With high demands for heat and power, and a ready resource in the form of biomass waste, Thailand's tapioca starch factories are an ideal opportunity for distributed bioenergy plant. **Richard Plevin** and **David Donnelly** look at one project that has exceeded all initial expectations.

Converting waste to energy and profit

Tapioca starch power in Thailand

A new biodigester system at the largest tapioca starch factory in South-east Asia provides nearly 100% of the factory's considerable energy demand, displacing significant annual purchases of fuel oil and grid electricity. The Korat Waste-to-Energy Co. Limited (KWTE) owns and operates the facility as a renewable energy services company, anaerobically treating the factory's wastewater, and selling biogas as a substitute for heavy fuel oil and electrical power at discounted rates. The system outperforms its design goals by significant margins, achieving 99% removal of the wastewater's total chemical oxygen demand (CODt) and reduction in solid waste, as well as producing correspondingly greater volumes of biogas than anticipated.

The grid-connected 5 MW power plant supplies all its electrical energy to the factory, with the added capability of selling surplus electricity to the local utility under Thailand's net-metering regulations. This generates additional revenues while further contributing to the country's green power portfolio.

The project has been designed and developed as one of the first that may benefit from international carbon trading to help support financing projects through the Clean Development Mechanism (CDM). Both the technology and the business model are highly replicable. The Clean Energy Development Company Limited of Thailand (Clean THAI), which conceived, financed, and developed the KWTE biodigester project, is developing 13 more cassava industry biodigester energy plants as CDM projects, and expects to start construction on four of these during 2004.

BIG FACTORY, BIG DEMAND

The province of Nakorn Ratchasima – also known as Korat – is home to South-east Asia's largest cassava processing plant, Sanguan Wong Industries (SWI). The facility, located about 250 kilometres north-east of Bangkok, processes 3000 tonnes of raw cassava roots each day, to produce 750 tonnes of native and modified tapioca starch. A new modified starch plant, due to commence operations in November 2004, will generate up to an additional 250 tonnes of modified starch per day. The sprawling facility operates three shifts, 350 days per year, and employs over 700 workers.

Cassava processing presents an ideal opportunity for distributed generation, coupling an excellent renewable resource with large heat and electricity loads. Significant energy is required to dry the starch, reducing its moisture content from 70%–80% to 15%–17% for bagging and shipment.

Biogas pipeline to the cassava plant

The power plant building at the KWTE facility

TABLE 1. Baseline consumption data at SWI (pre-KWTE)

Energy requirement	Annual demand	Annual costs	Unit cost
Heat	7.5–8 million litres HFO	60 million Baht (US$1.45 million)	7.50–9.0 Baht/litre ($0.18–0.21)
Electricity	35–37 million kWh	85 million Baht (US$2.06 million)	2.40–2.50 Baht/kWh (~$0.06)

Prior to the introduction of the biogas system, the factory combusted more than 7.5 million litres of heavy fuel oil (HFO) annually to produce the required heat. Table 1 gives a breakdown of the energy requirements.

Electricity powers all stages of processing, including conveyer transport, peeling and grinding the roots to a fine powder, and pressurizing and pumping 350 m^3 of water per hour for cleaning and process requirements. Present electrical demand at the SWI factory averages 5.8 MW, peaking at 6.4 MW. The new modified starch plant will further increase demand by 1.5 MW.

TURNING WASTE INTO ENERGY AND PROFIT

In addition to starch, the plant generates up to 8000 m^3 of nutrient-rich wastewater per day. Prior to construction and operation of the anaerobic biodigester, this wastewater was piped to an extensive facultative lagoon system (i.e. one that uses bacteria which can live with or without oxygen) occupying 48 hectares of land 2 km from the factory. While this natural aerobic treatment considerably exceeded local environmental standards, the lagoon system required vast tracts of land and wasted a valuable energy resource. In addition, several of the early ponds have become anaerobic, releasing large quantities of methane – a potent greenhouse gas – into the atmosphere. Table 2 gives details of the wastewater before and after digestion.

Recognizing the latent energetic and financial potential of this waste stream, Clean THAI approached the Tantiwong family, the owners of SWI, with the offer of 20% savings on their energy costs at no risk. Knowledgeable about anaerobic digestion, but wary of making a large investment in the technology themselves (as it was perceived to be risky), the highly proactive Tantiwongs nevertheless decided to introduce the technology into Thailand and the Thai cassava industry with Clean THAI, and agreed to implement the proposal.

Prior to the introduction of biogas, the factory combusted 7.5 million litres of heavy fuel oil a year

The facility was developed by Clean THAI on a build-own-operate-transfer (BOOT) basis. It is this BOOT concession that carries all commercial risk. KWTE was formed as a Project Operating Company (POC), to receive the investment and run the plant for the first 10 years, after which

TABLE 2. SWI wastewater before and after digestion

Attribute	Digester influent	Digester effluent[a]
Chemical oxygen demand (COD)	> 32,000 mg/litre	99% reduction
Five-day biochemical oxygen demand (BOD5)	> 16,000 mg/litre	99% reduction
Total suspended solids (TSS)	> 15,000 mg/litre	99% reduction
Total dissolved solids (TDS)	> 14,500 mg/litre	76% reduction
pH	3.8–4.2	7.1
Sulphates	< 300 mg/litre	–

[a] Measured at digester outlet.

SWI will assume ownership and responsibility for all operations. KWTE and its investors absorb all financial, technological and management risks; SWI needed provide only land and wastewater.[1] SWI has committed to purchase up to 100% of its electricity and heating demand from KWTE; the energy services are sold to the factory for 80% of current (floating) market rates for comparable quantities of grid electricity and fuel oil respectively. If KWTE fails to produce adequate supplies, SWI simply reverts to the grid and fuel oil for the balance of its needs. To facilitate fuel switching, KWTE upgraded SWI's starch-drying system to use flexible liquid/gas burners, which can use either biogas or fuel oil.

Based on the successful implementation at SWI, Clean THAI will start building four more plants in Thailand in 2004 using the same business model and technology, and plans to build at least as many more in 2005.

THE BIOGAS SYSTEM

The complete biogas system consists of the following modules:

- inlet system, comprising a rotary screen and a grit trap to remove sand
- pre-treatment balancing pond
- mixing module to maintain the chemical balance of the incoming wastewater
- Covered In-Ground Anaerobic Reactor (CIGAR)
- biogas treatment system that removes moisture from the gas
- power plant
- flare for burning excess biogas
- delivery system to the new burners in the factory.

The balancing pond

The wastewater exits the factory into a canal where a manual gate diverts the waste stream into the biodigester system. Prior to injection into the anaerobic digester, the slurry is mixed in a balancing pond, where its acidity is reduced for optimal biogas production.

The balanced slurry is then pumped into a covered lagoon of 100,000 m^3 (140 m x 115 m x 10 m) for anaerobic digestion. The lagoon is filled to 9.5 metres with liquid, including 7 metres of active bacterial mass, and is covered with 1 mm of HDPE (high-density polyethylene). The temperature inside the reactor ranges from 38°–40°C, ideal for the mesophilic digestion process.

The CIGAR adopts the best features of several digester designs from around the globe. The KWTE system – designed primarily by New Zealand-based Waste Solutions Ltd, with assistance from Clean THAI – is further customized to process cassava wastewater. In contrast with simpler lagoon designs, the CIGAR includes many features to maximize gas production throughout the lagoon. An extensive system of baffles converts the CIGAR into multiple simultaneous reaction zones which control the positioning, density, and movement of active bacterial mass inside the reactor. More than 2 km of piping, multiple submerged pumping systems, high-velocity injection nozzles, and a series of high-pressure valves positioned throughout the interior permit the delivery of rich organic-laden wastewater to any targeted area inside the reactor. Uniformly distributing the gas production also reduces the cover seam stress that would occur with ballooning.

> **Based on the successful implementation at SWI, Clean THAI will build further plants in Thailand in 2004–2005**

Furthermore, the piping also allows KWTE to non-invasively correct sectional biochemical underperformance that might occur in the CIGAR and cause sub-optimal biogas production rates. Internal piping and pumping systems permit the targeted removal of active bacterial sludge as well, which is sold, both wet and dry, as organic compost.

The biogas is drawn from the reactor using multiple Roots–Dresser positive displacement vacuum pumps, passed through a water bath and a filter system to remove dust particles, and then through a dehumidification system.[2] The biogas is then routed to the factory's starch driers, to the power plant or to the flare, as required.

Inside the factory, the biogas is combusted in hot oil boilers, which transfer the thermal energy to oil-carrying media inside the combustion chamber. The 250°C oil is then piped to four starch-drying stations. Air is forced over coils containing the hot oil and then over the wet starch on conveyor belts, reducing the moisture content of the starch for bagging and shipment. This drying method prevents the by-products of combustion from contaminating the starch, thereby ensuring a food-grade final product.

The biodigester system operation is completely automated,

ABOVE The biogas-impermeable cover of the CIGAR digester **BELOW** The plant's Jenbacher GS 320 gensets

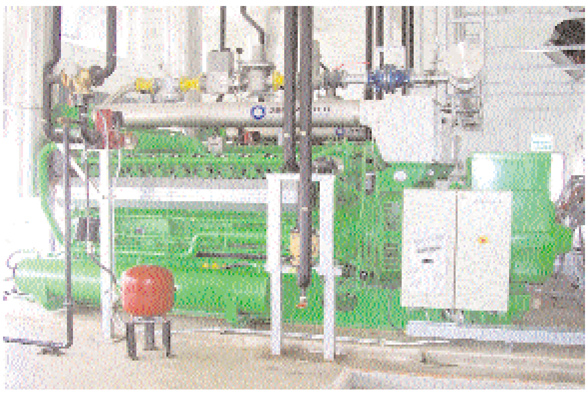
with sensors tracking all significant variables in real time, including wastewater flows, wastewater and sludge levels inside the CIGAR, biogas production rate, the methane and oxygen content of the biogas, and the pH level of the balancing pond. The SCADA (Supervisory Control And Data Acquisition) system incorporates a sophisticated touch-screen display to allow the operator to monitor all activity. Vital statistics are recorded in real time, allowing precise control and adjustment of the quantity, location, and pH of the influent.

> 25%–30% more biogas than was expected is available for conversion to electricity

SYSTEM PERFORMANCE

The system outperforms its design goals by a significant margin. Several factors are thought to contribute to this:

- *Greater conversion efficiency* – the digester is averaging more than 99% conversion of COD, BOD and TSS into biogas, compared with projections of 80%, 90% and 70% respectively. Thus the digester is generating more gas than anticipated. While these conversion rates will likely drop to the 90% level when the plant is at full operation later in 2004 (when SWI's new modified starch plant comes on-stream) performance will still exceed initial projections.
- *Higher organic load* – while KWTE estimated the long-term average organic load of the wastewater at 30,000 mg/litre, the measured organic load is running between this figure and 35,000 mg/litre, providing a surplus of organic matter to convert to biogas.



- *Greater combustion efficiency* – biogas burns more efficiently and more completely in SWI's hot oil boilers than liquid fuel oil, which must be aerosolized before combustion. Based on the energy content of the 2% low-sulphur fuel oil that SWI uses (40.9 MJ/litre) and the energy content of methane gas (CH_4) of 35.9 MJ/m^3, KWTE anticipated using 1.1 m^3 of CH_4 to offset 1 litre of HFO. However, due to the greater combustion efficiency in SWI's hot oil boilers, approximately 1.0 m^3 CH_4 is actually required.

The greater conversion efficiency and higher organic load together provide 20% more biogas than was projected, and the greater combustion efficiency means less biogas is required to offset HFO needs. Combined, these factors provide 25%–30% more biogas for conversion to electricity than was expected.

Since the commencement of CIGAR operations in 2003, the system has averaged a production of 60,000 m^3 biogas per day at 62% methane gas (equivalent to 32,000 litres of HFO per day). Since commencement of operations, the power plant has averaged generation of slightly more than 71,000 kWh per day at peak operation. Maximum biogas production at SWI's maximum wastewater flow rate of 350 m^3/hour is projected at 124,000 m^3. This level will increase once the wastewater from the new modified starch plant is added to the CIGAR.

Total system output for 2004 is projected at the equivalent of 8 million litres of HFO and 24 million kWh of electricity. Annual energy cost savings to the plant are estimated at US$250,000 in eliminated HFO fuel costs, and the same again in reduced grid electricity costs. Details of CIGAR performance are given in Table 3.

TABLE 3. CIGAR performance statistics

Biogas methane content	62%
Biogas production per m^3 wastewater	16.5 m^3
Methane production per m^3 wastewater	10.25 m^3
Maximum biogas production at full wastewater flow	124,000 m^3/day
GHG emission reductions	380,000 tonnes CO_2 equivalent

POWER PLANT

The power plant currently consists of three 1.048 MW (net) Jenbacher Model GS-320 generator sets. KWTE estimated genset availability at 93% per annum; availability has been running at 95% since power plant commissioning.

KWTE had initially projected offsetting 100% of SWI's HFO needs and 75%–80% of SWI's kWh needs. The first three Jenbacher units were purchased to meet these projections. However, based on total biodigester energy system performance data (as outlined above), two more identical units are planned for installation later this year.

Given the factory's dual electricity and heating requirements, even greater efficiencies could be achieved through cogeneration. Unfortunately, the land best suited for the power plant was located several hundred metres from the factory, precluding efficient use of the waste heat. Instead, biogas is piped to the heaters located inside the factory, and separately to gensets in the powerhouse.

The use of gas for cogeneration outside the factory is still under evaluation, however. SWI sells its 'wet cake' (starch-processing by-product used in the packaging and animal feed industries) throughout the year, but gets a proportionally better price the drier it is. During the eight dry (summer) months of the year, the 'wet cake' is sun-dried on eight hectares of concrete near the power plant, but frequent heavy rain from August to November makes this infeasible. During these months, the thermal energy from the power plant could be piped 40–50 metres to the concrete pad to dry the wet cake, augmenting sales revenues.

While the original system design anticipated flaring all excess biogas, Thailand's new 'Very Small Renewable Energy Power Producer' (VSPP) regulations allow grid connection of small-scale renewable energy systems that export up to 1 MW of electricity. KWTE hopes to convert excess biogas into additional income under these rules, although with SWI's new modified starch plant – including a new wastewater stream, with slightly different chemical characteristics – contributing to greater demand, it is not yet clear how much excess biogas there will be. Other Clean THAI cassava waste-to-energy projects under development will export surplus electricity to the grid under the VSPP.

ECONOMICS

The biogas system cost $4.5 million in materials, labour and design fees. Total annual revenue is projected at $1.9 million with $900,000 from biogas sales and $1 million from the sale of electricity.[3]

Annual operating and maintenance costs are presently $1.4 million (including annual depreciation and amortization totalling $450,000). Annual net income is projected at $500,000, yielding an annual cash flow of $950,000. Over the 10-year BOOT period, investor investment-return ratio (IRR) is estimated at 15%–17% per annum.

Anaerobic technology is new in Thailand, and not something SWI was willing to invest in it with its own financial resources. SWI did not invest directly in the POC, and so international finance had to be attracted. Such international financing usually demands higher project IRRs. Consequently, KWTE has implemented the project with the expectation of selling Certified Emissions Reduction (CER) credits for it under the Kyoto Protocol's proposed CDM. The CDM Project Design Document (PDD) developed by KWTE, Clean THAI, Waste Solutions and EcoSecurities, Ltd of Oxford, UK, submitted for review in November 2003, projects annual greenhouse gas reductions of 380,000 tonnes of CO_2 equivalent.[4] The Dutch INCaF fund, managed by the World Bank's IFC, has agreed to purchase KWTE's CERs once fully accredited. However, CER revenues will start flowing once the project receives Thai Host Nation Authorization on the project.

> About 40 Thai cassava plants – more than 50% of the country's total – offer sufficient economies of scale to warrant similar systems

REPLICABILITY

There are upwards of 70 cassava plants in Thailand, of which about 40 offer sufficient economies of scale to warrant similar systems. Clean THAI presently has 13 more biogas systems under development; construction on four of these is slated to begin in 2004, with several already underway. Together, these 14 systems will displace 33 million litres of HFO and over 130 GWh of grid-based electricity annually, offsetting 1.88 million tonnes of CO_2 equivalent each year, and saving factory owners $2.7 million in annual energy costs.

CONCLUSION

The KWTE biogas system has been a great success on several fronts, achieving impressive greenhouse gas reductions and demonstrating how the CDM can support project development in a sector with sufficient GHG mitigation potential. It also shows how strong returns can be generated for investors using the CDM, as well as significant cost reductions for the factory, and new employment opportunities in plant construction and operation. Operating as an energy service company has eliminated technology, financial and

Overview of the digester energy plant

management risks that can otherwise prevent factory owners from implementing turnkey systems.

Clean THAI has focused on the economic driver of energy cost savings to persuade Thai factory owners of the attractiveness of anaerobic digestion. Wastewater treatment efficacy is assured as well, but it is the energy cost savings that are persuasive, resulting in projects that deliver valuable renewable energy as well as required wastewater treatment, with substantial greenhouse gas mitigation included.

Clean THAI plans to employ the same business model and digester technology for additional cassava factories, for other organic waste streams, and in other countries.

Richard Plevin is a graduate student in Energy and Resources at the University of California, Berkeley. He recently returned from eight months in Thailand where he worked with the Thai Net Metering Project (www.netmeter.org).
Fax: +1 510 642 1085
e-mail: plevin@berkeley.edu

David Donnelly is the General Manager of Korat Waste-to-Energy, and a Principal of Clean THAI.
Fax: +66 2651 9904
e-mail: donnelly@cleanthai.co.th

NOTES

1. However, it was a net gain in land for SWI: the biodigester has eliminated the need for almost all of SWI's facultative ponds, freeing approximately 46.5 hectares of land for other productive purposes.
2. The KWTE biogas-handling system does not require an H_2S (hydrogen sulphide gas) scrubbing system because the cassava wastewater treated contains low sulphate levels, which translate into low-biogas H_2S levels, averaging less than 350 ppm.
3. No provision has yet been made for sales of thermal energy (heat recapture for wet cake drying) or compost/fertilizer, as these activities are still in the planning stage.
4. The Project Design Document can be found at: http://cdm.unfccc.int/methodologies/UserManagement/FileStorage/FS_942091788