PN-ABK-504

Report No. 91-16

A Report of the
Office of Energy and Infrastructure,
Bureau for Research & Development
U.S. Agency for International Development

ENERGY FROM CITRUS WASTES IN BELIZE:

INDUSTRY OVERVIEW

Prepared by

Winrock International Institute for Agricultural Development
1611 North Kent St., Suite 600
Arlington, Virginia 22209

Biomass Energy Systems & Technology Project
DHR-5737-A-00-9058

December 1991

Acknowledgements

The study team for this project consisted of:

Mark Moser, team leader and agricultural engineer, and President of RCM Digesters—Methane Recovery Systems, in Berkeley, California.

Dr. Ann Wilkie, microbiologist and Director of the Methane Fermentation Lab, University of Florida, Gainseville, Florida.

Jim Wimberly, project coordinator and Program Officer, Biomass Energy Systems and Technology Project, Winrock International, Arlington, Virginia.

The team members would like to express their sincere appreciation to the following individuals for their support and assistance with this project:

Citrus Company of Belize, Ltd.

Pat Polack, Chairman of the Board and Chief Executive Officer

Leon Drake, Board Member

Jerry Sharp, General Manager

Robert Wood, Factory Manager

Belize Food Products, Ltd.

Denzil F. Jenkins, Managing Director

Lennox L. Neal, Factory Manager

Government of Belize

Victor Gonzalez, Acting Permanent Secretary, Ministry of Tourism and Environment

Carlos Guerra, Waste Disposal & Pollution Control Specialist, Ministry of Health

USAID/Belize

Jeffrey H. Allen, Environmental Officer

Art Villanueva, Energy Officer

Winrock International

Franklin Tugwell, Director, Biomass Energy Systems & Technology Project

Allison Keeler, Development Intern, BEST Project

AID/Washington

Ross Pumfrey, Project Manager, Office of Energy

Other Individuals

Adam Bosschieter, Consultant

J. Vernon Christian, Environmental Energy Concepts, Sheffield, Alabama

Kelton Grubbs, Thermal Systems Engineering, Hot Springs, Arkansas

Gordon D. Hartman, Tropicana Products, Inc., Bradenton, Florida

Daniel Jantzen, Consultant, Denver, Colorado

Ron Orozco, Project Engineer, Central American Rural Electrification Support Program, National Rural Electric Cooperative Association

Jim Porteous, The Jones Group, Austin, Texas

Buren F. Shaw, Executive Vice President, Brown International Corporation, Winter Haven, Florida

Contents

Abbreviations and Acronyms

AID	U.S. Agency for International Development
BEB	Belize Electricity Board
BEST Project	Biomass Energy Systems & Technology Project
BFP	Belize Food Products, Ltd.
BTU	British Thermal Unit
CCB	Citrus Company of Belize, Ltd.
GOB	Government of Belize
kW	kilowatt
kWh	kilowatt-hour
lb	pound
USAID	AID office in Belize City

List of Tables and Figures

Executive Summary

The citrus industry in Belize is a major sector of the national economy and a major source of foreign exchange for the country, processing over 3 million boxes of citrus per year and producing over 11,000 tons per year of frozen citrus concentrate, primarily for export markets. The extraction process generates approximately 58,000 tons per year of solid wastes, and an unknown amount of liquid wastes. Current waste management practices utilized at Belizean citrus processing facilities consist primarily of open dumping of solid waste and untreated discharge of liquid wastes. These practices are costly and environmentally undesirable. The managers of the two existing processing facilities have been trying to identify available, environmentally benign, and cost-effective citrus waste management technologies applicable to their specific sites for many years. Production of cattle feed and other by-products, the conventional method of processing solid citrus wastes, has proven to be uneconomical in Belize. Additionally, government pressure to reduce and, ultimately, to eliminate environmentally undesirable waste management practices is expected. Thus, there is considerable pressure to identify alternative citrus waste management technologies that are appropriate and cost-effective. Further, the extremely high on-site energy costs experienced by both processing facilities dictate that a waste management solution that could also generate usable energy would be highly desirable.

The objective of this study was to identify technically feasible and environmentally acceptable options for converting citrus wastes in Belize into usable forms of energy. Five potential options for citrus waste management have been identified. Each option addresses the environmental problems, and three of the options generate significant amounts of usable energy.

- ***proper landfilling of solid wastes***: The environmental aspects of this option could be considered only marginally effective, and the practice results in no energy generation. Liquid effluents would also need to be properly treated and discharged to minimize environmental pollution. Further, some capital and operating costs would be required for landfilling activities, in addition to existing waste disposal costs, with zero returns on investment.

- ***cattle feed plus by-product recovery***: This is the conventional process for citrus waste conversion, but has already proven to be uneconomical in Belize. This option would be expected to be economical only if satisfactory product markets developed nearby (considered highly unlikely) or as a result of third party incentives, such as government subsidies for production and/or marketing expenses. Again, liquid effluents would also need to be properly treated and discharged to minimize environmental pollution. Although this option has been the focus of much attention, the options described below are considered more attractive.

- ***cattle feed plus anaerobic digestion***: This approach is more attractive than the previous option in that some biogas is generated through anaerobic digestion. The anaerobic digestion system for the peel press liquor could also be used for treatment of other liquid wastes (with additional pre-treatment as may be required). Preliminary estimates indicate that such a system could produce approximately 6 million BTUs per hour—enough to provide about 30% of the energy required to produce cattle feed. Supplemental energy, presumably from fuel oil, would still be needed for the balance of the drying requirements. This option, however, would result in a lower value feed product, since the press liquor would not be available for production of molasses (which is added back to the feed for nutritional purposes).

- ***anaerobic digestion of all solid and liquid wastes***: This option would address the environmental problems as well as generate substantial amounts of energy. Preliminary estimates indicate such a system could produce approximately 18 million BTUs per hour—enough to provide 100% of a site's electrical requirements plus approximately 50% of its boiler fuel requirements.

- ***combustion of solid wastes and anaerobic digestion of liquid wastes***: This option would also address the environmental problems and would generate the maximum amounts of energy of any of the options presented herein. Preliminary estimates indicate that combustion of the pressed and dried solid wastes could produce sufficient steam to displace the current oil-fired boiler system. Combining the energy from combustion of the pressed and dried solid wastes with the energy from anaerobic digestion of the peel press liquor and cold press wastes could produce enough steam for all of the facility's process steam and electrical requirements . The net result would be displacement of 100% of current fossil fuel consumption.

The last option represents the maximum potential generation of usable energy from citrus wastes, while simultaneously alleviating current waste disposal problems. In the last three options, capital and operating costs would be offset by the savings resulting from displaced fossil fuels.

While the anaerobic digestion options consist of processes not yet attempted on a commercial scale for citrus wastes, the technology is well known and widely used with other agricultural wastes. Moreover, there is increasing international interest in the technology, with a full-scale system under construction in Brazil for treatment of liquid wastes and another system currently being designed in Florida. The primary concern regarding anaerobic digestion of citrus wastes is the presence of citrus oil, which would inhibit digestion. Additional research is therefore required to ascertain the digestability of peel press liquor and other liquid citrus wastes.

Regarding combustion of citrus wastes, although this has apparently not been attempted on a commercial scale, there is no question that solid citrus wastes can be reduced, through mechanical pressing and subsequent drying, to a moisture level low enough to sustain combustion. In fact, such dried and shredded citrus wastes would be expected to have similar characteristics to bagasse, which is widely combusted for energy generation, including in Belize.

Cost estimates of the various technologies discussed herein were not part of the original scope of work for this study, nor can such costs reasonably be estimated without more investigation and effort. Nonetheless, several economic factors can be identified, including:

- current costs of the conventional cattle feed and by-products production option have proven uneconomical in Belize (estimated at a loss of $20 – $50 per ton of feed)

- 100% displacement of current on-site fossil fuel requirements by citrus waste-to-energy systems would result in savings in excess of $400,000 per year for each site

- waste-to-energy systems that address 100% of the solid and liquid citrus waste streams would eliminate current waste disposal costs currently estimated at $100,000 – $150,000 per year for each site

- Each processing facility already has two oil-fired burners/boilers that could be converted for combustion of citrus wastes, resulting in considerable savings in the capital costs of the combustion systems.

More detailed site-specific feasibility studies, including identification of required equipment and associated costs, is required to estimate the costs and financial performance of investments in such waste management/energy generation systems. Before proceeding with such assessments, however, additional investigations of the unknown technical issues such as the digestability of peel press liquor and other liquid citrus wastes or maximum moisture level for sustained combustion of solid citrus wastes should be undertaken to verify some of the key technical assumptions in this study and to more accurately project the amounts of potential energy generation. These issues should be addressed prior to investing the considerable resources required for detailed site-specific feasibility studies.

It is therefore recommended that a pre-feasibility study be undertaken to investigate the unknown technical issues and verify the technical assumptions used in these calculations. The results of these activities would be applicable to either of the two existing processing facilities in Belize and would enable a preliminary equipment list to be made, plus an assessment of associated equipment costs and the financial performance of an investment in such a waste-to-energy system.

1. Background

In cooperation with the Belizean citrus industry, the Government of Belize (GOB), and the United States Agency for International Development's office in Belize (USAID), Winrock International's Biomass Energy Systems & Technology (BEST) Project has undertaken a study of the potential application of waste-to-energy conversion systems for the citrus industry in Belize. This report presents the results of an overview study of the Belizean citrus industry, which identifies various technical options for citrus waste-to-energy conversion systems and associated concerns and unknowns.

1.1 The Citrus Industry in Belize

The citrus processing industry in Belize is a major sector of the national economy and a major source of foreign exchange for the country. The Belize citrus crop is comprised of oranges (approximately 70%) and grapefruit (approximately 30%). The Belize citrus processing industry currently consists of two facilities: the Citrus Company of Belize, Ltd. (CCB), which has been in existence for over 40 years, and Belize Food Products, Ltd. (BFP), a relatively new company which has acquired an approximately 12 year old processing plant. Both facilities are located in the Stann Creek District, approximately 25 miles inland from Dangriga. The primary product is frozen concentrate. Most of the concentrate is exported to the United States, with some exported to the European Community. Additional products include cold press oils and citrus essences. The Belizean citrus industry has been successful and is expanding, perhaps by as much as two- to five-fold by the end of this decade. Near-term expansion is expected to include increased processing capacity at one or both of the existing facilities, plus possible construction of a new processing plant(s).

Both processing facilities use imported petroleum products to meet their energy needs. All on-site electricity is currently produced using diesel generators. Grade C bunker oil is used in the boilers for process steam requirements. CCB's estimated on-site electrical generation costs are US$ 0.17 per kilowatt-hour (kWh). The company also provides electricity to the surrounding community, consisting primarily of CCB workers and their families. The Belize Electricity Board (BEB) has a diesel-fired generating station in Dangriga and is currently installing a new powerline to both sites, although at least one facility does not intend to purchase electricity from BEB (at a current price of US$ 0.225/kWh), meaning the line will serve primarily residential and light-duty loads.

During the juice extraction process, approximately 45% - 50% (by weight) of the harvested fruit results in extracted liquid for further processing. The remainder consists of peel, pulp, and seeds, which are referred to as *solid wastes*. These wastes are hauled approximately 3 miles from the processing facilities and dumped in an environmentally undesirable manner.

The second form of citrus processing waste is *liquid waste*, which includes wash water, evaporator condensate, and cold press wastes. These liquid wastes are currently discharged with little or no treatment into streams and rivers or spread on roads for dust control. Environmental and downstream pollution resulting from these disposal practices have historically been localized and considered relatively insignificant.

However, several factors have resulted in increased concern regarding current citrus waste disposal practices:

- increasing population in the area, particularly downstream;
- increasing focus on sound environmental practices, particularly in view of Belize's expanding eco-tourism industry;
- increasing waste disposal costs, particularly truck operating costs;
- increasing on-site power generation costs; and
- persisting threat of hurricanes that could spread the dumped materials.

These wastes should be viewed as *resources*: they could provide the processors with a significant portion of their energy requirements, thus displacing some diesel and fuel oil needs, while simultaneously reducing the environmental burden of the solid and liquid waste streams. In order to determine this potential, the technical and economic feasibilities of citrus waste-to-energy conversion systems must be assessed.

Table 1 summarizes the production characteristics of the two existing facilities. Figure 1 summarizes the main functions and operations performed at both plants, and indicates the sources of major portions of both solid and liquid wastes from the plants.

1.2 Study Objectives and Activities

The managers of the two processing facilities acknowledge both existing and potential problems associated with current waste management practices. Each facility has been trying to identify available, environmentally benign, and cost-effective citrus waste management technologies applicable to their specific sites. The anticipated expansion of the industry emphasizes the need to adopt appropriate solutions. Both facilities are aware of the standard approach to solid citrus waste management -- the production of cattle feed -- as described in this report. However, this option has proved to be uneconomical in Belize, hence the desire to identify alternate options for citrus waste management.

At the same time, the thermal and electrical energy costs for both processing facilities is extremely high, whether the energy is produced on-site or provided, at least in part, by the Belize Electricity Board. Thus, employing environmentally benign citrus waste management technologies that could simultaneously provide on-site energy, thereby displacing a portion of the imported fossil fuel requirements, is certainly desirable.

The objective of this study was to identify technically feasible and environmentally acceptable options for waste-to-energy conversion systems for the citrus industry in Belize. The study has included the following activities:

- a review of relevant literature regarding citrus waste-to-energy conversion technologies and related citrus processing technologies, and identification of successful and unsuccessful activities that are in use or have been attempted;

- site visits to the two citrus processing facilities to obtain sufficient data for a preliminary assessment of the current waste problems and opportunities, and discussions with plant managers and representatives from the GOB and USAID; and

- assessment of appropriate technologies for energy generation/waste management, including preliminary calculations of potential energy generation from citrus waste-to-energy conversion systems.

This report presents the results of this overview assessment. More in-depth follow-up studies are required to quantify the unknowns associated with the technical options presented herein, and to determine the economics of the investments required in the proposed citrus waste-to-energy conversion systems.

Table 1.
Annual Production Characteristics
Belize Citrus Industry
(total of two processing facilities)

- Products:
  - Orange juice concentrate
  - Grapefruit juice concentrate
  - Cold press oils
  - Citrus essences

- Production season: .... October to May or June

- Current annual raw citrus input: .... 117,000 tons (estimated)

- Current annual concentrate production: .... 11,000 tons (estimated)

- Current annual solid waste production: .... 58,500 tons (estimated) at 85% moisture

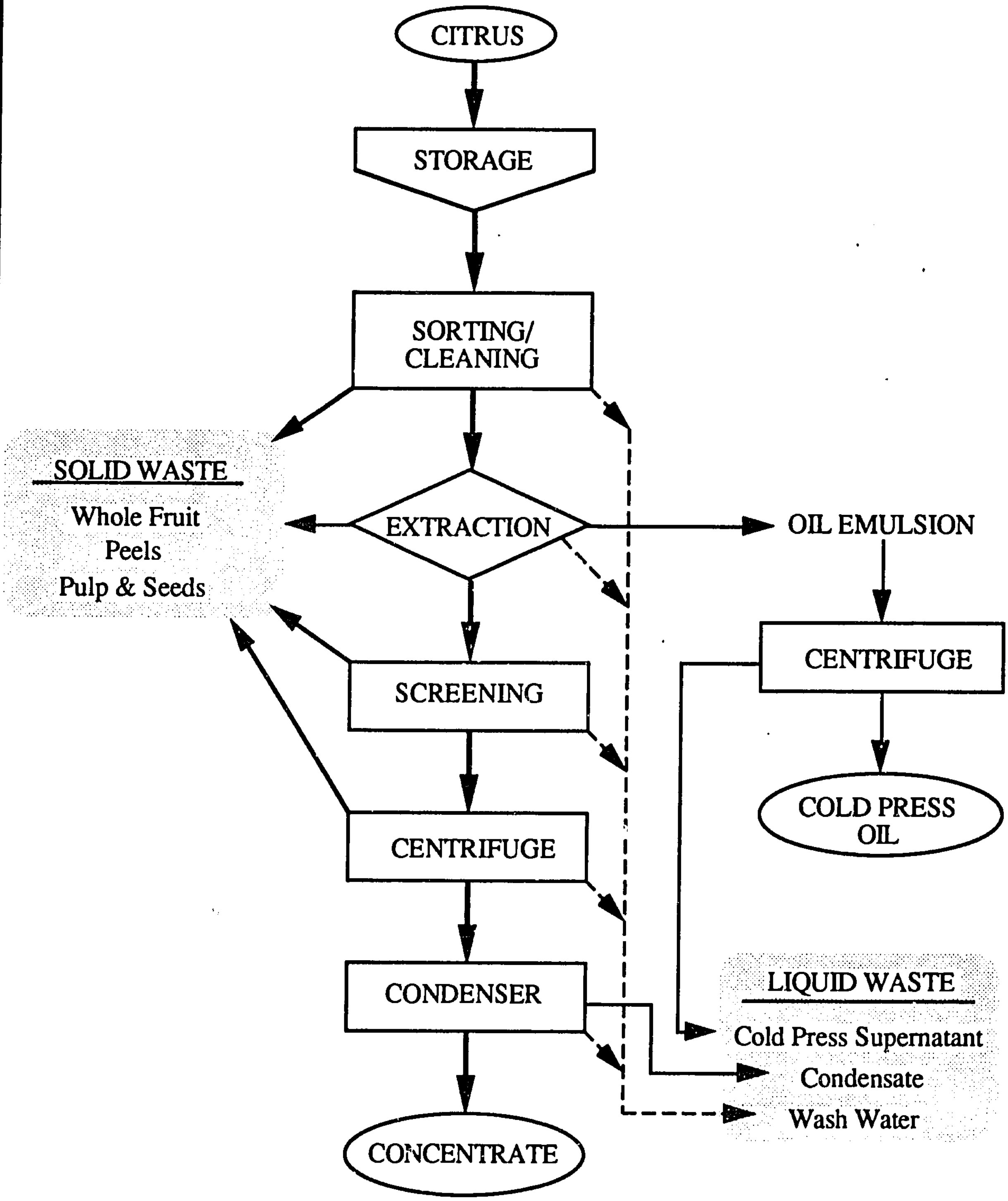
- Current annual liquid waste production: .... Unknown

- Energy use:
  - electricity .... 3,500,000 kWh (estimated)
  - steam...................................... 62,400,000 pounds (estimated)

- Fuel consumption:
  - diesel .... 260,000 gallons (estimated)
  - grade C bunker oil .... 400,000 gallons (estimated)

- Fuel cost:
  - diesel .... US$425,000 (estimated)
  - bunker oil .... US$370,000 (estimated)

Figure 1
Unit Processes and Waste Generation
at Belizean Citrus Processors



2. Technical Considerations

2.1 Conventional Solid Waste Management

The worldwide citrus industry has historically solved its solid waste problem by processing peel, pulp and seeds into cattle feed, molasses and D-limonene. Other, less common by-products include citric acid, pectin and alcohol.[1] The solids are mechanically pressed to remove as much liquid as possible. Pressing forces approximately half of the liquid out of the pulp. The resulting liquid is referred to as peel press liquor.[2,3] The solids are dried, usually in a rotary or flatbed dryer—an energy intensive process. The liquids are pumped to a waste heat evaporator, where D-limonene is volatilized while evaporating water from the liquor, resulting in molasses. Molasses can be added directly to the cattle feed to improve the nutritional value or can be sold separately for alcohol production.

To be economically successful, conversion of solid wastes to cattle feed depends on low cost energy for drying solids from 70% moisture to 15% moisture, low cost energy to vaporize D-limonene and to concentrate molasses, and a readily available local market for the cattle feed and associated products.

BFP installed equipment for producing cattle feed about 10 years ago. However, the relatively high cost of energy in Belize for feed drying, the lack of a local market for the feed, and the high cost of transportation to export markets led to the abandonment of the process and the dismantling of the equipment. Current estimates of cattle feed production from solid citrus wastes in Belize indicate a loss of $20 – $50 per ton of feed.

Several specialty products can be developed from citrus pulp, peels and seeds. Specialty products typically have a higher value per pound of production and could be considered as options for solid waste management in Belize. Pectin extraction [4] from the peel could be a viable product but would only remove 4% - 6% of the peel waste. Many other options such as single cell protein production [5,6,7] and silage production [8] enhance the feed value of the solids.

2.2 Conventional Liquid Waste Management

In Belize, there are currently no regulations governing the treatment of liquid wastes prior to discharge to waterways. Both plants discharge condensate and wash water directly into the Stann Creek river. BFP recovers supernatant, the liquid waste from the cold oil press, and uses it for road dust control, while CCB discharges the supernatant with the rest of the plant waters.

In the United States, the most common approach to treatment of wastewater is aerobic, secondary treatment. Anaerobic lagoons have also been used to partially reduce organic loading and, due to rising costs for electricity and sludge disposal, anaerobic processes are being more commonly adopted. In the U.S., citrus industry wastewater is treated and discharged to either a river, a municipal treatment plant for further processing, or applied to fields through spray irrigation. Lack of nutrients such as nitrogen, plus the presence of residual citrus oils in the wastewater, limit the extent of biological degradation and methane generation in waste treatment.[3]

2.3 Potential Energy from Citrus Wastes

Although citrus waste processing has typically entailed conversion of solid wastes to cattle feed (plus associated products) and processing of liquid wastes using aerobic treatment, it is possible to convert citrus wastes into usable forms of energy. Generation of energy from citrus wastes in Belize could simultaneously address existing waste management problems and reduce on-site energy costs. Several citrus waste-to-energy conversion techniques have been investigated.

2.3.1 Alcohol Production through Fermentation

Alcohol production from peel press liquor has been proposed.[9] Pressing is required, and the process still requires management of the pressed solids. This was piloted in the US, but the plant was not successful, as occasional doses of citrus oil created fermentation upsets. Costs of distillation, combined with uncertain yields, precluded economical operation.[10] Thus, generation of alcohol from peel press liquor does not appear to be a viable technical option at this time.

Alcohol production from molasses is a common process. However, molasses is an end-of-stream by-product, and entails high operating and energy costs to produce.

2.3.2 Biogas Production through Anaerobic Digestion

Biogas production technology from agricultural wastes is well known and widely applied.[11] Biogas production from solid and liquid citrus wastes has been investigated many times, but only at the laboratory scale.[1,12,13,14,15,16] Successful laboratory trials were not scaled up to commercial activities possibly due to the attractiveness of the existing cattle feed plus by-product recovery systems. In most of these situations, ready markets for cattle feed probably already existed; also, energy costs probably were significantly lower than existing energy costs in Belize.

Citrus anaerobic waste digestion requires the addition of nutrients to promote bacterial growth. Citrus oils present in peel press liquor and peels have been found to be inhibitory to methane production.[13,17,18] However simple pretreatment of peel press liquor using aeration [19,20] and peels using mechanical means [16] eliminated citrus oils.

Lane [12] and McNary [13] used natural fermentation of peel press liquor after removal of citrus oils to produce a dilute alcohol solution as a feed stock for an anaerobic methane-producing digester. Distillation of the solution for alcohol recovery would be prohibitively expensive due to the dilute concentration. Lane also successfully digested comminuted orange peels after oil removal from the feedstock.[16] According to Lane, anaerobic digestion destroyed virtually all of the solids. Anaerobic digestion yields biogas (approximately 60% CH_4 + 40% CO_2) and an effluent that would require further treatment prior to discharge.

Although the authors could not identify any full-scale anaerobic digestion systems currently treating citrus wastes, there is increasing international interest in the technology, with a full-scale system under construction in Brazil [21] and a another system currently being designed in Florida.[22] In both cases, the anaerobic digestion systems will be used to treat liquid wastes.

2.3.3 Thermal Energy through Combustion

Another option for converting citrus wastes into usable energy is the generation of thermal energy from combustion of the solid citrus wastes. Such energy, in the form of steam, could be used for process steam requirements and/or generation of electricity.

No published references to combustion of solid citrus wastes have been identified, although it is entirely possible that this potential has simply been discounted because of traditional by-product production (i.e., conversion of solid citrus wastes into cattle feed). In 1989, however, CCB engaged J. Vernon Christian, a professional engineer specializing in biomass combustion, to assess the technical feasibility of combustion of citrus wastes.[23] Christian concluded that solid citrus wastes could be successfully combusted (provided that the material was dried to a sufficiently low moisture content), and that such combustion could yield a significant amount of heat energy that could contribute to the citrus processing facility's operations. The concept of combustion of citrus wastes was also endorsed by Kelton Grubbs, another professional engineer specializing in biomass combustion, based on the similarities of partially dried citrus wastes to other biomass materials (e.g., sugarcane bagasse, sawdust).[24] Combustion of such materials is well-known and widely used (e.g., Tower Hill, a 6,000 ton/day sugar factory in Orange Walk, Belize, generates all of its own energy needs from combustion of bagasse).

The maximum allowable moisture level of solid citrus wastes for sustained combustion, i.e., steady-state combustion based entirely on the biomass material and without any supplemental energy such as bunker oil, is not yet known. However, reasonable estimates can be made. Since the maximum moisture level of similar biomass materials that can sustain combustion is approximately 50% – 55% (wet basis), we have assumed that this would also be true for citrus wastes, since the physical characteristics of macerated and partially dried solid citrus wastes are similar to those of shredded bagasse at similar moisture levels. We have used 52% as the maximum allowable moisture level for our calculations. Note, however, that the lower the moisture level of the material to be combusted, the better the combustion, both in terms of sustainability of combustion and heat energy derived (since less energy is required for moisture evaporation).

Since the initial moisture level of the solid citrus waste stream after juice extraction in the processing facility is approximately 85%, the moisture level of the waste stream must be reduced at least 20% – 25% for sustained combustion. Mechanical presses, typically used to dewater solid citrus waste streams prior to production of cattle feed, are known to reduce the moisture level down to below 70% (even as low as 59%).[2,25] Our calculations assume the moisture level of the pressed solid wastes is 65%. Additional drying would be required to reduce the moisture level of the waste stream to the maximum sustainable moisture level (assumed to be 52%). Such drying could be accomplished using standard drying technologies, such as a rotary dryer. Heat for drying could come from the waste stack heat of the combustion system, or from flue gases from the combustion system itself. Some of the drying heat could be the waste stack heat from the diesel generators. Yet another potential source of drying heat would be the methane generated through anaerobic digestion of the peel press liquor (refer to §3.3). The latter is a potentially large source of energy, which could be used to dry the solid waste stream to a relatively low moisture level (which would result in significantly more steam generated through combustion) or could be co-fired in the furnace/boiler, along with combustion of the solid waste, for steam generation. Additional analyses need to be undertaken to determine which option (or combination of the two options) would be more efficient, in terms of methane use vs. steam generation.

Bone dry citrus solids have a higher heat value of approximately 7,100 – 8000 BTU/lb, based on calorific tests of citrus wastes (including pressed wastes from processing facilities in Florida which use the same extraction technologies as those at the two processing facilities in Belize) and from Christian's analyses.[23] We have conservatively used 7,100 BTU/lb in our calculations. This number can be compared to wood residues with a higher heat value of 8,500 - 10,000 BTU/lb [27] or rice husks at 6,000 BTU/lb [26].

2.4 Summary

The Belize citrus processing industry currently consists of two facilities operated by the Citrus Company of Belize and Belize Food Products Limited, respectively. Both processing facilities fill their energy requirements from imported petroleum products. All on-site electrical needs are currently met using diesel generators, and grade C bunker oil is used in the boilers for process steam requirements.

The extraction process results in approximately 50% – 55% by weight of the harvested fruit as *solid wastes*. These wastes are hauled approximately 3 miles from the processing facilities and dumped in an environmentally undesirable manner. The second form of citrus processing waste is *liquid waste*, which is currently discharged without treatment to local waterways, or spread on roads for dust control.

The citrus industry has historically solved its solid waste problem by processing peel, pulp and seeds into cattle feed, molasses and D-limonene. The high cost of energy for solid waste drying, lack of a local market for the feed, and high costs of transportation to export markets makes this option unattractive in Belize.

In the United States, the most common approach to treatment of liquid wastes is aerobic, secondary treatment processes. In Belize, there are currently no regulations governing such liquid waste treatment.

It is technically possible to convert citrus wastes into usable forms of energy. Generation of energy from citrus wastes in Belize could simultaneously address existing waste management problems and reduce on-site energy costs. Energy options include alcohol production from peel press liquor or molasses, biogas production from solid and/or liquid wastes, and thermal energy from combustion of solid wastes.

Generation of alcohol from peel press liquor does not appear to be technically viable at this time. Although technology exists for generation of alcohol from molasses, the process entails high operating and energy costs to produce.

Biogas production from agricultural wastes is well known and widely applied. Anaerobic digestion technology for biogas production is considered viable for citrus waste treatment. Although the authors could not identify any full-scale anaerobic digestion systems currently treating citrus wastes, there is increasing international interest in the technology, with a full-scale system under construction in Brazil for treatment of liquid wastes and another system currently being designed in Florida.

Although no published references to combustion of solid citrus have been identified, private experiments with small-scale combustion of citrus wastes have proven successful. Moreover, combustion technology for similar agricultural wastes is well-known and widely used. Combustion of solid citrus wastes is considered technically viable.

3. Potential Options for Belize

Figure 2 represents the potential pathways that might be followed to manage, use and dispose of citrus wastes, including biogas and thermal energy generation possibilities. All portions of the various options have been demonstrated at some scale. Based on the previous technical discussion and the various possible configurations shown in Figure 2, we have identified five primary options for managing citrus wastes in the Belizean citrus industry:

- Proper Landfilling
- Cattle Feed + Byproduct Recovery
- Cattle Feed + Anaerobic Digestion
- Anaerobic Digestion of Solid & Liquid Wastes
- Combustion + Anaerobic Digestion

Each option is discussed in detail below.

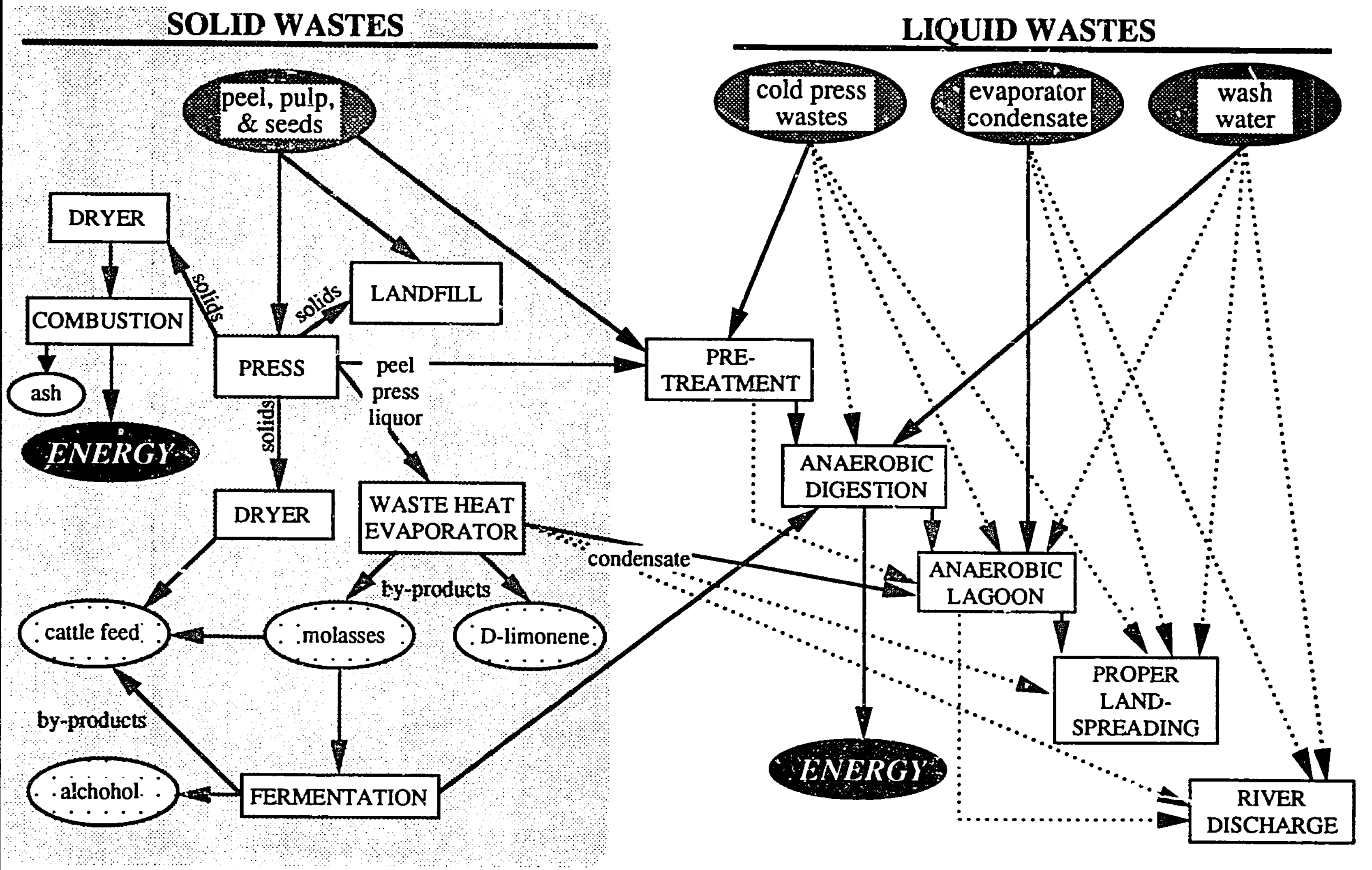
3.1 Proper Landfilling

Figure 3 shows the material flow for option 1, proper landfilling of solid wastes. This would entail pan scraping and stockpiling dirt, followed by burial of accumulated waste. Operations would require a pan and bulldozer and an area where cover dirt can be found. This option involves expenses in addition to existing solid waste transportation costs, but with no economic returns.

Liquid effluents should also be properly treated and discharged to minimize environmental pollution. Liquids can be treated in a properly designed anaerobic lagoon and either spray irrigated or discharged to the river. Cold press wastes may require some degree of pretreatment. In some instances the liquids have been spray irrigated without lagoon treatment , but such procedures have come under increasing scrutiny.

A variation of the landfilling option would be to press the solid waste, combine the peel press liquor and cold press wastes (plus other liquid wastes as may be required, based on the toxicity of the various liquid waste streams) and anaerobically digest the solution to produce biogas. Pressing would enable landfilling of somewhat dryer solid material. The advantage of this over burying wet solid wastes is the removal of the high strength liquid wastes from the disposal area. Further treatment of the peel press liquor could produce enough gas to generate approximately 400 kW of power. (Refer to preliminary calculations presented in Annex 1.) Additional benefits from pressing include reduced volume of material, reduced transportation costs to the landfill, and extended landfill life. Effluent from the anaerobic reactor could be treated and discharged as previously noted for liquid wastes.

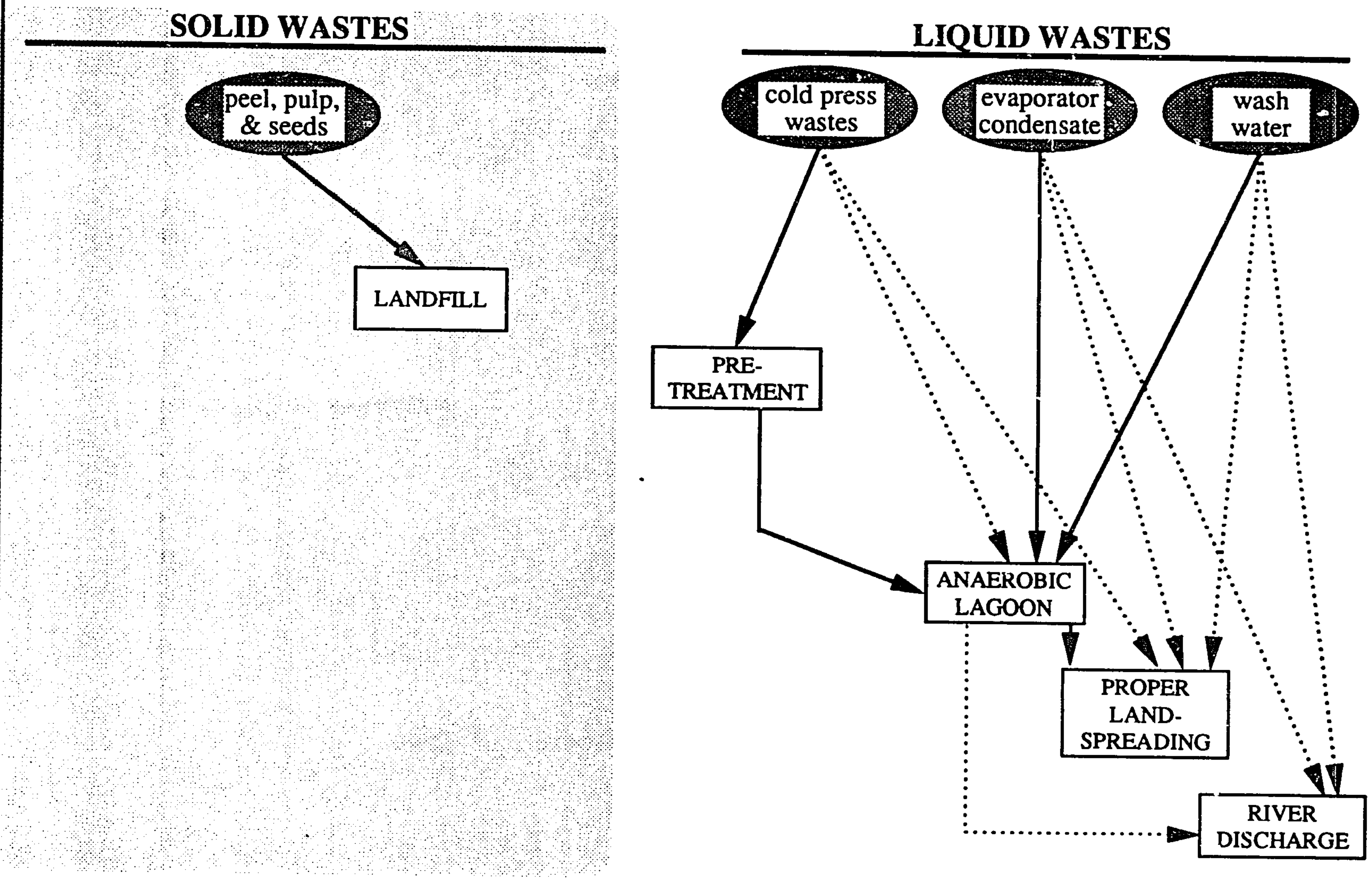
Figure 2
Options for Waste Utilization



dashed lines denote process contingent on nature of waste stream

Figure 3

Proper Landfilling Option



dashed lines denote process contingent on nature of waste stream

25

3.2 Cattle Feed + By-product Recovery

Figure 4 shows the material flow for option 2, conventional feed production and by-product recovery. Solids are pressed, peel press liquor is pumped to the waste heat evaporator, D-limonene is recovered, and molasses is produced and added directly to the feed or used for alcohol production. This option represents the traditional approach to solid citrus waste management and handling. Considerable energy would be required for drying the pressed solid wastes in order to make cattle feed. Additional electricity capacity would be required to run the feedmill operation.

Liquid effluents should also be properly treated and discharged to minimize environmental pollution. Liquids can be treated in a properly designed anaerobic lagoon and either spray irrigated or discharged to the river. Cold press wastes may require some degree of pretreatment. In some instances the liquids have been spray irrigated without lagoon treatment , but such procedures have come under increasing scrutiny.

3.3 Cattle Feed + Anaerobic Digestion

Figure 5 shows the material flow for option 3, production of cattle feed plus anaerobic digestion of peel press liquor. This is a variation of option 2 in which the peel press liquor and cold press wastes (plus other liquid wastes as may be required, based on the toxicity of the various liquid waste streams) are anaerobically digested to produce biogas. The peel press liquor and cold press wastes may require some degree of pretreatment. Preliminary estimates indicate that such a system could produce approximately 6 million BTUs per hour—equivalent to almost one-third of current on-site thermal and electrical energy requirements. (Refer to preliminary calculations in Annex 1.)

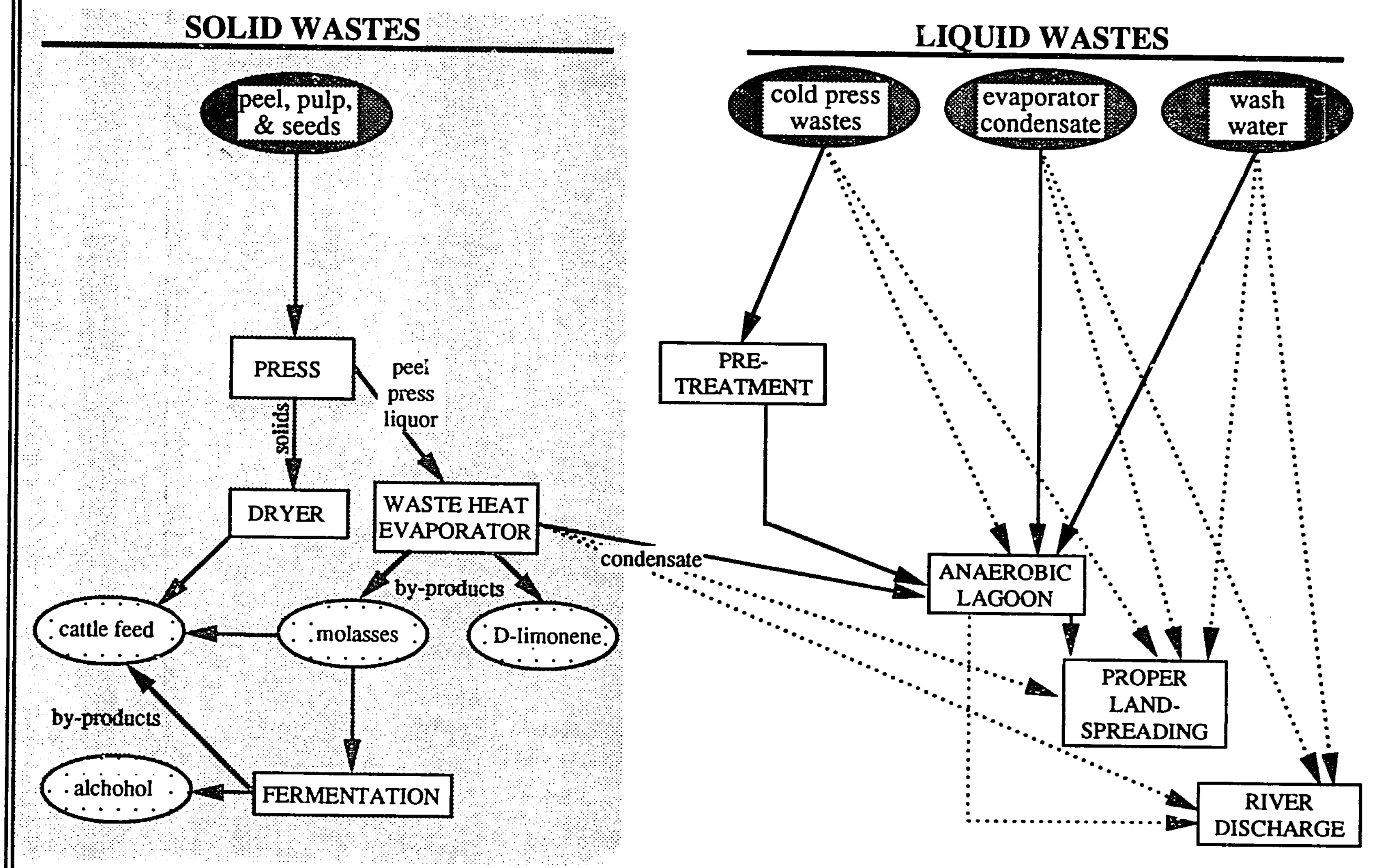
This option, however, would eliminate the production of molasses (from the press liquor) which is used to enrich the cattle feed product, resulting in a lower value feed product, presumably having less market value. Liquid effluents, including products from the anaerobic reactor, should be properly treated and discharged as previously noted.

3.4 Anaerobic Digestion of all Solid and Liquid Wastes

Figure 6 shows the material flow for option 4, anaerobic digestion of *all* solid and liquid wastes. After pretreatment to remove citrus oil, the material is anaerobically digested to produce biogas. Preliminary estimates indicate such a system could produce approximately 18 million BTUs per hour—equivalent to almost 95% of current on-site thermal and electrical energy requirements. (Refer to preliminary calculations presented in Annex 2.)

Liquid effluents, including products from the anaerobic reactor (plus other liquid wastes as may be required, based on the toxicity of the various liquid waste streams), should be properly treated and discharged as previously noted.

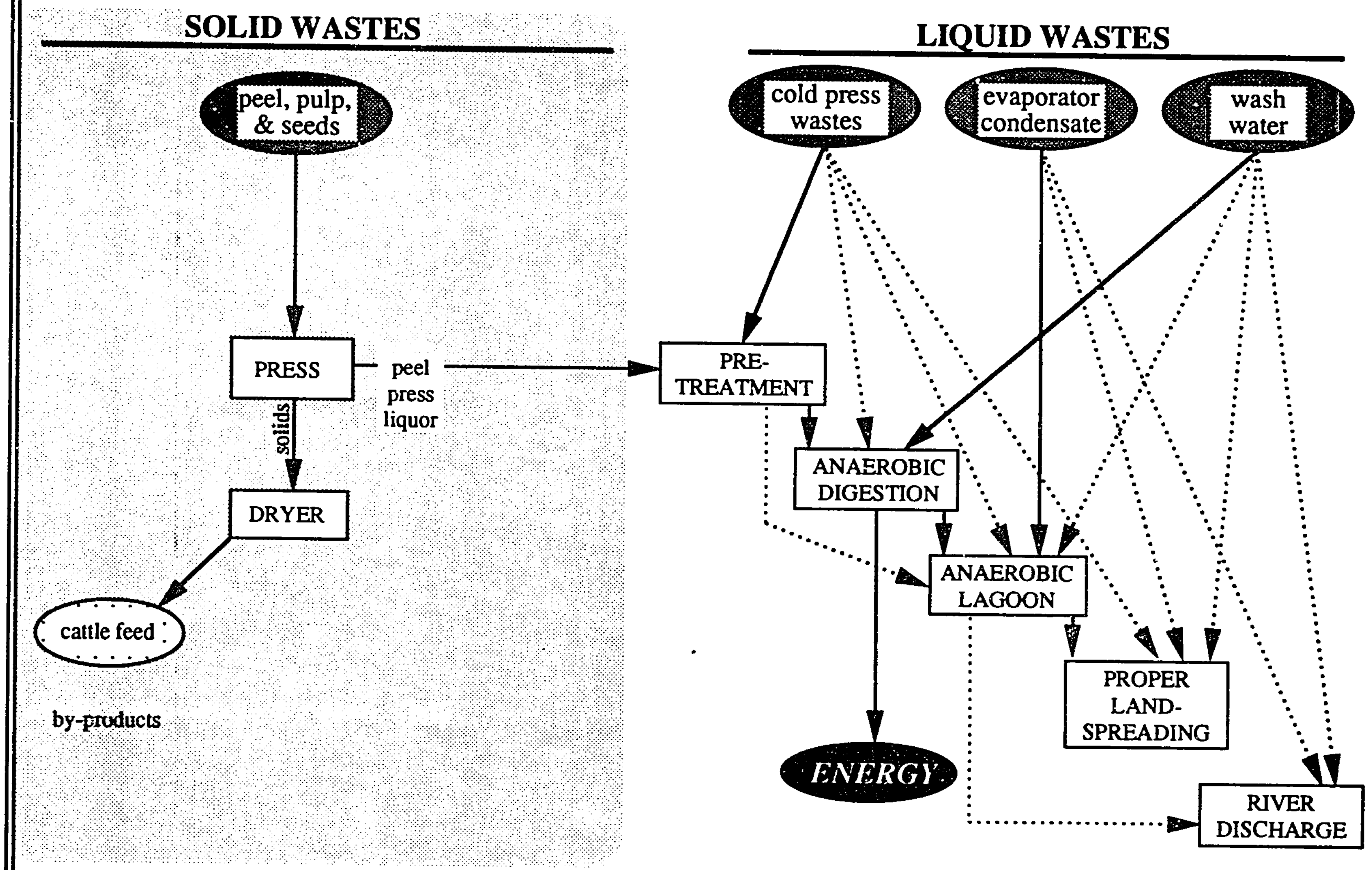
Figure 4
Cattle Feed + Byproduct Recovery Option



dashed lines denote process contingent on nature of waste stream

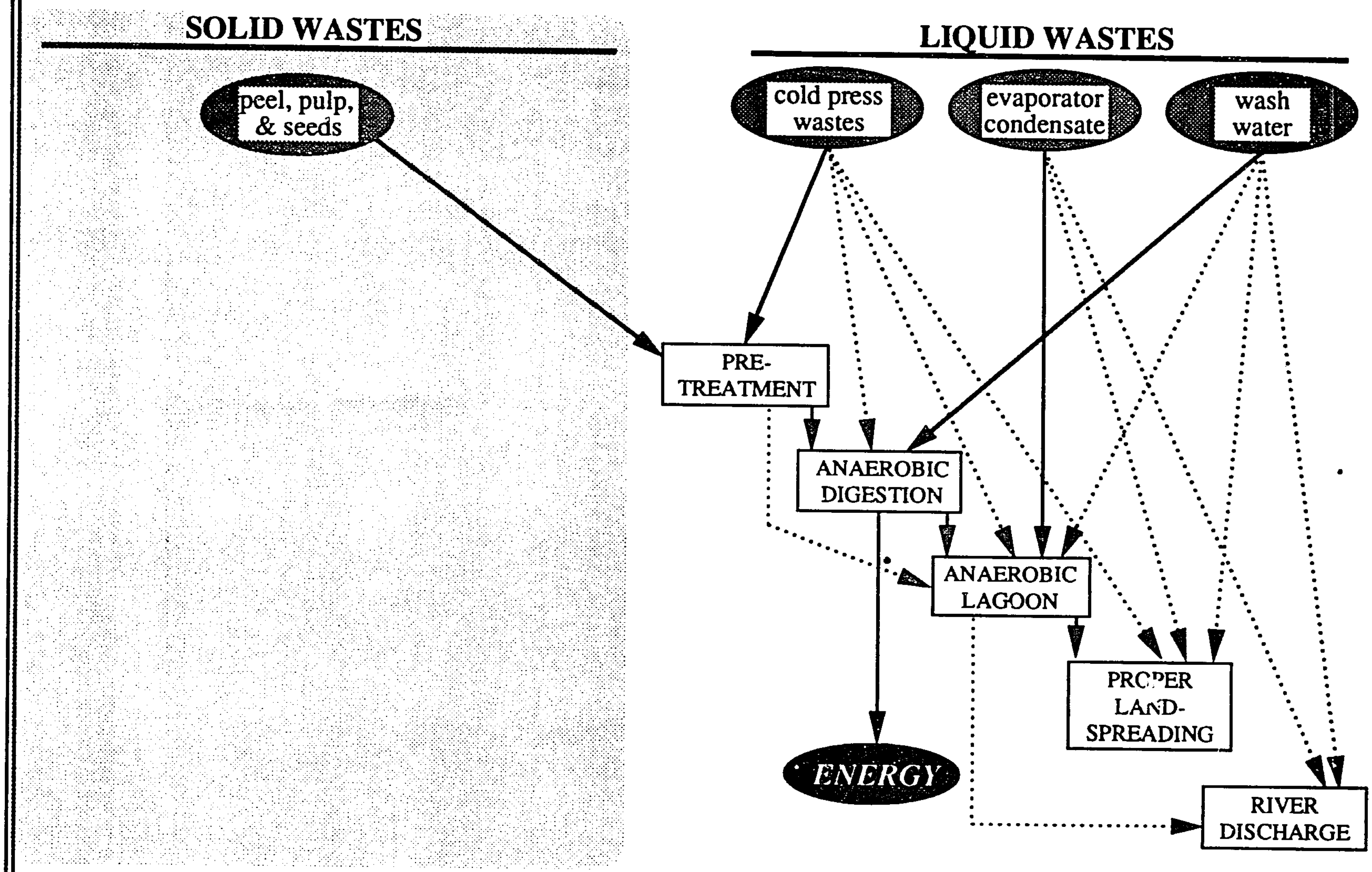
Figure 5

Cattle Feed + Anaerobic Digestion Option



dashed lines denote process contingent on nature of waste stream

Figure 6
Anaerobic Digestion of all Wastes Option



dashed lines denote process contingent on nature of waste stream

3.5 Combustion + Anaerobic Digestion

Figure 7 shows the material flow for option 5, combustion of solid wastes and anaerobic digestion of liquid wastes, including peel press liquor. The solids wastes are mechanically pressed and subsequently dried, using exhaust heat from the diesel generators and/or exhaust heat from the biomass combustion system itself.

The peel press liquor would be combined with the cold press wastes (plus other liquid wastes as may be required, based on the toxicity of the various liquid waste streams) and anaerobically digested to produce biogas. All liquid effluents, including products from the anaerobic reactor, should be properly treated and discharged as previously noted.

Preliminary estimates indicate that combustion of the pressed and dried solid wastes could produce approximately 17 million BTUs per hour—equivalent to almost 90% of current on-site thermal and electrical energy requirements. (Refer to preliminary calculations presented in Annex 3.) Combining the energy from combustion of the pressed and dried solid wastes (17 million BTU/hour) with the energy from anaerobic digestion of the peel press liquor and cold press wastes (6 million BTU/hour) would provide approximately 23 million BTU/hour—equivalent to about 120% of current on-site thermal and electrical energy requirements. Although some additional energy would be required for operating the waste-to-energy systems, we can reasonably assume that this combination combustion/anaerobic digestion system could provide 100% of on-site energy requirements, thereby displacing 100% of current fossil fuel consumption. (Refer to preliminary calculations presented in Annex 4.)

This option represents the maximum potential generation of usable energy from citrus wastes, while simultaneously alleviating current waste disposal problems. While this option consists of processes not yet attempted on a commercial scale for citrus wastes, both combustion and anaerobic digestion technologies are well known and widely used with other agricultural wastes.

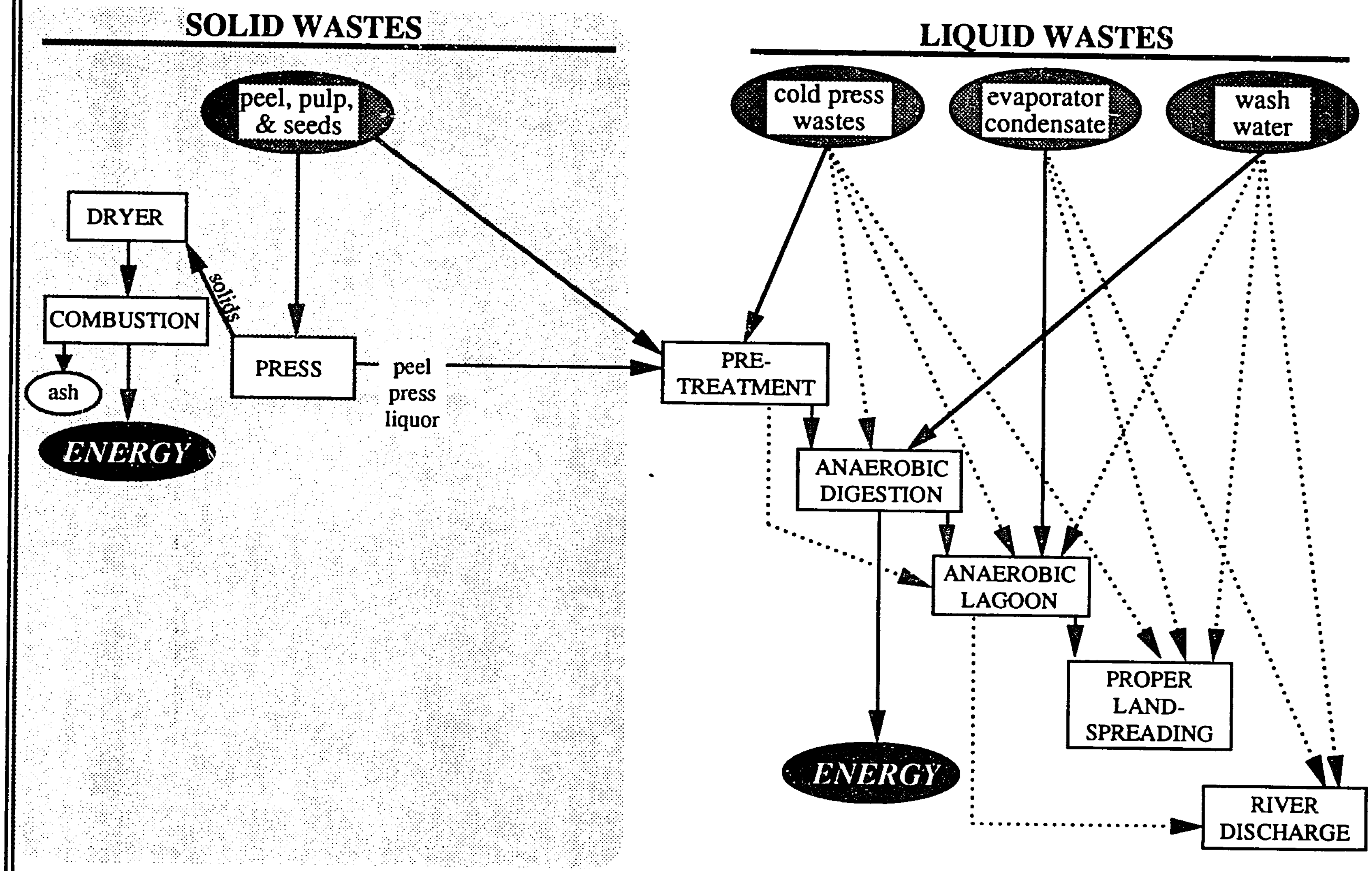
The amount of ash is estimated at approximately 2% - 3%, and could be used for a variety of purposes, including concrete or asphalt filler (i.e., the ash could be mixed with road surfacing materials).

3.6 Summary

We have identified five potential options for waste management at the two citrus processing facilities in Belize. All of the options address the environmental problems, and three of the options incorporate generation of usable energy.

- The first option, ***proper landfilling***, does not provide a fully acceptable solution. The environmental aspects could be considered only marginally effective, and the practice results in no energy generation. Liquid effluents would also need to be properly treated and discharged to minimize environmental pollution. Further, some capital and operating costs would be required for operations, in addition to the existing waste disposal costs, with zero returns on investment.

Figure 7
Combustion + Anaerobic Digestion Option



dashed lines denote process contingent on nature of waste stream

A variation of the landfilling option would be to press the solid waste, combine the peel press liquor and cold press wastes (plus other liquid wastes as may be required, based on the toxicity of the various liquid waste streams) and anaerobically digest the solution to produce biogas. Pressing would enable landfilling of somewhat dryer solid material. The advantages of this over burying wet solid wastes is the removal of the high strength liquid wastes from the disposal area, generation of usable energy through anaerobic digestion, and reduced costs of landfilling operations.

- The second option, ***cattle feed plus by-product recovery***, is the conventional citrus waste conversion process, but has already been tried in Belize and proven to be uneconomical. From a waste management perspective, the capital costs of the system would be considerable, and would entail substantial operating costs, in particular the additional energy required for drying the solid wastes into cattle feed. These costs would be partially offset by revenues from sale of the cattle feed and other by-products. However, this option would be expected to be economical only if satisfactory product markets were available nearby (considered highly unlikely) or as a result of third party incentives, such as GOB subsidies for production and/or marketing expenses. Although this option has been the focus of much attention, we believe the options described below are more attractive.

Both of the first two options still require a system to process existing liquid wastes that are currently discharged to the Stann Creek river but are considered environmentally toxic.

- The third option, ***cattle feed plus anaerobic digestion***, is more attractive than option 2 in that some biogas is generated, which could provide approximately 30% of the energy required to dry the *solid* wastes into cattle feed. Further, the anaerobic digestion system for the peel press liquor could also be used for disposal of other liquid wastes (with additional pre-treatment as may be required). Supplemental energy, presumably from fuel oil, would still be needed for the balance of the drying requirements. This option, however, would result in a lower value feed product , since the press liquor would not be available for production of molasses, (which is added back to the feed for nutritional purposes).

- The fourth option, ***anaerobic digestion of all solid and liquid wastes***, would address the environmental problems and generate substantial amounts of energy. However, although the required anaerobic digestion technologies are well known and widely used for various agricultural wastes, such technologies have only been proven at the laboratory scale for citrus wastes, and additional research is required before full-scale commercial applications are undertaken.

- The fifth option, ***combustion of solid wastes and anaerobic digestion of liquid wastes***, would also address the environmental problems and would generate the maximum amounts of energy of any of the options presented herein. As with anaerobic digestion, the required combustion technologies are well known and widely used for various agricultural wastes, but have not,to our knowledge, ever been used for commercial-scale combustion of citrus wastes. Nonetheless, we are confident that dried solid citrus wastes could be burned using existing combustion technologies for similar agricultural wastes, such as bagasse. Again, additional research is required before full-scale commercial applications are undertaken.

In the last three options, capital and operating costs would be offset by the savings resulting from displaced fossil fuels. It is conceivable that such systems could actually result in enhanced revenues, with positive returns on investment.

Anaerobic digestion of all solid and liquid wastes could potentially produce a large portion of the energy required for each processing plant. Combustion of pressed/dried solid wastes plus anaerobic digestion of liquid wastes would reduce the waste stream to ash and a relatively benign liquid discharge, and could possibly produce all of the energy required for each plant.

Table 2 summarizes the potential energy generation from each option investigated. It is important to note that these figures are based on preliminary calculations, and are presented to indicate the magnitude of the potential energy generation that could result from these systems. More detailed calculations, including verification of several key assumptions, need to be undertaken. Verification of these assumptions will require additional research of the following technical issues:

- quantification of liquid waste volumes and concentrations
- anaerobic treatability of peel press liquor
- anaerobic treatability of solid wastes
- oil removal or neutralization from liquid waste streams
- combustibility of pressed solid wastes (e.g., determination of maximum moisture levels for sustained combustion)

Table 2
Potential Energy Generation and Use

Option	Energy Production Potential
proper landfilling	0
cattle feed + by-product recovery	0
cattle feed + anaerobic digestion of liquid wastes	6,000,000 BTU/hr
anaerobic digestion of solid & liquid wastes	18,000,000 BTU/hr
combustion of solid wastes + anaerobic digestion of liquid wastes	23,000,000 BTU/hr

4. Conclusions & Recommendations

The objective of this study was to identify technically feasible and environmentally acceptable options for waste-to-energy conversion systems for the citrus industry in Belize. This review of such potential technologies, in conjunction with the preliminary calculations presented herein, suggest that substantial energy can be generated from citrus wastes. A combination of combustion of solid wastes and anaerobic digestion of liquid wastes would address the environmental problems resulting from current dumping practices and would generate the maximum amount of energy of any of the options presented here—preliminary calculations indicate sufficient energy generation to satisfy 100% of on-site thermal and electrical energy requirements for each facility.

Cost estimates of the various technologies discussed herein were not part of the original scope of work for this study, nor can such costs reasonably be estimated without more investigation and effort. Nonetheless, several economic factors can be identified:

- Costs of the cattle feed and by-products production option, the conventional method of processing solid citrus wastes, have proven uneconomical in Belize. Current estimates of cattle feed production from solid citrus wastes in Belize indicate a loss of $20 – $50 per ton of feed.
- Waste-to-energy systems that displace 100% of the on-site fossil fuel requirements for electrical and process steam generation, as discussed in option 5 discussed herein, could result in savings in excess of $400,000 per year for each site.
- Waste-to-energy systems that address 100% of the solid and liquid waste streams would eliminate current waste disposal costs currently estimated at $100,000 – $150,000 per year for each site.
- Each processing facility already has two oil-fired burners/boilers that could be converted for combustion of citrus wastes, resulting in considerable savings in the capital costs of the combustion systems.

More detailed site-specific feasibility studies, including identification of required equipment and associated costs, is required to estimate the costs and financial performance of investments in such waste management/energy generation systems. Before proceeding with such assessments, however, additional investigations of the unknown technical issues such as the digestability of peel press liquor and other liquid citrus wastes or maximum moisture level for sustained combustion of solid citrus wastes should be undertaken to verify some of the key technical assumptions in this study and to more accurately project the amounts of potential energy generation. These issues should be addressed prior to investing the considerable resources required for detailed site-specific feasibility studies.

It is therefore recommended that a pre-feasibility study be undertaken to investigate the unknown technical issues and verify the technical assumptions used in these calculations. The results of these activities would be applicable to either of the two existing processing facilities in Belize and would enable a preliminary equipment list to be made, plus an assessment of associated equipment costs and the financial performance of an investment in a waste-to-energy system.

Annex 1
Preliminary Calculations:
Energy from Anaerobic Digestion of Press Liquor
(estimated flow-rates & calculations are for each facility)

Assumptions (in addition to those set forth in Annex 1):

1.	COD strength of peel press liquor	=	100,000	ppm
2.	COD destruction efficiency	=	70 %	
3.	biogas generation per pound of COD destroyed	=	10.2	cf/lb
4.	biogas energy generation rate	=	550	BTU/cf
5.	biogas power generation rate (includes engine derating for biogas operations @ 15%)	=	0.04	kWh/cf

a. determination of potential energy generation

amount of peel press liquor	:	15,714	lbs/hour
(COD strength of peel press liquor)	x	100,000	ppm COD
COD generation	=	1,571	lbs COD/hr
(COD destruction efficiency)	x	70%	
COD destruction	=	1,100	lbs COD/hr
(biogas generation per pound of COD destroyed)	x	10.2	cubic feet (cf)
biogas generation	=	11,220	cf/hr
(biogas energy generation rate)	x	550	BTU/cf
energy generation	=	6,171,000	BTU/hr

b. determination of potential power generation

methane generation	:	11,220	cf/hr
(biogas power generation rate)	x	0.04	kWh/cf
power generation	=	449	kW

CONCLUSION:

Digestion of press liquor could generate approximately

6,000,000 BTU/hour.

Annex 2
Preliminary Calculations:
Energy from Anaerobic Digestion of Entire Solid Waste Stream

(estimated flow-rates & calculations are for each facility)

Assumptions (in addition to those set forth in Annexes 1&2):

1.	methane concentration in biogas	=	55%	
2.	biogas yield, based on total solids added	=	7.96	cf/lb
3.	biogas energy generation rate @ above concentration	=	550	BTU/cf
4.	solid waste stream is macerated but not pressed			
5.	on-site electrical load	=	600	kW
6.	biogas power generation rate (includes engine derating for biogas operations @ 15%)	=	0.04	kWh/cf

a. determination of potential energy generation

biogas yield, based on total solids added :	7.96	liters/gram
x	4,125	lbs/hour
biogas generation =	32,835	cf/hr
(biogas energy generation rate @ above concentration) x	550	BTU/cf
energy =	18,059,250	BTU/hour

b. determination of amount of biogas required for electricity generation

on-site electrical load :	600	kW
(biogas power generation rate) ÷	0.04	kWh/cf
amount of biogas required =	15,000	cf/hr

b.2 determination of surplus energy generation

amount of biogas generated :	32,835	cf/hr
amount of biogas required for electricity generation -	15,000	cf/hr
amount of biogas available for other uses =	17,835	cf/hr
(biogas energy generation rate @ above centration) x	550	BTU/cf
energy =	9,809,250	BTU/hour

CONCLUSION:

Digestion of the entire waste stream could generate approximately

18,000,000 BTU/hour.

Annex 3
Preliminary Calculations:
Energy from Combustion of Solid Wastes

(estimated flow-rates & calculations are for each facility)

Assumptions:

1.	initial moisture content of solid waste steam (based on information provided by the Belizean facilities)	=	85%	wet basis
2.	solid waste flow rate from extractors (based on information provided by the Belizean facilities)	=	27,500	pounds/hour
3.	moisture level of solid wastes after mechanical pressing (note: this is the highest measured value reported, and is used for conservative estimates)	=	65%	wet basis
4.	higher heating value of the solid wastes (BTU/lb of dry matter) (note: this is the lowest measured value reported, and is used for conservative estimates)	=	7,100	BTU/lb-DM
5.	target moisture level for sustained combustion	=	52%	wet basis
6.	unburned combustible loss	=	2%	
7.	heat of vaporization of water	=	1,040	BTU/lb
8.	enthalpy of steam @ 150 psig	=	1,196	BTU/lb
9.	enthalpy of water @ 60° and atmospheric pressure	=	28	BTU/lb

a. Determination of flow rates

amount of dry matter	=	4,125	lbs/hour
amount of water in solid waste stream after pressing	=	7,661	lbs/hour

b. Determination of energy required for moisture removal

higher heating value of dry matter	:	7,100	BTU/lb-DM
less unburned combustible loss	=	-142	
less heat loss for water evaporation @ (7,661 lbs water to be removed / 4,125 lbs solids) x 1040 BTU/lb	=	-1,931	
other heat requirements (including products of combustion)	=	-886	
available heat	=	4,141	BTU/lb-DM

c. Determination of potential energy generation

net heat value of dry matter	:	4,141	BTU/lb-DM
(amount of dry matter)	x	4,125	lbs/hour
available energy	=	17,079,857	BTU/hour

CONCLUSION:

Combustion of solid wastes could generate approximately

17,000,000 BTU/hour.

Annex 4
Preliminary Calculations:
Energy from Combustion of Solid Wastes
plus
Energy from Anaerobic Digestion of Press Liquor
(estimated flow-rates & calculations are for each facility)

a. Determination of potential energy generation from combustion of solid wastes

from Annex 1 :	17,000,000	BTU/hour

b. Determination of potential energy generation from anaerobic digestion of press liquor

from Annex 2 :	6,000,000	BTU/hour

c. Determination of total potential energy generation

=	23,000,000	BTU/hour

d. Estimate of on-site energy requirements

on-site electrical load :	600	kW
x	3,412	BTU/hr/kW
estimated generation efficiency (using a steam turbine/generator) ÷	60%	
amount of energy required =	3,412,000	BTU/hour
on-site thermal load :	400	HP
x	33,480	BTU/hr/HP
estimated generation efficiency ÷	84%	
amount of energy required =	15,943,000	BTU/hour
total estimated on-site energy requirements =	19,000,000	BTU/hour

CONCLUSION:

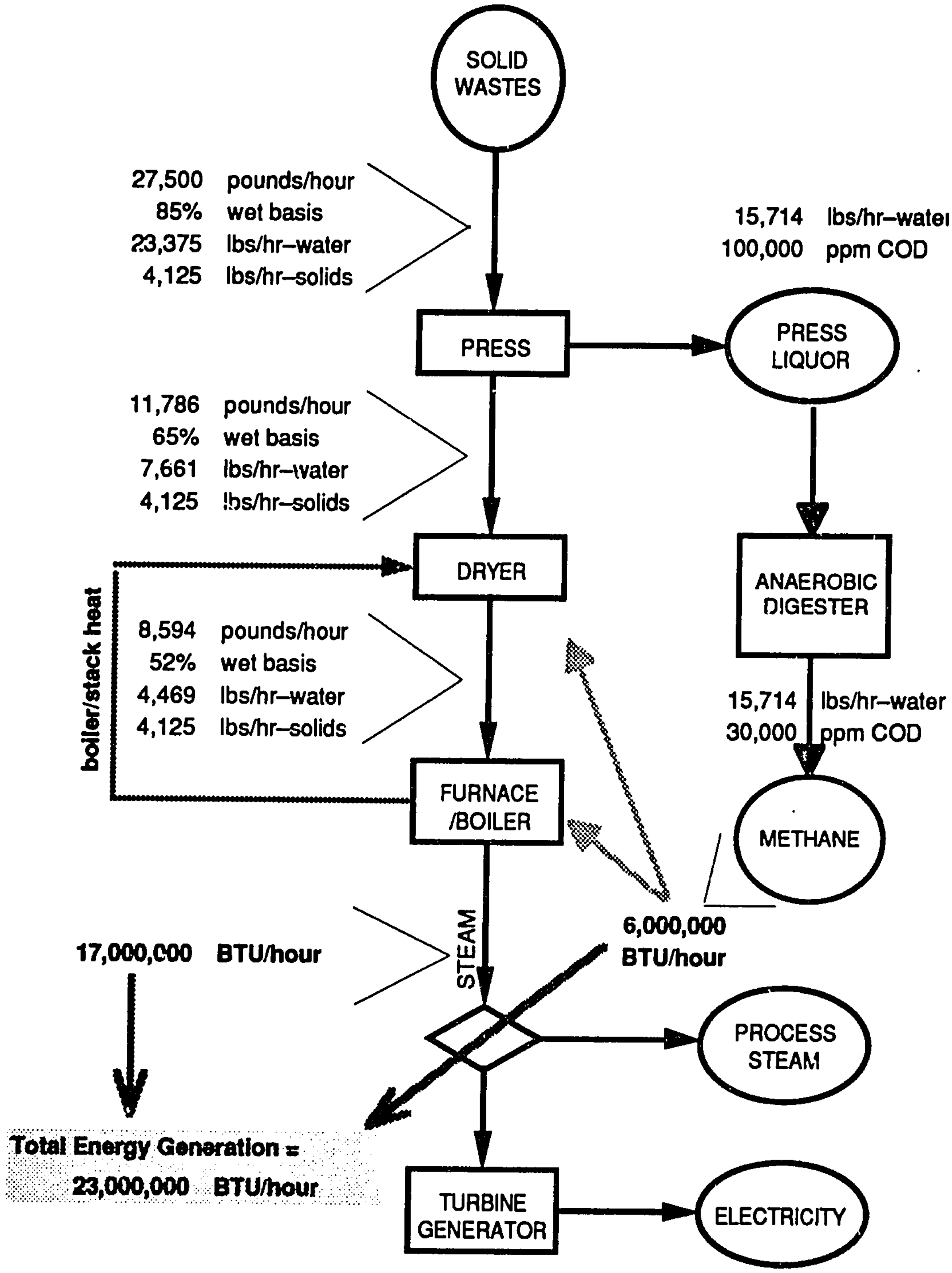
Combustion + anaerobic digestion could generate approximately

23,000,000 BTU/hour,

thereby displacing approximately

121% of on-site energy requirements.

Summary of Materials Flow Chart & Energy Generation: *Combustion + Anaerobic Digestion Option*



5. References

1. Lawrence, Fred P., "Summary of Research Investigations being Conducted in the Citrus By-products Field", *The Citrus Industry*, 30(2), February, 1949.

2. Keough, David A., "Treated Wastewater Reuse in the Citrus Industry", IFT Short Course, Gainesville, FL, 1989.

3. Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Apple, Citrus and Potato Processing Segment of the Fruits and Vegetables Processing Industry of the Canned and Preserved Fruits and Vegetable Point Source Category", EPA-440/1-74-027a. Washington D.C. 1974.

4. El-Nawawi, S.A. and F. R. Shehata, "Short Communication: Effect of the Extraction Temperature on the Quality Characteristics of Pectin Extracted from Egyptian Orange Peel", *Biological Wastes*, 24, 307-311, 1988.

5. Vaccarino, C., et. al., "SCP from Orange Peel by Fermentation with Fungi - Submerged and Surface Fermentations", *Biological Wastes*, 29, 279-287, 1989.

6. Nishio, N. and S. Nagai, "Single Cell Protein Production from Mandarin Orange Peel", *European Journal of Applied Biotechnology*, 11, 156-160, 1981.

7. Vaccarino, C., et. al., "SCP from Orange Peel by Fermentation with Fungi - Acid Treated Peel", *Biological Wastes*, 30, 1-10, 1989.

8. Ashbell, A. and N. Lisker, "Chemical and Microbiological Changes Occurring in Orange Peels and in the Seepage During Ensiling", *Biological Wastes*, 24, 213-220, 1987.

9. Clark, Wesley C., "Energy Recovery by Production of Fuel from Citrus Wastes", *Food Technology*, May 1982.

10. Personal communication, Adam Bosschieter, Consultant.

11. Wilkie, A. and Colleran, E. (1989). "The development of the anaerobic fixed-bed reactor and its application to the treatment of agricultural and indurstrial wastes." *International Biosystems*, III, 183-226. D. L. Wise (ed.), CRC Press, Inc., Boca Raton, Florida.

12. Lane, A.G., "Pretreatment of Citrus Peel Press Liquor before Anaerobic Digestion", *Environmental Technology Letters*, 4, 73-78, 1983.

13. McNary, R.R., et al, "Experimental Treatment of Citrus Waste Water", *Food Technology*, 5, 319-323, August 1951.

14. Buswell, A.M. and W.D. Hatfield, "Anaerobic Fermentations", Division of the Water Survey, State of Illinois Department of Registration and Education, Bulletin No. 32, 1936.

15. Lane, A.G., "Anaerobic Digestion of Citrus Peel Press Liquors", *Environmental Technology Letters*, 4, 349-352, 1983.

16. Lane, A.G., "Anaerobic Digestion of Orange Peel", *Food Technology in Australia*, 36(3), No. 3, 125-127, March 1984.

17. Lane, A.G., "Production of Aromatic Acids During Anaerobic Digestion of Citrus Peel", *Journal of Chemical Technology and Biotechnology*, 30, 345-350, 1980.

18. Mizuki, E., et al, "Inhibitory Effect of Citrus Peel on Anaerobic Digestion", *Biological Wastes*, 33, 161-168, 1990.

19. Wolford, R.W., et al, "A Method for Removal of Peel Oil from Citrus Juices and Process Liquids", *Food Technology*, 6(11), November 1952.

20. Lane, A.G., "Removal of Peel Oil from Citrus Peel Press Liquors before Anaerobic Digestion", *Environmental Technology Letters*, 4, 65-72, 1983.

21. Personal communication, Jim Porteous, The Jones Group, Austin, Texas.

22. Personal communication, Gordon D. Hartman, Tropicana Products, Inc., Bradenton, Florida.

23. Personal communication, J. Vernon Christian, Environmental Energy Concepts, Sheffield, Alabama.

24. Personal communication, Kelton Grubbs, Thermal Systems Engineering, Hot Springs, Arkansas.

25. Personal communication, Buren F. Shaw, Executive Vice President, Brown International Corporation, Winter Haven, Florida.

26. "Energy from Rice Residues", Winrock International Institute for Agricultural Development, 1611 North Kent St., Arlington, Virginia 22209, 1990.

27. Pacific Northwest and Alaska Bioenergy Program Glossary, U.S. Department of Energy, 1986.

The Office of Energy and Infrastructure

The Agency for International Development's Office of Energy and Infrastructure plays an increasingly important role in providing innovative approaches to solving the continuing energy crisis in developing countries. Three problems drive the Office's assistance programs: high rates of energy use and economic growth accompanied by a lack of energy, especially power in rural areas; severe financial problems, including a lack of investment capital, especially in the electricity sector; and growing energy-related environmental threats, including global climate change, acid rain, and urban air pollution.

To address these problems, the Office of Energy and Infrastructure leverages financial resources of multilateral development banks such as The World Bank and the InterAmerican Development Bank, the private sector, and bilateral donors to increase energy efficiency and expand energy supplies, enhance the role of private power, and implement novel approaches through research, adaption, and innovation. These approaches include improving power sector investment planning ("lease-cost" planning) and encouraging the application of cleaner technologies that use both conventional fossil fuels and renewable energy sources. Promotion of greater private sector participation in the power sector and a wide-ranging training program also help to build the institutional infrastructure necessary to sustain cost-effective, reliable, and environmentally-sound energy systems integral to broad-based economic growth.

Much of the Office's strategic focus has anticipated and supports recently-enacted congressional legislation directing the Office and A..I.D. to undertake a "Global Warming Initiative" to mitigate the increasing contribution of key developing countries to greenhouse gas emissions. This strategy includes expanding least-cost planning activities to incorporate additional countries and environmental concerns, increasing support for feasibility studies in renewable and cleaner fossil energy technologies that focus on site-specific commercial applications, launching a multilateral global energy efficiency initiative, and improving the training of host country nationals and overseas A.I.D. staff in areas of energy that can help to reduce expected global warming and other environmental problems.

To pursue these activities, the Office of Energy and Infrastructure implements the following six projects: (1) The Energy Policy Development and Conservation Project (EPDAC); (2) The Biomass Energy Systems and Technology Project (BEST); (3) The Renewable Energy Applications and Training Project (REAT); (4) The Private Sector Energy Development Project (PSED); (5) The Energy Training Project (ETP); and (6) The Energy Technology Innovation Project (ETIP).

The Office of Energy and Infrastructure helps set energy policy direction for the Agency, making its projects available to meet generic needs (such as training), and responding to short-term needs of A.I.D.'s field offices in assisted countries.

Further information regarding the Office of Energy and Infrastructure projects and activities is available in our Program Plan, which can be requested by contacting:

Office of Energy and Infrastructure
Bureau for Research and Development
U.S. Agency for International Development
Room 508, SA-18
Washington, D.C. 20523-1810
Tel: (703) 875-4052