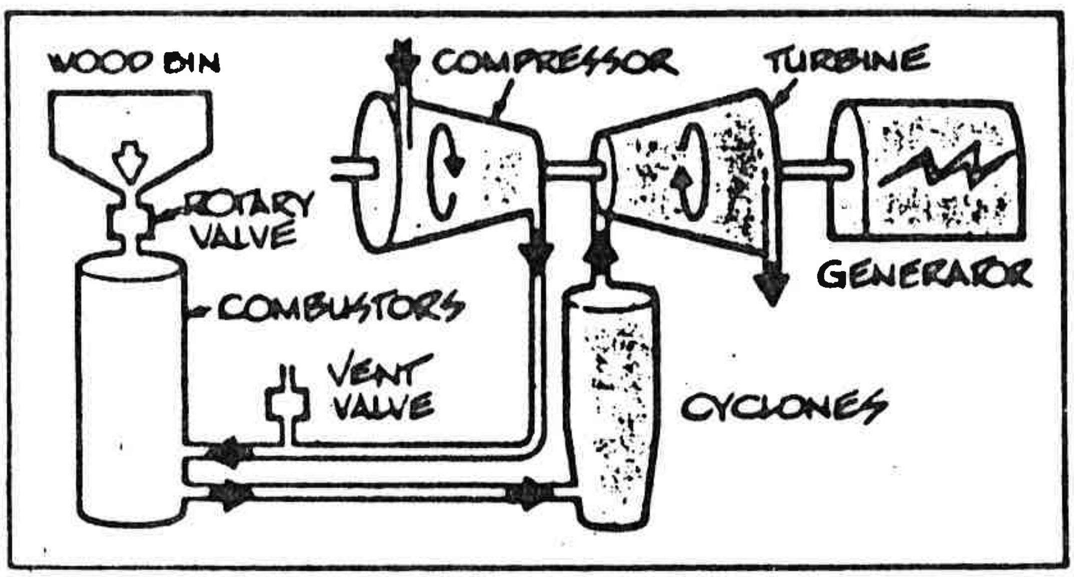


Figure 2

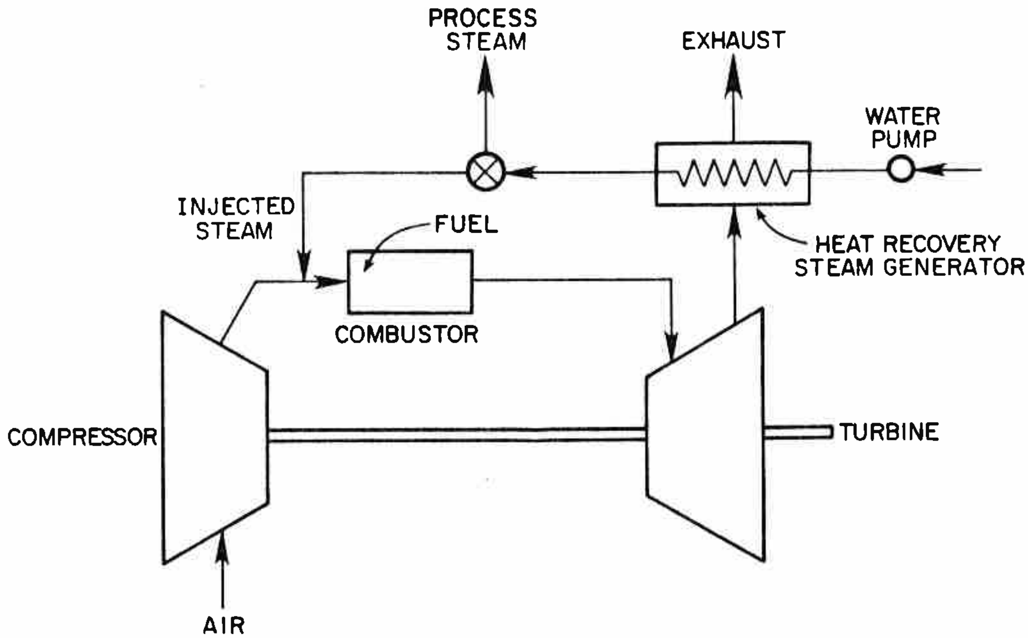
1983), and for high-temperature metallic alloy and high-performance ceramic heat exchangers that could be used with various combustors (Ward, Metcalfe, and Dapkunas, 1983; Wright and Minchener, 1983).

Also under active development are directly-fired open-cycle gas turbines operating on a biomass (Hamrick, 1984). In this cycle, air exiting the compressor is ducted to a high pressure combustor in which the biomass burns. After passing through a cyclone to remove particulates that would damage the turbine blades, the hot gases are ducted back to the turbine (see Figure 3). Since no high-temperature heat exchanger is required, the efficiency of this system should be higher, and capital costs lower, than for the indirectly-fired unit, while its electricity-to-heat ratio would be comparable. However, as with any simple-cycle gas turbine, its part load performance is poor. A small commercial-scale (3 MW) saw-dust fired unit is presently undergoing trial operation in Red Boiling Springs, Tennessee (Hamrick, 1985), in part to determine the extent of hot gas clean-up required to insure adequate turbine life, the primary unknown with this technology.



Open-Cycle Gas Turbine Directly-Fired with Wood
Figure 3

The performance of both the indirectly and directly-fired gas turbines would be enhanced, with very little increase in capital costs, if they were operated with steam injection. In this cycle, steam produced in the heat recovery steam generator is injected back into the high-pressure hot gas stream before it enters the turbine (see Fig. 4). The higher mass flow through the turbine, obtained without additional compressor work, leads to a significant increase in both efficiency and output (Larson and Williams, 1985a). From the perspective of maximizing total electrical generation over the year, this cycle is perhaps unmatched. In addition to having a high electricity-to-heat ratio at full steam load, this cycle's electrical output can be augmented at part load by injecting unneeded process steam (Larson and Williams, 1985b). Thus, for example, during the off-season when no cane is being processed in a refinery or distillary, a steam-injected cogeneration system might be converted into a very high efficiency, high output unit for producing electric power only.



SCHEMATIC STEAM-INJECTED
GAS TURBINE CYCLE

Figure 4

Another cycle which can maintain high efficiency at part-load is the indirectly-fired, closed-cycle gas turbine. In this cycle, heat is transferred in a high temperature heat exchanger from an external combustor to the working fluid (see Fig. 5) (Lee, 1982). Since the cycle is closed, the working fluid can a gas other than air, providing an additional degree of freedom in optimizing the design of the cycle. This cycle has a high electricity to heat ratio, and its efficiency increases moderately as the process steam load drops, due primarily to adjustments in the cycle pressure levels and the amount of circulating working fluid (Marciniak, et al., 1980). A potential disadvantage of the cycle is its moderate cooling water requirement, although lower quality water can be used. This may actually prove to be an advantage in applications where low-temperature heat (hot water) can be utilized. Like the indirectly-fired open-cycle, greater utilization of this cycle is limited by heat exchanger material constraints. Increased capital costs due to the heat exchanger may be offset by lower costs for the turbo-machinery, which can be substantially smaller than in a comparable-output open cycle (Campbell and Lee, 1982).

The gas turbine directly fired with bagasse would probably be the most attractive alternative to the steam turbine because of its high efficiency and low capital cost. However, if developments do not proceed as expected

Closed-Cycle Gas Turbine

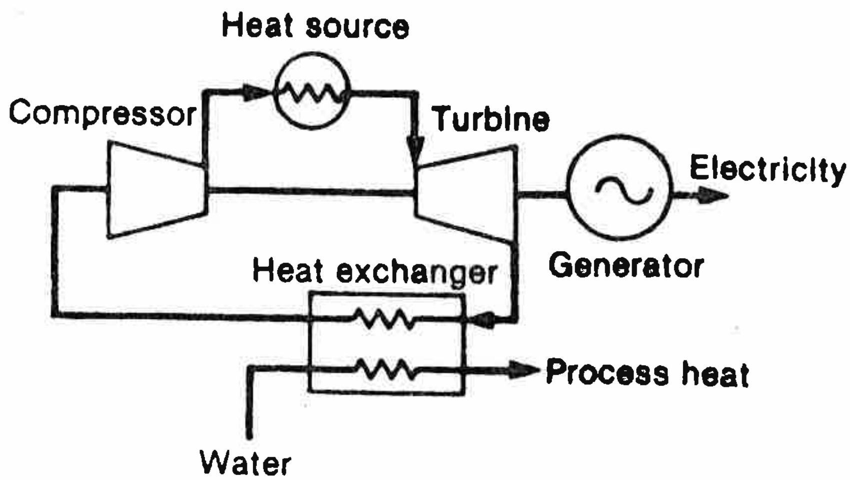


Figure 5

with this technology, an important alternative would be the use of gasified bagasse in a directly-fired gas turbine, with or without steam injection. In this case, the extra cost of a gasifier would have to weighed against the cost of advanced heat exchangers for indirectly-fired units. A 100 MW demonstration gas turbine-steam turbine combined cycle central station power plant recently began operation on gas from coal in the US (Douglas, 1984). The process used in this plant requires cooling of the gas, primarily to permit removal of sulfur, thereby degrading efficiency. However, significant research and development is ongoing on hot-gas clean-up systems for coal, which would lead to higher efficiency. Hot sulfur removal is an important, as-yet unsolved problem. Since the sulfur content of bagasse is quite low, hot-gas clean up may prove easier than for coal. Large-scale bagasse gasification was evidently in use at one time (Paturau, 1969),* and work related to bagasse gasification for methanol production has been done more recently (Baker and Brown, 1984).

Gas derived from bagasse could alternatively be used in diesel engine cogeneration systems. In this cycle, steam could be generated from both the hot exhaust gases in a heat recovery system, and from the engine itself, via a water-steam jacket (Office of Technology Assessment, 1983). This technology has advantages that include a high electricity-to-heat

* Paturau (1969) indicates that gas plants utilizing bagasse have been built in capacities varying from 920 to 2500 cubic meters per hour. He cites several references including: Tromp., L.A., "Bagasse and Producer Gas," International Sugar Journal, Vol. 42, 1940.

ratio, high efficiency in small size, and good part-load performance. The widespread availability of diesel engines and familiarity with their operation and servicing may be perhaps its most important advantages.

This brief overview suggests that there are many high efficiency cogeneration technologies with high electricity-to-heat ratios that have the potential for being fired with bagasse. These technologies could permit sugar refineries and alcohol distilleries to generate large amounts of electricity in excess of onsite needs. As the BUN begins its outreach role to its member countries, we hope that some of these new technologies would be given serious consideration.

Closure

At the Center for Energy and Environmental Studies, we have been involved in evaluating advanced cogeneration technologies for the last several years and plan to continue our work in this area. In particular we are interested in exploring the relevance of alternative cogeneration technologies for biomass applications, and we feel that assessments of relevance to the sugar industry would be an appropriate initial focus, where there may be considerable user interest.

To carry out a meaningful assessment of performance relative to real-world conditions requires a fairly good data base, which we hope the BUN would be able to develop and make available.

We have given some thought to the data requirements for a sugar industry/cogeneration assessment and have formulated a questionnaire that would facilitate the development of this data base. While the questionnaire was designed to gather data relevant to a sugar/cogeneration study, the resulting data base would be broadly relevant for making assessments of alternative energy options the BUN may wish to explore for the sugar industry.

Attached are two survey questionnaires that might be used by the BUN as an initial step in developing a data base for bioenergy in the sugar industry. One questionnaire deals with relevant country-level statistics and the other with detailed characteristics of the sugar industry. Such data for a particular country would provide a good basis for the technology assessment in that country. Data from several countries would permit comparisons that would test the generality of the findings.

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BIOENERGY SURVEY
(Country-Level Statistics)

A general statistics section of the data base could contain important national data which may be obtainable through requests to government ministeries or equivalent institutions. The only additional work that might be required of BUN members coordinating a survey would be translation of data into a universally understandable form. Some of the institutions, and the types of information that might be useful to include in a bioenergy-related database, include:

Ministry of Energy (or equivalent)

National energy balances, including current and recent historical trends in production, imports, and exports of fossil fuels and biomass energy. In addition, data on consumption by sector and fuel type, and by end-use, if available. In many cases, the best available end-use data may be in the form of surveys conducted in limited geographical areas (major cities, states, etc.).

Electricity production by source of fuel, and consumption by sector and by end-use, if available.

Prevailing prices (in local currency units) for the major fossil fuels (LPG, kerosene, diesel oil, gasoline, natural gas, coal, etc.) by sector and/or by end-user. Similar prices for marketed biomass fuels and electricity.

Energy taxes paid in different sectors for different fuels.

Type of distribution systems used for each major fossil or biomass fuel.

National energy plan projections of energy supply and demand for perhaps the next decade.

Ministry of Agriculture (or equivalent)

Current and historical trends in land-use: total land under cultivation by crop, land used for sugar crops, for domestically consumed crops, for export crops, and for fuelwood crops; production and per hectare yields by crop; projections for future land-use.

Imports of food crops.

National Electric Utility Board (or equivalent)

The extent of the national electric utility grid, particularly the proximity of grid lines to existing sugar refineries and alcohol distilleries.

Current and historical trends in monthly electricity production (kWh) by fuel type. Monthly hydro-electricity production. Status of electricity generation by bagasse (capacity, sales, prices paid by the utility to producers, etc.).

Prices for purchased electricity, by sector.

Descriptions of utility regulations governing: interconnections with industrial cogenerators and small power generators; the purchase by the utility of cogenerated electricity.

Minister of Finance (or equivalent)

Sources of financing available for energy projects in sugar plants. Typical interest rates for different types of financing arrangements.

Ministry of Industry (or equivalent)

Current and historical trends in the production of major heavy industrial products and light manufactured goods.

Employment statistics by major industry (e.g., sugar) and by season.

Environmental regulations relating to sugar refineries and/or alcohol distilleries (concerning stillage, excess bagasse disposal, boiler stack emissions, industrial noise, etc.)

BIOENERGY SURVEY
(Sugar Industry Characteristics)

A survey to determine characteristics of the sugarcane processing industries in individual countries might best be coordinated at the data collection level by the National Sugar Association (or equivalent institution), with BUN members serving only to initiate the work and transmit the collected data, in a suitable form, into the BUN international data base.

Three types of data would probably be most useful in doing energy-related analyses of the sugar/alcohol industry.

1. Actual operating data of the type that is typically reported in the final manufacturing (operating) report of each plant at the end of each crop season. Requests to 25-30 representative sugar refineries and alcohol distilleries for copies of their final manufacturing reports for the last 5-10 crop seasons, together with a brief description of the objective of the data collection effort, may be sufficient to obtain a significant base of data by which to characterize plant operations in each BUN country.

2. The use of data reported in the plant manufacturing reports would be facilitated by an equipment performance inventory for these same plants (or a subset of them). This would include detailed nameplate ratings (of capacity, efficiency, water rates, etc.) for turbine-generators, turbine-mills and knives, boilers, juice evaporators, juice heaters, vacuum pans, etc., used by each plant. These data could be requested from individual plants, or they may be available directly from the National Sugar Organization.

3. Detailed end-use energy consumption data from 2-3 plants in each country. This type of data would be the most useful of any that might be gathered, but would also probably be the most difficult to obtain. The National Sugar Organization may be particularly useful in identifying particular, knowledgeable plant engineers who would be willing to complete a detailed survey on energy consumption in their plant. An end-use survey delivered by the sugar organization to individual plants might include instructions and questions like those on the following pages.

Energy End-Use Survey

Please answer the following questions based on average conditions that prevail during a typical crop processing season. If possible, provide answers in the units indicated. If other units are more convenient, please indicate clearly what units are being used. Please answer each question with either a number or "NA" (for information Not Available). It would be of greatest use to have all of the questions answered, but the questions marked by ** are particularly important.

The letters "tc" means "tonne of cane (1000 kg)."

1. Current plant operations.
   ** a) Processing capacity (tc/day) =
   ** b) Production capacity:
      i) raw sugar (tonnes/day) =
      ii) molasses (tonnes/day) =
      or
      iii) anhydrous ethanol (liter/day) =
   ** c) capacity utilization:
      i) length of cane processing season (days/year) =
      ii) hours per day of full operation during season =
   ** d) water consumption:
      i) for imbibition (liters/tc) =
      ii) make-up water for steam (liters/tc) =
      iii) other water consumption (liters/tc) =
   ** e) stillage production (liters/tc) =

2. Bagasse characteristics and availability.
   ** a) Baggasse production (tonnes/tc) =
      Estimated bagasse moisture fraction: (wet - dry)/wet =
   b) Lower heating value of dry baggase (MJ/kg) =
   ** c) Fraction of total bagasse consumed by in-plant boilers =
   d) Fraction of the bagasse used for other purposes =
      What are the other purposes?
   e) Can the bagasse be stored?________ If yes, for how long?

3. Electricity.
   a) Production:
      ** i) Total electricity generated (kWh/tc) =
      ** ii) Purchased electricity (kWh/tc) =
      iii) Generated by back-pressure steam turbine (kWh/tc) =
         Steam-to-electricity efficiency =
      iv) Generated by condensing steam turbine (kWh/tc) =
         Steam-to-electricity efficiency =
      v) Generated by other equipment (kWh/tc) =
         (please specify type and efficiency):
   b) End uses:
      i) Driving cane knives (kWh/tc) =
      ii) Driving pumps, fans, conveyors, etc. (kWh/tc) =
      iii) Sale to outside users (kWh/tc) =
      iv) All other uses (lights, heaters, etc.) (kWh/tc) =

4. Live (high pressure) steam.

** a) Production: Flow (kg/tc) =
Pressure (kg/cm^2) =
Temperature (^{o}C) =

b) Boiler:
- i) Age (years) =
- ii) Pressure (kg/cm^2) =
- iii) Bagasse consumption (tonnes/tc) =
  Estimated bagasse moisture fraction =
- iv) Feedwater temperature (^{o}C) =
- v) Steam production (kg/tonne bagasse) =
  Estimated bagasse moisture fraction =
- vi) Steam temperature (^{o}C) =

c) End uses:
- ** i) Live steam used to produce electricity (kg/tc) =
  in back-pressure turbines (kg/tc) =
  in condensing turbines (kg/tc) =
- ** ii) Live steam used for mechanical-drive (kg/tc) =
  in back-pressure turbines (kg/tc) =
  in condensing turbines (kg/tc) =

5. Exhaust steam.

** a) Production: Flow (kg/tc) =
Pressure (kg/cm^2) =
Temperature (^{o}C) =

b) End uses in sugar refinery; steam used in:
- i) juice heaters (kg/tc) =
- ii) juice evaporators (kg/tc) =
- iii) vacuum pans (kg/tc) =
- iv) boiler feedwater de-aerator (kg/tc) =
- v) stillage evaporator (if used) (kg/tc) =
- vi) all other uses (kg/tc) =

c) End uses in alcohol distillery; steam used in:
- i) juice heaters (kg/tc) =
- ii) juice evaporators (kg/tc) =
- iii) distillation & dehydration (kg/tc) =
- iv) boiler feedwater de-aerator (kg/tc) =
- v) stillage evaporator (if used) (kg/tc) =
- vi) all other uses (kg/tc) =

6. If excess electricity is produced on site, is it sold to a utility?

** a) If yes, price obtained per kWh in 1984 and/or 1985 =

b) If no, what is done with excess electricity?

7. ** Operating and maintenance costs (local currency/tc) =

6. Employment.

a) Full-time (40 hrs/wk) employees during processing season =

b) Full-time employees during off-season =