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Biogas Application and Investment from North to South Asia

Green power and heat production from biogas is one of the most reliable and consistent forms of renewable energy. This paper examines the potential and successful conversion of various raw feedstocks to biogas.

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Abstract

Green power and heat production from biogas is one of the most reliable and consistent forms of renewable energy. Biogas can be produced from different substrates or raw feedstocks. This paper examines the potential and successful conversion of various raw feedstocks to biogas. Once the biogas is produced, the follow-on conversion to power and heat can provide very efficient utilization of the valuable biogas energy. This paper addresses the different feedstocks, the various biogas conversion technologies, and the different biogas generator set sizes and efficiencies for each application.

Biogas-to-power projects also represent great financial return opportunities if the risks are properly managed. We discuss an actual case where waste matter from the production of palm oil is converted to power and heat, including the deal structure, financial terms, and the payback and return on investment.

Introduction

Biogas is generated through the anaerobic digestion of organic matter. This can be done either under mesophilic (35 to 38°C) or thermophilic (50 to 55°C) conditions (Figure 1).

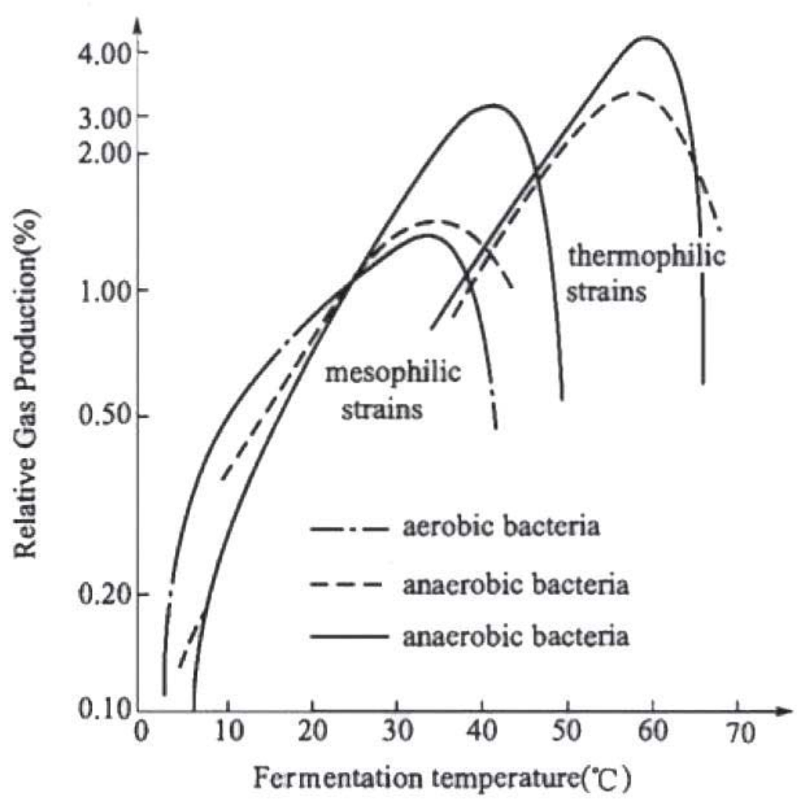

Figure 1: Impact of fermentation temperature on biogas yield rate.

There are several anaerobic digester or reactor designs – those commonly found in Asia are shown in Figure 2. We strongly recommend the use of steel tank designs with limited gas storage capacity to enhance both efficiency and safety. We also suggest a fully automated design to improve reliability and reduce the potential for human intervention or error.

Anaerobic Digester and Reactor Designs Found in Asia

Reactor Name	Characteristics	Range	Safety	Efficiency
Continuously Stirred Tank Reactor (CSTR)	Good for moderate to high total solids (TS)	TS<12%	High	High
Upward Flow Anaerobic Sludge Blanket (UASB)	Good for wastewater with low to moderate COD	COD<30,000 mg/l suspended solids < 1,000 mg/l	High	High
Covered in Ground Anaerobic Reactor (CIGAR)	Good for moderate to high COD (or low TS)	TS < 3%	Low	Low

Figure 2: Typical anaerobic digester designs and characteristics.

The basic feedstock or required production capacities for various agricultural byproducts and livestock manure are listed in Figure 3.

Feedstock	Volume or Count	Typical Unit	Waste Name	Suggested Biogas Reactor Technology
Cassava	70	TPD of starch	Wastewater	Mesophilic EGSB or UASB
Cassava	70	TPD of Starch	Pulp or Wetcake	Thermophilic CSTR
Cassava	40	TPD of Ethanol	Stillage	Thermophilic CSTR
Palm	30	TPH of FFB	POME	Thermophilic CSTR
Dairy, Cow	10,000	Head	Manure	Mesophilic CSTR
Dairy, Buffalo	13,000	Head	Manure	Mesophilic CSTR
Beef Cattle	15,000	Head	Manure	Mesophilic CSTR
Sow	100,000	Head	Manure	Mesophilic CSTR
Layer/Broiler	1,000,000	Head	Manure	Mesophilic CSTR
Food Waste	100	TPD of Waste (at 12-15% TS)	Restaurant Disposal	Mesophilic CSTR
Sorted Municipal Solid Waste	125	TPD of Waste (at 25-35% TS)	Kitchen Disposal	Mesophilic CSTR
Industrial	28	TPD of COD	Wastewater	Mesophilic or Thermophilic CSTR
Sewage	850	TPD (at 6% TS)	Surplus Activated Sludge	Mesophilic CSTR
Napier Grass	100	Hectare	Fresh Grass	Mesophilic CSTR

Figure 3: Typical feedstock or process requirements for the production of 1 eMW of Power.

It is of paramount importance to understand that in biogas reactor designs, there is no such thing as one-size-fits-all. Each feedstock needs to be managed differently, and each needs different pretreatment before it goes into the digester. The criticality of pretreatment cannot be underestimated. Additionally, if the biogas is to be further utilized, then post-treatment is required, generally involving the reduction of hydrogen sulfide (H_2S) and moisture. This can be easily managed with automated, properly sized and reliable scrubbers and dryers.

Furthermore, each plant needs to be sized differently if there are issues with seasonality of the feedstock. Proper design and optimization of the biogas plant size and type are keys to technical, commercial and financial success and project continuity. An overall view of a biogas-to-power plant is shown in Figure 4.

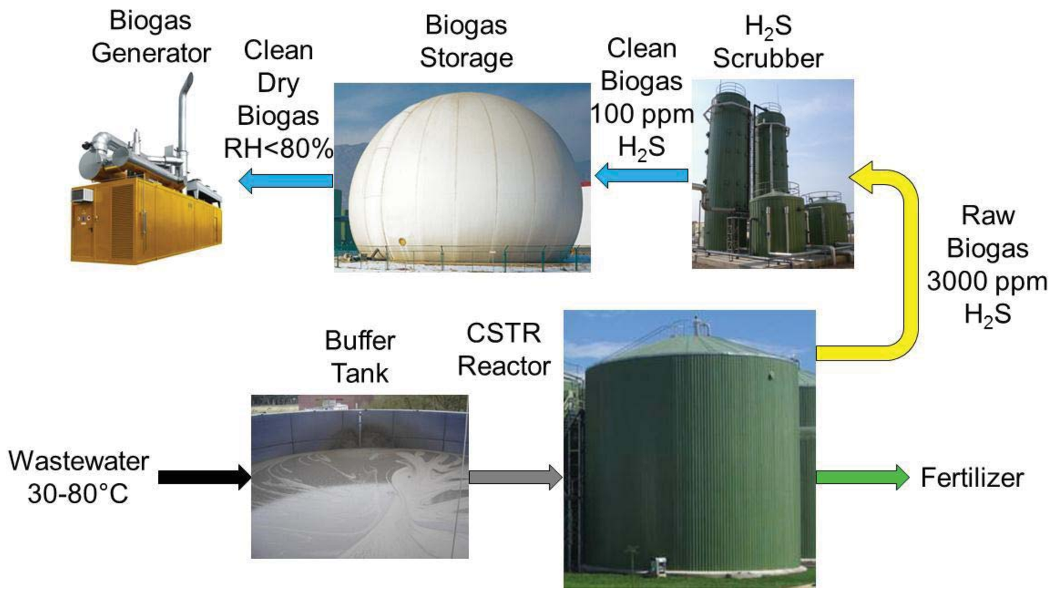

Figure 4: Typical process flow diagram with major subsystem layout for CSTR biogas-to-power generation system.

We have discussed the basics of biogas generation systems to a great extend in Lee et al (2014). In general, a mesophilic or thermophilic continuously stirred tank reactor (CSTR) steel tank design provides high robustness and reliability. Initial capital expenditures (CAPEX) maybe be higher, but in the long run, with a proper, safer, more efficient, more reliable and more robust design, the payback should be quicker and more consistent.

Biogas-to-Power Applications

Fundamental to the financial feasibility of any project is uptime. More uptime (run time) means more revenue or savings. The Impact of climate and seasonality, feedstock consistency and conditions, and ease of operation and maintenance have significant impacts on uptime and cannot be overstated.

Discussion with many successful project owners reveals that one of the keys to project success and high uptime is careful and professional project management from the start to the end of the project life. Key stakeholders must have a vested interest to see the project through from end to end. The project manager must have sufficient management skills to ensure that the technology is working and that the commercial and financial aspects of the project are also executed in a timely and contractual fashion. According to many, projects seldom fail due to technology. Projects fail even with the best technologies, if proper project planning, execution and management are not in place.

Lastly, it is very critical to ensure that the equipment suppliers and their service teams are engaged in the routine maintenance and protection of the operational assets. Proper preventive maintenance by certified technicians and service engineers is extremely critical to project success. Use of ill-qualified service teams may have significant negative impact on the product warranty and performance guarantee, leading to unwanted downtime and loss of revenue.

Moving on, we start with North Asia and discuss three types of substrates used for biogas-to-power generation. Then we move to Southeast Asia and discuss five more biogas-to-power applications. This discussion covers a wide range of feedstock and substrate types and various technologies used to convert the organic waste to green biogas power and heat.

North Asia

The typical environmental conditions in North Asia – low ambient temperatures during the winter months – mandate the use of engine waste heat recovery systems to maintain the operational health of the anaerobic digesters. By recovering the waste heat in a combined heat and power (CHP) configuration, total system efficiencies can reach over 80%. Net gas power efficiency (NGPE) can be as high as 2.2 kWh/Nm^3 of biogas production. The high efficiency and reliable conversion of biogas energy to power and heat, combined with a favorable feed-in-tariff (FiT) or subsidies, can make project financial payback extremely quick.

1. Hokkaido, Japan

This project uses dairy cattle manure trucked in from the surrounding farms to produce biogas. The digester technology is a thermophilic CSTR from Mitsui Ship Building and Engineering (MES). This biogas system is one of a kind in being located in an extremely cold climate. Typical winter operational ambient temperatures are well below -10 degrees C. This extreme cold is a major challenge to keeping the anaerobic system working efficiently. Project specifics:

Dairy cow count:	4,500 head
Daily manure tonnage:	280 tons/day
Daily biogas production estimate:	13,000 Nm^3/d, 55% CH_4
Digester type:	Thermophilic CSTR
Biogas use:	Power and hot water
Genset configuration:	2+1x Cat© CG132-12, 600 ekW each
Electrical and overall efficiencies:	42% power only, 82% CHP
Net electrical generation efficiency:	2.2 kWh/Nm^3 of biogas
Power use:	Export to Hokkaido grid at JPY39/kWh
Key challenge:	Extreme cold climate

Figure 5 shows the overall biogas-to-power plant layout.

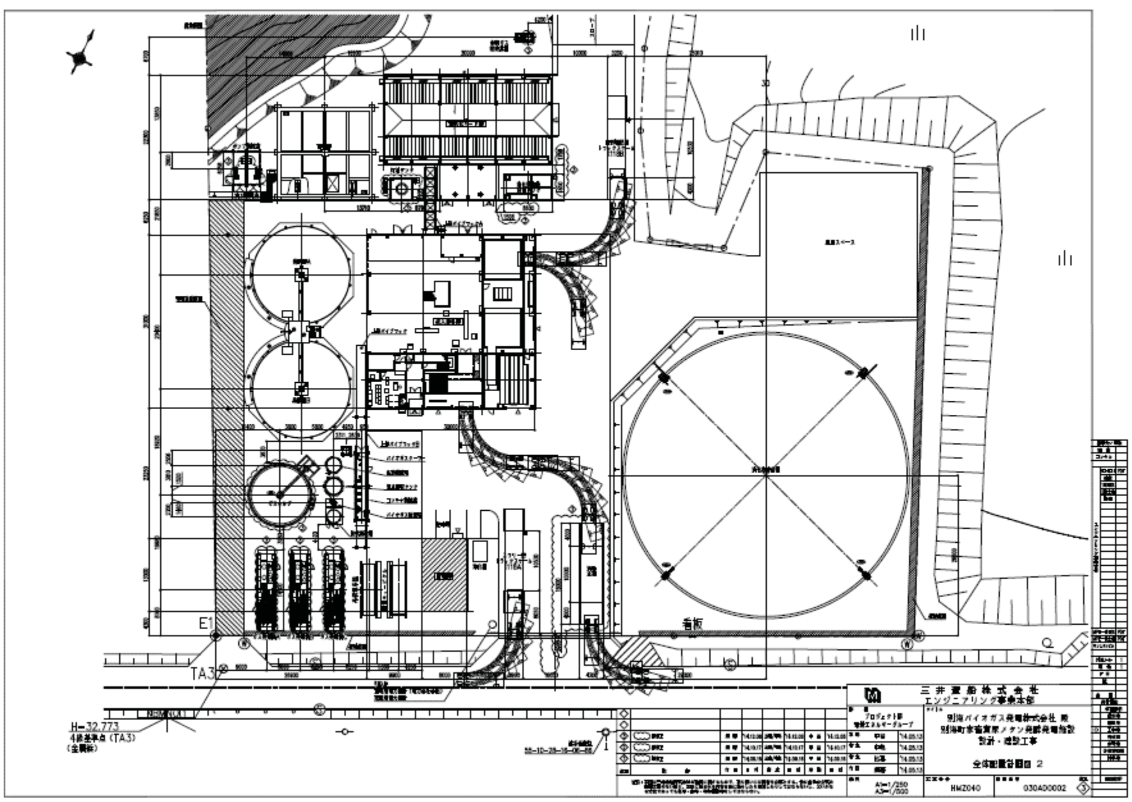

Figure 5: MES Hokkaido biogas-to-power project: Basic layout.

Figure 6 shows the biogas CHP genset installation. The complete system is factory supplied in an 85 dBA at 1 m sound-attenuated enclosure.

Figure 6: MES Hokkaido biogas-to-power project: Cat CG132-12, 3x 600 ekW biogas generator sets in containerized sound enclosure (85 dBA at 1 m).

As shown in Figure 7, both the exhaust waste heat and the high-temperature water loop waste heat are used to produce hot water at 80°C for maintaining the anaerobic digester temperature year round.

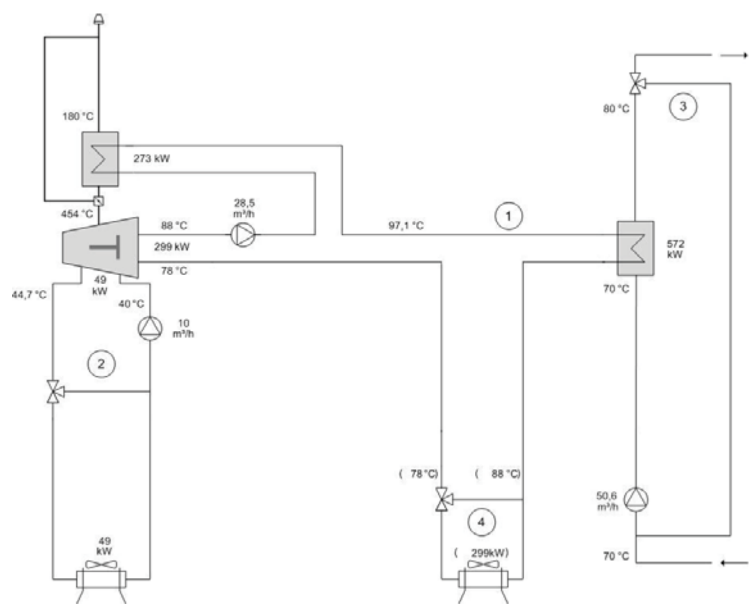

Figure 7: MES Hokkaido biogas-to-power project: Biogas CHP plant process flow diagram.

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2. HeBei Province, People's Republic of China

This project, three hours outside Beijing, uses pig manure to produce biogas. The digester technology is a mesophilic CSTR from HangZhou Energy & Environmental and Engineering (HEEE). Project host is Yu Feng Jing An (YFJA). The YFJA renewable energy project is one of the largest swine-manure-to-biogas-to-power projects in Northern China with power export and sales to the national grid. Being only three hours outside Beijing, it is a key showcase job and has received national and international attention. Project specifics:

Sow and finisher count:	200,000 head
Daily manure tonnage:	~200 tons/day (2 kg/day/head)
Daily biogas production	15,000-18,000 Nm^3/d, 55-60% CH_4
Digester type:	Mesophilic CSTR
Biogas use:	Power and hot water
Genset configuration:	2x Cat CG170-12, 1,200 ekW each
Power use:	Export to HeBei grid
Electrical and overall efficiencies:	42% power only, 83% CHP
Net electrical generation efficiency:	2.2 kWh/Nm^3 of biogas
Payback:	~5 years
Internal rate of return:	~20%
Key challenge:	Cold climate

Figures 8 and 9 show the overall biogas-to-power plant layout.

Figure 8: YFJA HeBei Province project: Basic layout.

Figure 9: YFJA HeBei Province project: Overall view of site.

Figure 10 shows the biogas generator sets CHP installation in a powerhouse.

Figure 10: YFJA HeBei Province project: Cat CG170-12, 2x 1,200 ekW biogas gensets view.

As shown in Figure 11, both the exhaust waste heat and the high-temperature water loop waste heat are used to produce hot water at 90°C for maintaining the anaerobic digester temperature year round.

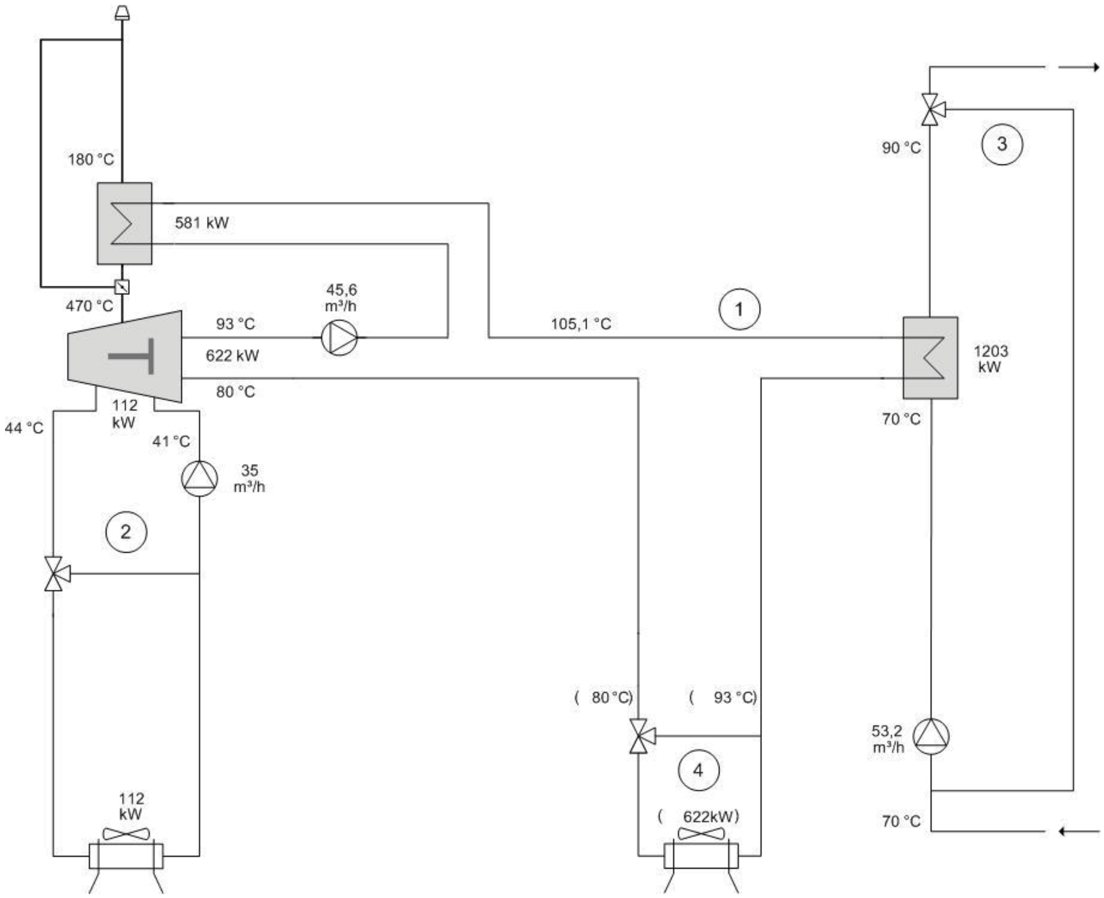

Figure 11: YFJA HeBei Province project: Biogas CHP plant process flow diagram.

3. Tainan, Taiwan

This project uses chicken layer (hen) manure to produce biogas. The digester technology is a mesophilic CSTR from HangZhou Energy & Environmental and Engineering (HEEE). Project host is ShiAn Farms. ShiAn is one of the largest organic chicken egg layer farms in Taiwan. It uses humane and environmentally friendly technologies and approach in the egg production processes. The digestate or discharge from the anaerobic digester is used as liquid and solid fertilizer for nearby produce (fruit and rice) farming. The land application of the digestate is a first in Taiwan. ShiAn has received several national and international awards for sustainability and humane farming. It is a role model site worthy of recognition and a visit. Project specifics

Hen count:	550,000
Daily biogas production	~8,000 Nm^3/d, 55-65% CH_4
Digester type:	Mesophilic CSTR
Biogas use:	Electric power and hot water
Genset configuration:	2x Cat CG132-08, 400 ekW each
Power use:	Internal use, limited grid export NTD3.3803/kWh
Electrical and overall efficiencies:	41% power only, 82% CHP
Net electrical generation efficiency:	2.1 kWh/Nm^3 of biogas
Payback:	~7 years
Internal rate of return:	~14%
Key challenges:	Amino poisoning from chicken manure

Figures 12 to 14 show the overall biogas-to-power plant layout and overall site view of the biogas system.

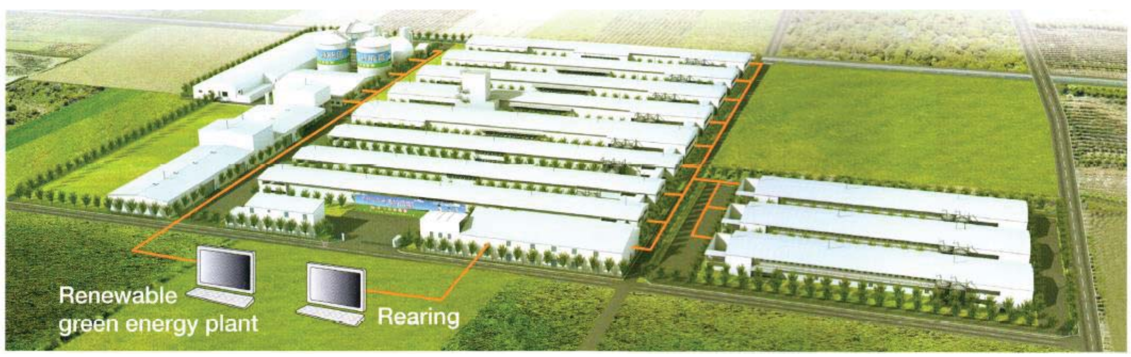

Figure 12: ShiAn Tainan Project: Site overview.

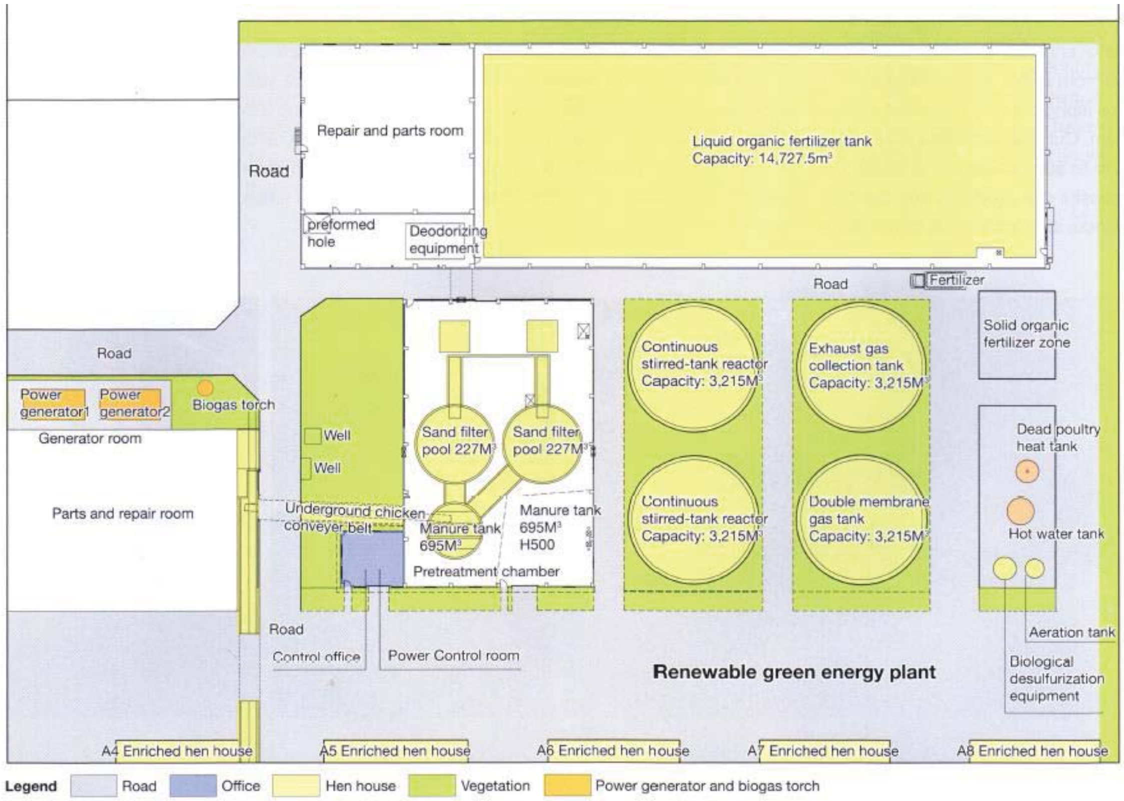

Figure 13: ShiAn Tainan Project: Plant layout.

Figure 14: ShiAn Tainan Project: CSTR biogas system with double-membrane biogas storage and H_2S scrubber system.

As shown in Figure 15, there is no amino stripping system required in this system. This is the key feature in the HEEE pure chicken manure anaerobic digester design.

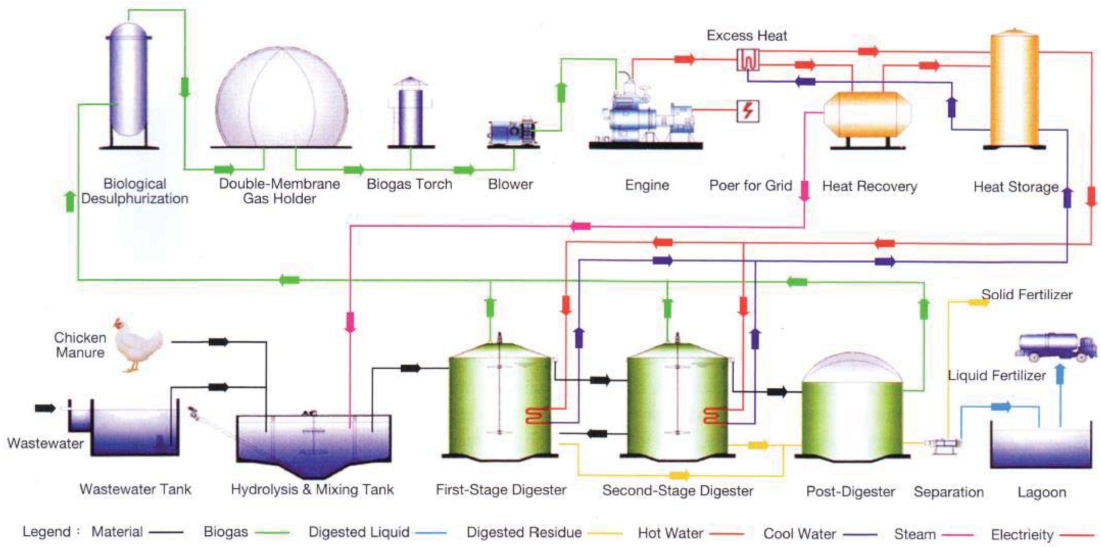

Figure15: ShiAn Tainan Project: Total plant process flow schematic diagram.

Figures 16 and 17 show the biogas generator set CHP installation in locally made sound enclosure systems designed to 54 dBA at 10 m.

Figure 16: ShiAn Tainan Project: Cat CG132-08, 2x 400 ekW biogas generator sets in 54 dBA (10 m) sound enclosure.

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Figure 17: ShiAn Tainan Project: Cat CG132-08, 2x 400 ekW biogas generator sets in 54 dBA (10 m) sound enclosure.

As shown in Figure 18, both the exhaust waste heat and the high-temperature water loop waste heat are used to produce hot water at 90°C for maintaining the anaerobic digester temperature during the colder winter months in Taiwan.

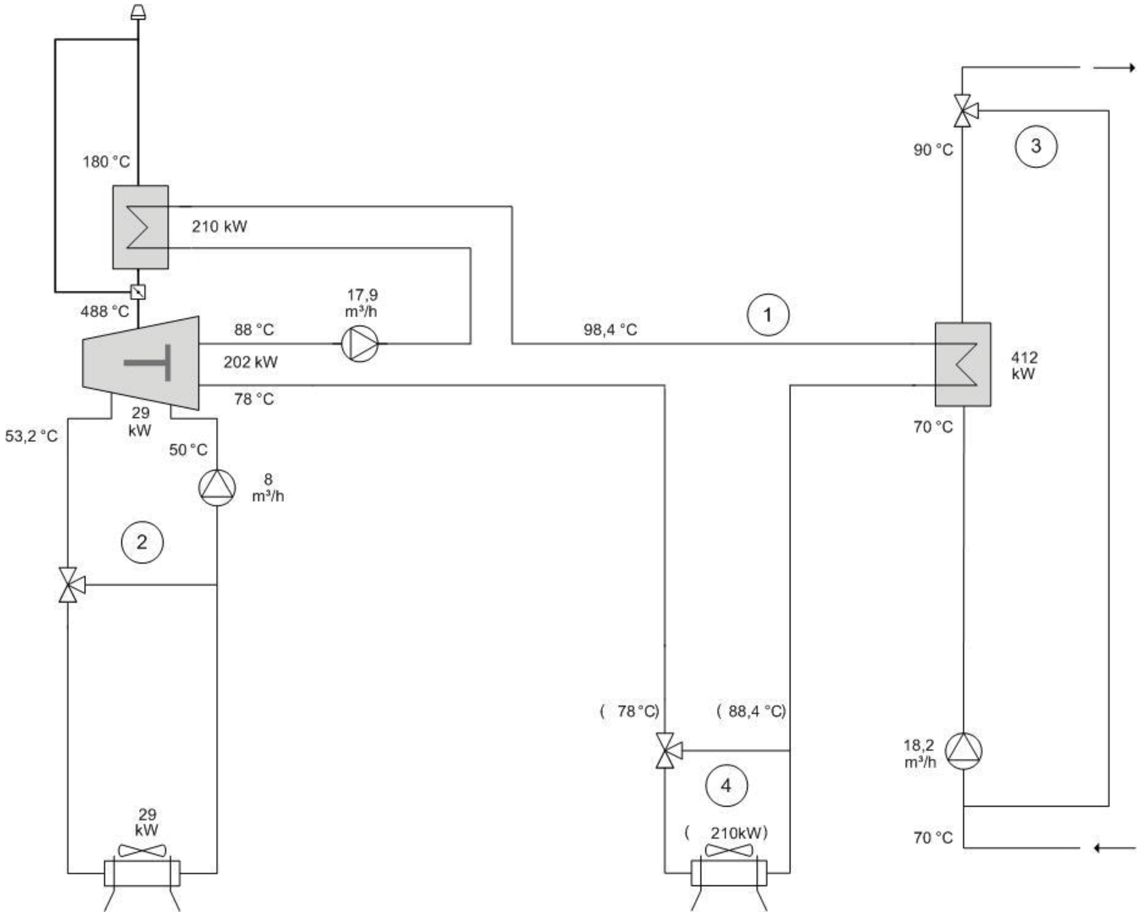

Figure 18: ShiAn Tainan Project: Biogas CHP plant process flow diagram.

Southeast Asia

Five projects in Southeast Asia demonstrate the use of three different substrates for biogas-to-power generation. The generator sets are custom designed for hot and humid conditions in Southeast Asia, with daily average temperature as high as 35 to 38°C and 80 to 90% humidity.

1. Singapore

This project uses chicken layer (hen) manure to produce biogas. In response to the Singapore government's efforts to raise the local egg production, the owner has granted the investor a design-build-own-operate-transfer (DBOOT) concession. The digester technology is a mesophilic CSTR from Anaergia. The host is Seng Choon Chicken Farm (SCCF).

Project specifics

Hen count:	500,000 (potential to expand to 1,000,000)
Daily manure tonnage:	80 tons/day
Daily biogas production:	~12,000 Nm^3/d, 55% CH_4
Digester type:	Mesophilic CSTR
Biogas use:	Power and hot water
Genset configuration:	2x Cat CG170-12, 1,200 ekW each
Power use:	Internal; balance export to grid at SGD0.16/kWh
Payback	~5 years
Internal rate of return:	~20%
Key challenge:	Reduce gas H_2S from 1,000 ppm to 150 ppm

A built-in H_2S desulphurization system is provided in the fermenter design. The system monitors the biogas composition constantly and automatically introduces air into the freeboard space. With additional substrates and other materials, this allows bacteria formation, removing the H_2S biologically. The process takes a few weeks to stabilize, dependent of H_2S concentration, substrate and bacteria growth.

Figures 19 to 22 show the overall biogas-to-power plant layout and overall site view of the biogas system.

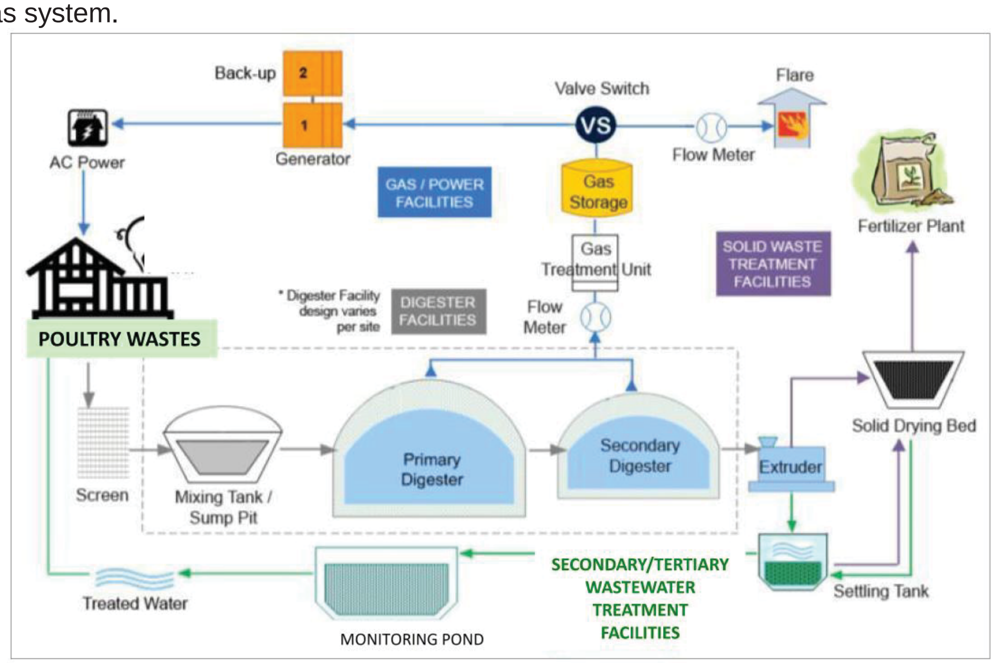

Figure 19: Anaergia SCCF Singapore project: Process flow diagram.

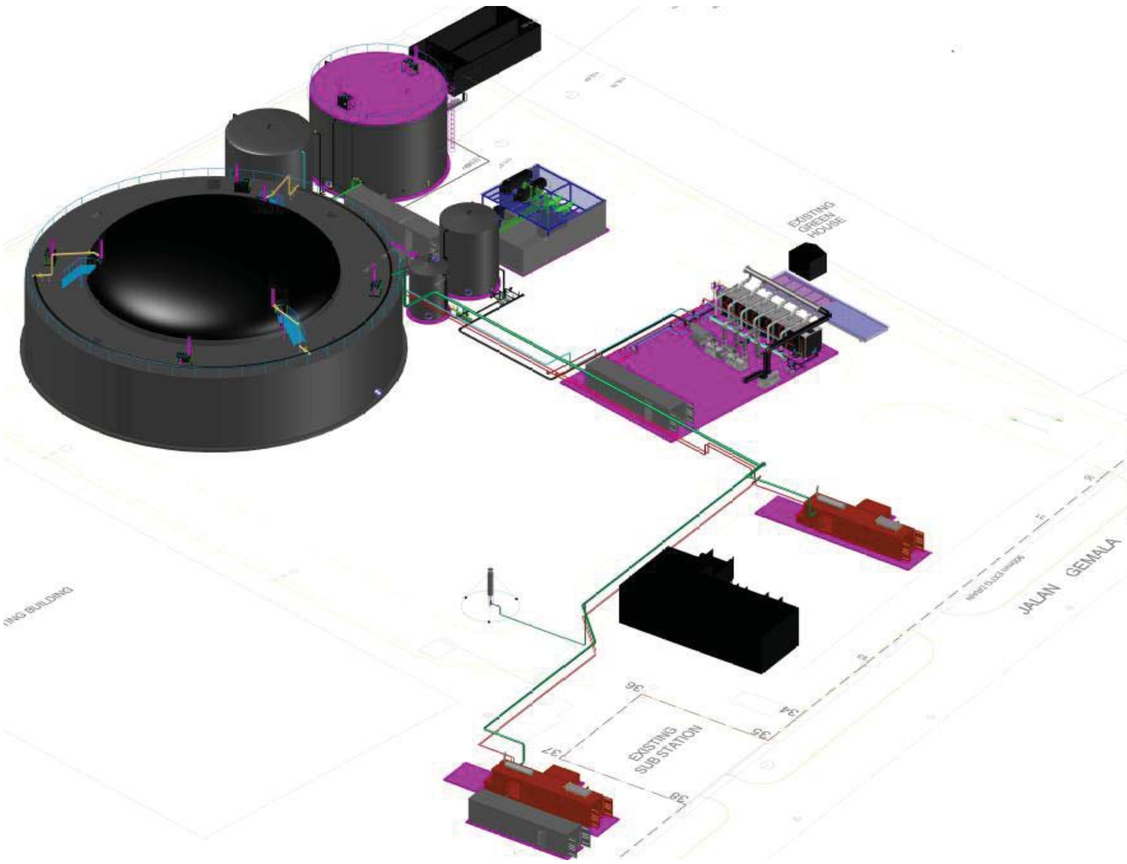

Figure 20: Anaergia SCCF Singapore project: Plant layout diagram.

Figure 21: Anaergia SCCF Singapore project: Site overview.


Figure 22: Anaergia SCCF Singapore project: Triton anaerobic digester is on the right.

Figure 23 shows the biogas CHP generator set installation. The complete system is factory supplied in an 85 dBA at 1 m sound enclosure.

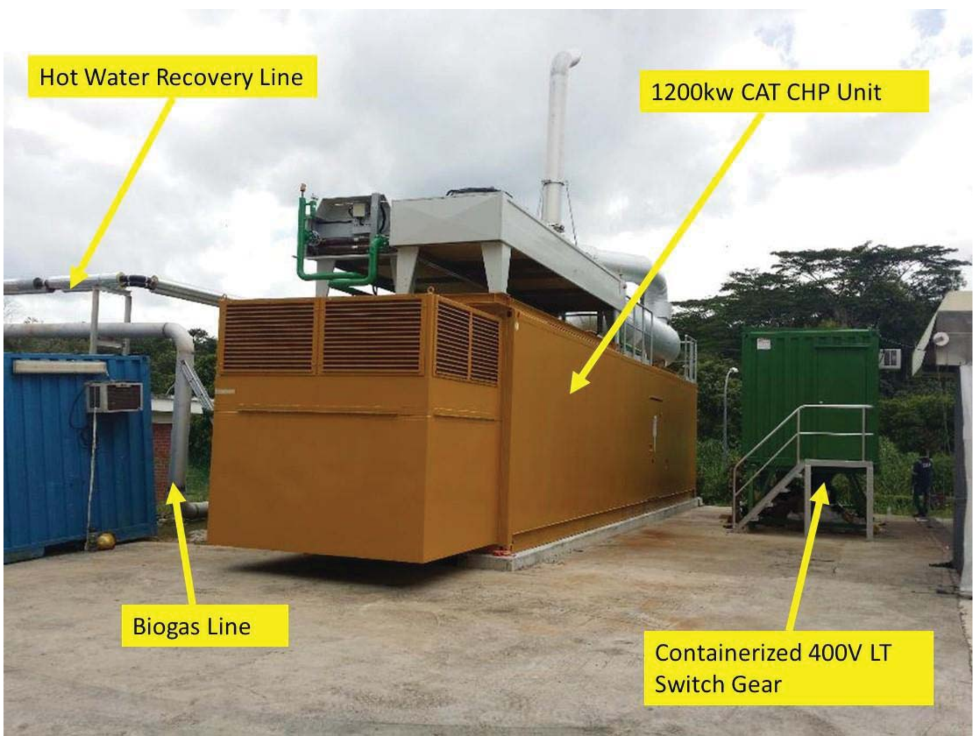

Figure 23: Anaergia SCCF Singapore project: Cat CG170-12, 1,200 ekW biogas generator set in 85 dBA (1 m) sound enclosure with full CHP unit on top of the container.

2. Kemayan, Pahang, Malaysia

This project uses palm oil mill effluent (POME) to produce biogas. The digester technology is a mesophilic concrete tank combined high concentration reactor/CSTR and upflow anaerobic sludge blanket (UASB) type from Tenaga Tiub (TT). The site is located in Kemayan, Pahang, Malaysia and the host is Jeng Huat Palm Industries. Project specifics:

Crude palm oil mill size:	40 tons/hour
Daily biogas production	~13,000 Nm^3/d, 63% CH_4)
Digester type:	Mesophilic combined HCSR, CSTR and UASB in series
Biogas use:	Power only
Genset configuration	1x Cat CG170-12, 1,200 ekW
Power use:	Export to grid at RM0.4669/kWh
Payback:	~5 years
Pre-tax internal rate of return:	19.5%
Key challenge:	Seasonality

Figures 24 to 26 show the overall biogas-to-power plant layout and overall site view of the biogas system.

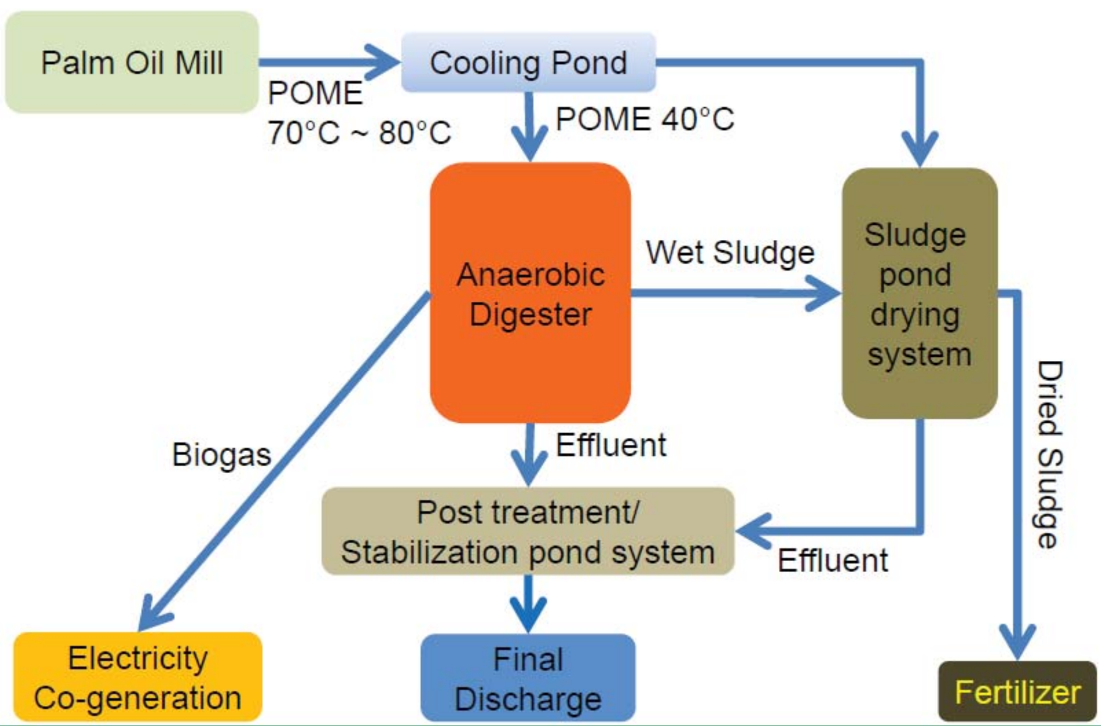

Figure 24: Jeng Huat Kemayan project: Process flow schematic diagram.

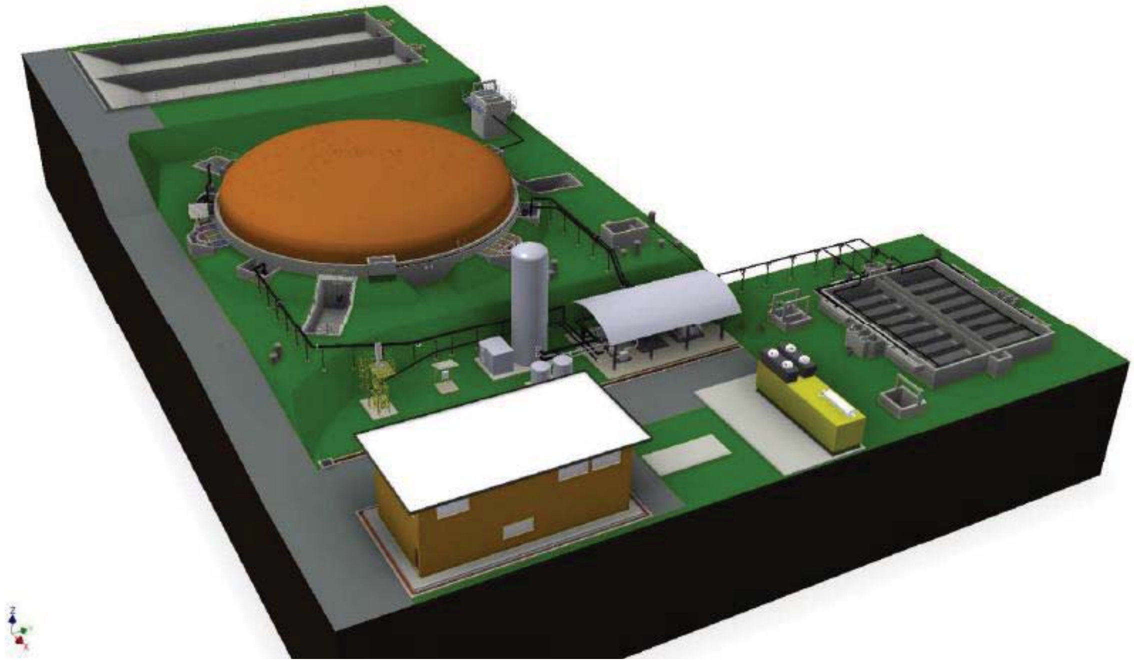

Figure 25: Jeng Huat Kemayan project: Site overview.

Figure 26: Jeng Huat Kemayan project: Site overview.

3. Kanchanaburi, Thailand

This project uses wastewater from cassava starch production to produce biogas. The digester technology is a mesophilic modified covered lagoon from Chaowanee Thai biogas Limited Partnership. The host is Thai Quality Starch (TQS). Project specifics:

Cassava mill size	200 tons/day native starch production
Daily biogas production	~24,000 Nm^3/d, 55% CH_4
Digester type	Mesophilic modified covered lagoon
Biogas use:	Heat and power
Genset configuration:	1x Cat G3516A+, 1,100 ekW
Power use:	Internal, offsets grid power at THB0.45/kWh
Payback:	3.5 years
Internal rate of return:	28%
Key challenges:	Seasonality and shortage of feedstock

The site overview is shown in Figure 27. The covered lagoon design typically takes up much more space than a CSTR digester, and the high-density polyurethane (HDPE) cover is quite large in general. The HDPE cover must be routinely inspected for leaks, but it is relatively inexpensive.

Figure 27: TQS Kanchanaburi project: Lagoon digesters.

The powerhouse design is shown in Figure 28. Heat is recovered through a heat recovery steam generator (HRSG). The medium-pressure (roughly 12 bar gauge saturated) steam is used for starch powder drying. This CHP configuration is typical of most cassava starch wastewater-to-biogas-to-CHP applications.

Figure 28: TQS Kanchanaburi project: Cat G3516A+, 1,100 ekW biogas generator set.

4. Prachuap Khiri Khan, Thailand

This project also uses palm oil mill effluent (POME) to produce biogas. The host is Palm Power Green (PPG). The digester technology is a mesophilic modified covered lagoon from HEMCO. The typical applications for the fresh fruit bunch (FFB) in Thailand includes production of crude palm oil (CPO), fibers and shells for biomass power plants, as well as biogas for power plants, as shown in Figure 29.

Project specifics:

Crude palm oil mill size:	45 tons/hour
Daily biogas production:	~25,000 Nm^3/d, 55% CH_4
Digester type:	Mesophilic modified covered lagoon
Biogas use:	Power only
Genset configuration:	3x Cat G3516A+, 1,100 ekW each
Power use:	Export to grid at THB0.45/kWh
Payback:	4 years
Internal rate of return:	25%
Key challenges:	Seasonality and shortage of feedstock

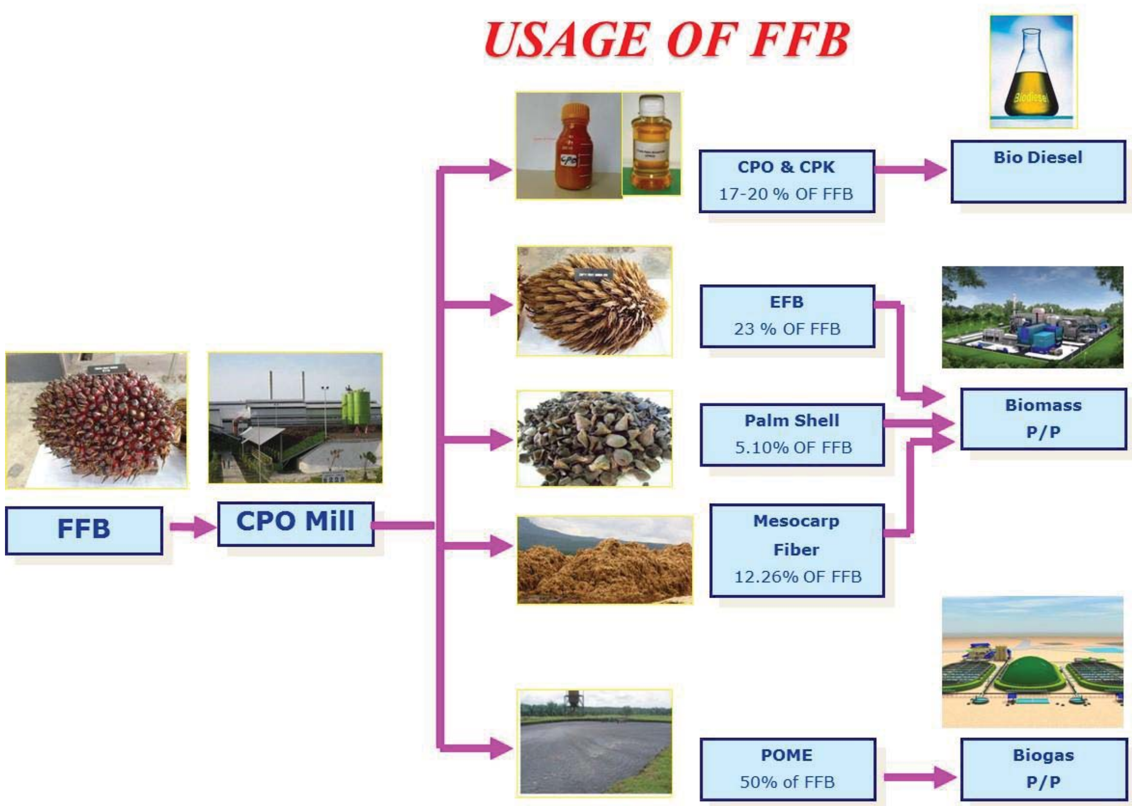

Figure 29: Typical usage of oil palm fresh fruit bunch (FFB).

Figures 30 and 31 are the overall plant layout and the site overview. The modified lagoons have cement bases and are partially below ground level. Stirring occurs within the modified lagoon, thus reducing the lagoon footprint.

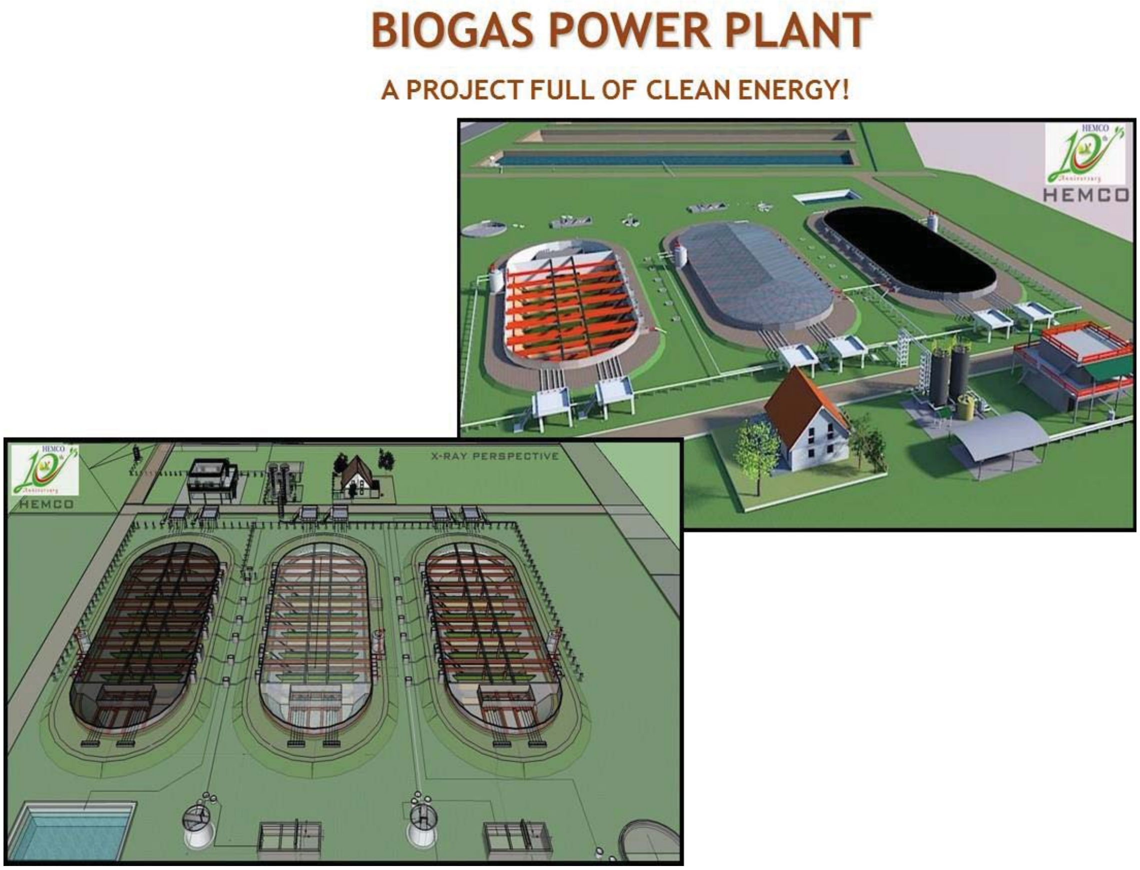

Figure 30: HEMCO PPG site layout and concept.

Figure 31: HEMCO PPG site overview.

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The biogas generator set and powerhouse design is shown in Figure 32. There is no heat recovery for this application, as is the case in most POME-to-biogas-to-power applications.

Figure 32: HEMCO PPG site overview and powerhouse design.

5. Krabi, Thailand

This project also uses palm oil mill effluent (POME) to produce biogas. The digester technology is a mesophilic modified covered lagoon from AsiaBiogas (ABC). The project was developed on an 8-year build-own-operate-transfer (BOOT) basis by ABC with equity co-investment by Metro Machinery (MetroCat), sole distributor of Caterpillar equipment in Thailand, with 70% senior debt provided by Caterpillar Power Finance.

Project specifics:

Crude palm oil mill size:	45 tons/hour
Daily biogas production:	~12,000 Nm^3/d, 55% CH_4
Digester type:	Mesophilic modified covered lagoon
Biogas use:	Power only
Genset configuration:	2x Cat CG170-12, 1,200 ekW each
Power use:	Export to grid at THB0.45/kWh)
Payback:	5 years
Internal rate of return:	20%
Key challenges:	Seasonality and shortage of feedstock

The project site overview is shown in Figure 33. This is a traditional modified covered lagoon, and the footprint is in general larger than tank-style designs.

Figure 33: ABC Krabi project: Overall view of site.

Financing Biogas to Power Projects: An Example

The Asia Biogas project at Krabi in Thailand provides one example of the various ways in which sound financing can be structured for biogas-to-energy projects. In this case, the financing package places the project company, Krabi Waste To Energy Co Ltd (KWTE), as the borrower with Cat Financial's local Thai subsidiary, Caterpillar Leasing Thailand Limited (CLTL), as the lender. CLTL has a local Thai lending licence and has a long track record of providing financial solutions in Thailand. CLTL has access to Thai Baht funding and provided KWTE with a Thai Baht-denominated loan. KWTE has a significant number of stakeholders and project participants in the overall commercial and technical project concept (Figure 34).

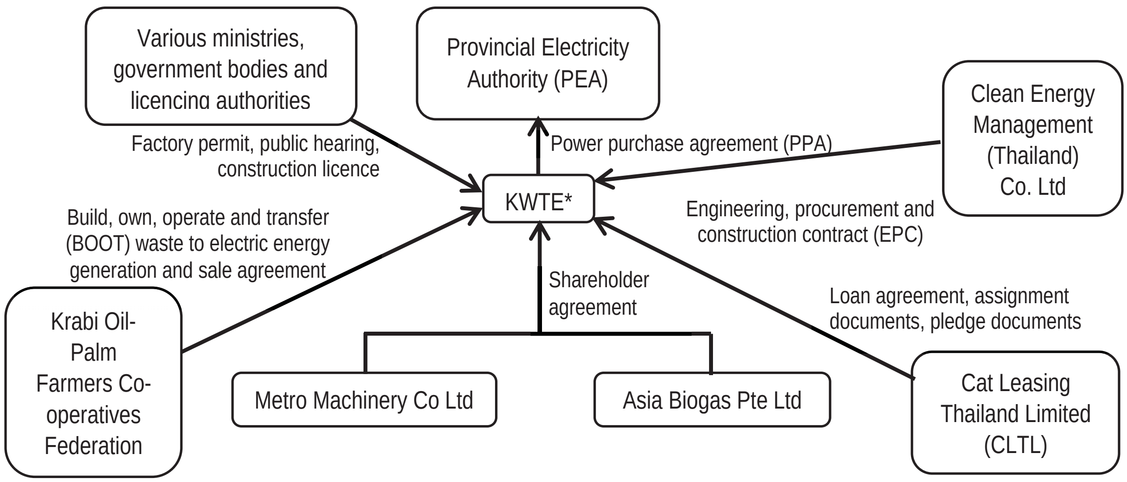

Figure 34: KWTE Project Structure and Relationships.

Funding Currency

The financing arrangement is set up as a project finance transaction with partial recourse during the construction period, estimated at one year. Due to the non-recourse nature of the loan, Cat Finance funded the loan currency in Thai Baht in order to match up with Thai Baht receipts from the Provincial Electric Authority (PEA).

Commercial Provisions for Project Finance

A project finance loan essentially transfers a substantial component of the commercial and financial risk to Cat Financial. In safeguarding its interests as the senior lender in the transaction, Cat Financial will be required to exercise some control over the various key project documents listed in the diagram above. In particular, the engineering, procurement and construction (EPC) contract and the build-own-operate-transfer waste-to-electric-energy generation and sale contract (BOOT contract) comprised significant commercial, technical and legal review for Cat Financial. As the project lender, Cat Financial needed to ensure that all contracts were well coordinated with each other and would avoid conflicting terms as well as uncovered gaps, commercially and technically.

BOOT Contract

The BOOT contract includes three key elements in the commercial model of the project – the land lease, commitment for the supply of wastewater for the biodigester, and compensation to the wastewater supplier. For the wastewater supply, Cat Financial required guarantee provisions in the BOOT contract to ensure that the base case amount of wastewater feedstock was contractually agreed and confirmed by both parties. The payout made to the supplier for its wastewater is based on a royalty payment calculated as a percentage of the electricity sales made by KWTE to the PEA under the power purchase agreement (PPA). The contract requires a reduction in the royalty percentage if the amount and concentration of wastewater, which is captured as the loading rate of the digester, falls below the guaranteed level. The cash not otherwise distributed to the supplier is used to replenish the shortfall in cash flow caused by insufficient wastewater. This also effectively aligns the financial benefits of the wastewater supplier with the project. This ensures a cooperative commercial arrangement between KWTE and the wastewater supplier.

EPC Contract

The EPC contract is between the EPC contractor, Clean Energy Management (Thailand) Co. Ltd (CEMT), and KWTE. CEMT is responsible for contracting with various suppliers to procure components for the biodigester, engaging civil works contractors, and managing the overall construction management schedule for KWTE. At the end of successful commissioning of the entire project, CEMT will hand over the project to KWTE to begin commercial operations. Analysis of infrastructure and renewable energy projects typically leads to the conclusion that the period from the beginning of construction to the early years of operation is the highest at-risk period. In order to better manage and reduce the financial risks during this period, Cat Financial required typical project finance provisions such as:

- A cost overrun bond (10% of total project cost) provided by the shareholders, Metro Machinery Co. Ltd. and Asia Biogas Pte Ltd., which is released at the time of commercial operations.
- A performance bond (10% of total project cost) provided by the CEMT to cover performance guarantees as set out in the EPC contract, which expires at the time of commercial operations.
- A warranty bond (10% of total project cost) provided by CEMT, which expires at the end of the first year of commercial operations.

Figure 34 below sets out the bond requirements by Cat Financial during the project.

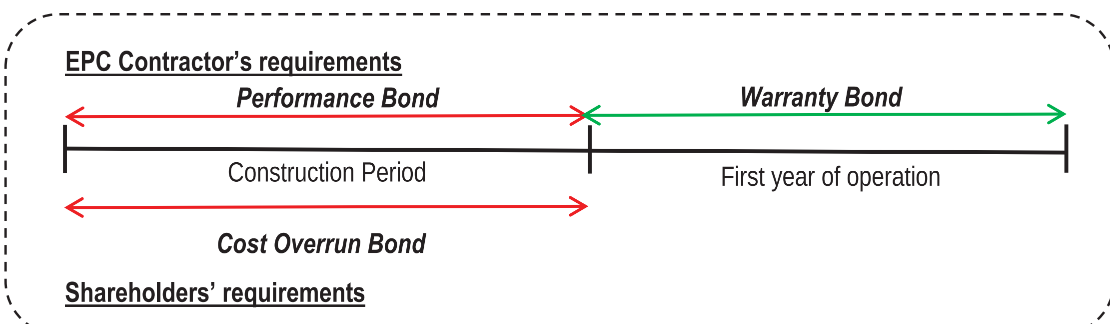

Figure 34: KWTE Project bond requirements.

Other relevant provisions required for the EPC contract for project finance include strict performance guarantees set out in the EPC contract, complete with schedule, emissions and performance points. Liquidated damages will be calculated accordingly during commissioning and testing to assess damages if KWTE opts to accept performance of the power plant from CEMT.

Soft Costs

Project finance transactions can be complex, with many parties taking on various roles and responsibilities. The process can take time and is expensive, resulting in significant soft costs. Various consultants, including legal, technical and financial, are needed to provide independent expert opinions that each element of the project is properly scoped, designed, coordinated and managed before the first dollar of debt can be funded. A project sponsor should approach a project with enough resources (money and time) to weather the delays that can result in any project development. Soft costs generally do not vary with the size of the transaction. Therefore smaller transactions in particular need to carefully manage these costs.

Loan Evaluation

Under project finance arrangements, the loan's primary credit support is based on the expected base case cash flows that will be generated from sales of electricity to the PEA, net of operating costs of the biogas power project, which include general biodigester and engine maintenance and overhauls of the engine when the gas engine has run a threshold number of run hours. The best way to represent project cash flows is via a detailed financial model that sets out the operating, commercial and financial parameters of the project in a clear, concise manner. The financial model should cover the planned operating regime of the power plant, the correct weighted average pricing formula used in determining its revenues, forecasts of future PEA prices relevant to the Very Small Power Producer (VSPP) program in Thailand, as well as how the operating regime and inherent gas quality impact operations and maintenance costs, staffing and parts requirements to keep the project operating over a substantial period, usually about 15 years. The operating cash flows of a biodigester power plant, which incorporate revenue and operating costs, will then be classified as Cash Flow Available for Debt Service (CFADS).

Accurately determining the right level of CFADS on a year-on-year basis in the financial forecast is crucial for a financier to find out how much leverage it can afford to provide for the project that is sustainable, beneficial to all parties and still provides a buffer for unexpected changes in performance of the project. The key drivers of the project, usually set out as assumptions in the financial model, were verified by commercial and technical specialists and consultants acting in the interests of Cat Financial.

Once the appropriate level of CFADS was confirmed, Cat Financial determined that a gearing level of 70% was sufficient for KWTE. Through its CFADS, KWTE provided a significant cash buffer of about 50% relative to the amount of cash required to service KWTE's debt on a quarterly basis.

Projects differ in terms of design, technical concept and complexity, as well as commercial application. Technical considerations have significant impact on the project's capital and operating cost profile, whereas commercial requirements can affect the project's cash generation ability. The projects that are the most financeable are therefore those that require the least cash to construct and will still generate the most cash at the design conditions.

Design and operational efficiency in plants translate into financial efficiency. The tables below set out how the analysis is done and concluded for a financeable project and an unfinanceable project based on project cash flows.

Figure 35 presents an example of the cash flow forecast for a financeable biogas project based on a minimum hurdle of 1.50x debt service coverage ratio, or a 50% buffer over debt service.

Financeable Biogas Project Cash Flow Forecast

Total project CAPEX	[US$MM]	5.0
Gearing	[%]	70%
Amount of loan	[US$MM]	3.5
Term of loan	[yrs]	7
Interest rate of loan	[%]	7.0%

Year		1	2	3	4	5	6	7	8	9	10
Electricity Revenues	[US$MM]	2.0	2.1	1.7	3.0	1.9	2.0	2.0	2.1	2.1	2.1
Operating Costs	[US$MM]	(0.6)	(0.8)	(0.2)	(0.5)	(0.9)	(0.7)	(0.3)	(0.1)	(0.9)	(0.9)
Cashflow Available for Debt Service	[US$MM]	1.4	1.3	1.5	2.5	1.0	1.3	1.7	2.0	1.2	1.2
Debt Service - Principal	[US$MM]	0.4	0.4	0.5	0.5	0.5	0.6	0.6	-	-	-
Debt Service - Interest	[US$MM]	0.2	0.2	0.2	0.2	0.1	0.1	0.0	-	-	-
Total Debt Service	[US$MM]	0.6	0.6	0.6	0.6	0.6	0.6	0.6	-	-	-
Cashflow Available for Debt Service	[US$MM]	1.4	1.3	1.5	2.5	1.0	1.3	1.7	2.0	1.2	1.2
Total Debt Service	[US$MM]	0.6	0.6	0.6	0.6	0.6	0.6	0.6	-	-	-
Debt Service Coverage Ratio	[x]	2.16	2.00	2.31	3.85	1.59	1.96	2.64	-	-	-
Minimum Debt Service Coverage Ratio	[x]	1.59									
Minimum Buffer above debt service	[%]	59.1%	**<----Since 59.1% is greater than a minimum 50% cash buffer, project is financeable.**								

Figure 35: Financial model that indicates financeable project conditions.

Figure 36 presents an example of the cash flow forecast for an un-financeable biogas project based on a minimum hurdle of 1.50x debt service coverage ratio, or a 50% buffer over debt service due to too much gearing (90%) applied to project as opposed to 70% in the earlier example. In this case, the project is capable of supporting up to 70% gearing.

Un-financeable Biogas Project Cash Flow Forecast

Total project CAPEX	[US$MM]	5.0
Gearing	[%]	90%
Amount of loan	[US$MM]	4.5
Term of loan	[yrs]	7
Interest rate of loan	[%]	7.0%

Year		1	2	3	4	5	6	7	8	9	10
Electricity Revenues	[US$MM]	2.0	2.1	1.7	3.0	1.9	2.0	2.0	2.1	2.1	2.1
Operating Costs	[US$MM]	(0.6)	(0.8)	(0.2)	(0.5)	(0.9)	(0.7)	(0.3)	(0.1)	(0.9)	(0.9)
Cashflow Available for Debt Service	[US$MM]	1.4	1.3	1.5	2.5	1.0	1.3	1.7	2.0	1.2	1.2
Debt Service - Principal	[US$MM]	0.5	0.6	0.6	0.6	0.7	0.7	0.8	-	-	-
Debt Service - Interest	[US$MM]	0.3	0.3	0.2	0.2	0.2	0.1	0.1	-	-	-
Total Debt Service	[US$MM]	0.8	0.8	0.8	0.8	0.8	0.8	0.8	-	-	-
Cashflow Available for Debt Service	[US$MM]	1.4	1.3	1.5	2.5	1.0	1.3	1.7	2.0	1.2	1.2
Total Debt Service	[US$MM]	0.8	0.8	0.8	0.8	0.8	0.8	0.8	-	-	-
Debt Service Coverage Ratio	[x]	1.68	1.56	1.80	2.99	1.24	1.52	2.05	-	-	-
Minimum Debt Service Coverage Ratio	[x]	1.24									
Minimum Buffer above debt service	[%]	23.8%	**<----Since 23.8% is lesser than a minimum 50% cash buffer, project is NOT financeable.**								

Figure 36: Financial model that indicates unfinanceable project conditions.

Project Drivers – Sensitivity of assumptions against IRR

The KWTE project contained a number of key drivers that determined the strength of the CFADS supporting the project. These included a high level of availability, a strong renewable tariff provided by the Thai authorities under the VSPP scheme, and an affordable operations and maintenance budget that supports the high availability of the project based on engineering estimates. Figure 37 below sets out the change required in a project assumption to effect the same change in the internal rate of return (IRR) of the KWTE project.

KWTE Project Assumptions and Resulting Internal Rate of Return (IRR)

Assumption	Units	Change in assumption to affect 1% change in IRR	Percentage change in assumption to affect 1% change in IRR
Electricity Tariff	THB/kWh	0.05	1.5%
Operating Days per year	days	4	1.6%
Wastewater flow per day	m3/day	9	1.7%
Wastewater chemical oxygen demand	mg/l	1273	1.8%
Capital expenditure	THBMM	2.9	1.9%
Operating expenditure per year	THBMM/yr	0.6	5.4%
Debt Gearing	% of total project CAPEX	4.1%	5.8%
Debt Term	years	1	14.3%
Debt Interest Rate	%	0.9%	15.3%

Figure 37: Project sensitivity analysis.

For clarity, the feedstock provided by the wastewater supplier to KWTE is free of charge. Operating expenditure per year includes all non-feedstock-related operating costs, including engine and biogas system maintenance and labor to operate both the engine and biodigester. This table suggests that the tariff and uptime availability (or operating days) are key drivers of financial performance of a biogas plant. As an example, losing four days of operations will slice off 1% of IRR from the base case of the project. Using that as a simple rule of thumb, projects that have a significant level of outages of three months or more may lose about 22 percentage points of IRR, which could easily wipe out the return of most infrastructure projects. The high degree of sensitivity to operating hours also means that a great deal of contingency planning and project resources need to be centered upon maintaining the biogas project at its optimal run hours, with emphasis placed on the availability of trained personnel to ensure smooth operations, spare parts availability to support ad hoc maintenance requirements, and proper planning and monitoring of the plant and feedstock.

The high IRR sensitivity explains the popularity of the VSPP program in Thailand. With a strong track record over the past 10 years, investors take a significant degree of comfort in the stability of the program. This has incentivized continued growth in the Thai biogas sector and has built confidence among investors that the IRRs promised in development projects in Thailand are achievable over the long run.

On the other hand, this table also suggests that the role of the interest on the loan is one of the smallest drivers of value in a financed biogas project. Operating expenditures, being a smaller determinant of CFADS, also move the IRR needle by a smaller amount compared to the revenue drivers. For projects with a greater level of technical sophistication that may require a larger operating expenditure base than the KWTE project, operating expenditures may be more sensitive than IRR in this example. Also, if the feedstock is purchased and will then be factored into operating expense, this will also increase the sensitivity of the project's IRR to this parameter.

Summary

Rigorously structured non-recourse or limited-recourse project finance transactions enable investors to leverage return on equity, while at the same time aligning the various parties involved in the project to maximize the probability of a successful outcome. It has been independently documented that project finance transactions, which cover many of the largest and most complex projects in the world, have a probability of default that runs close to low-investment-grade corporate debt. Although the soft costs of carrying out a project finance transaction can be quite high, the results of a well-structured deal will mutually benefit all of the participants in the project.

Conclusion

Biogas projects can be executed successfully so long as the engineering, commercial and financial designs are executed properly in a timely and cost-effective fashion. Developers must use the services of experienced, reliable and reputable biogas technology providers. Power and heat can be produced reliably from any biogas using Caterpillar biogas generator sets provided the biogas quality and quantity are well maintained. Experience demonstrates that the fundamental factor influencing success is the proper management of the project and the people involved. The technologies available on the market generally will work, although some better than others. The key is to effectively manage the people executing, operating and maintaining the project. The critical point to remember is that the revenue and/or savings from any project are significantly a function of the kilowatt-hours and the quantity of heat generated. These in turn are a function of the hours of uptime, and thus a product of high-quality operation and maintenance.

References

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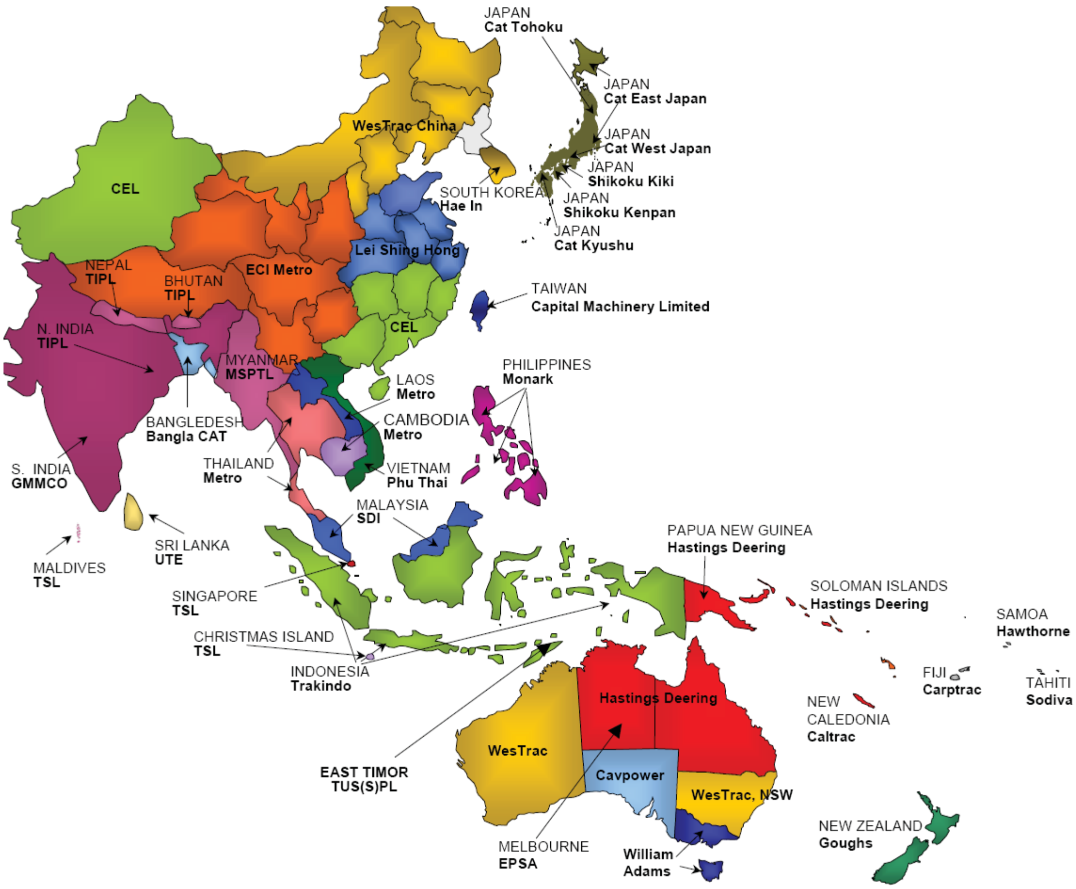
For 90 years, Caterpillar Inc. has been making sustainable progress possible and driving positive change on every continent. Customers turn to Caterpillar to help them develop infrastructure, energy and natural resource assets. With 2014 sales and revenues of $55.184 billion, Caterpillar is the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines and diesel-electric locomotives. The company principally operates through its three product segments - Construction Industries, Resource Industries and Energy & Transportation.

The Electric Power Division of Caterpillar Inc. operates out of the Energy and transportation product segment and is a world-leading manufacturer of diesel and gas engine generator sets, including a broad range of ancillary equipment for projects using biogas, landfill gas, syngas and coal mine methane. Cat biogas power plants are designed to operate under the harshest operating conditions and still provide the most efficient, reliable and robust operations. The adjacent table lists some example biogas generator set ratings for both 50 Hz and 60 Hz operating frequencies.

Biogas [1]					
Model	rpm	Electric Power [3] @ 1.0 pf	Efficiency [4]		
			Electrical Efficiency	Thermal Efficiency	Total Efficiency
		kW_e	%	%	%
G3306	1500	68	27.9	61.5	89.4
G3406	1500	107	28.8	60.7	89.5
G3412	1500	174	27.4	62.0	89.4
CG132-8	1500	400	42.8	42.1	84.9
CG132-12	1500	600	42.7	42.3	85.0
CG132-16	1500	800	42.8	42.3	85.1
G3516A	1500	1041	32.1	48.0	80.1
G3516A+	1500	1105	36.9	41.5	78.4
CG170-12	1500	1200	42.1	43.8	85.9
CG170-16	1500	1560	41.8	44.0	85.8
G3520C	1500	1982	39.4	45.7	85.1
CG170-20	1500	2000	42.9	43.3	86.2
CG260-12	1000	2830	42.3	40.8	83.1
CG260-16	1000	3770	42.9	43.4	86.3

Caterpillar also provides a worldwide network of dealers organized to provide expert operational and aftermarket support. Caterpillar and its dealers have invested heavily in the gas engine business to build local, in-country support infrastructure, providing clients with high-quality product support. The company has 178 dealers worldwide, more than 3,300 locations, with 162,000 employees. Dealers have invested more than US$20 billion in their local sales and service infrastructures. The accompanying map shows the Cat dealer presence in Asia.

Map of Caterpillar Power System Dealers: Asia Pacific



Caterpillar also provides financing and related services through its Financial Products segment. Caterpillar Power Finance, the company's captive finance organization, offers customized financing for with specific expertise in renewable electric power projects. The finance team has deep expertise in the industry and can work with renewable energy project developers to provide innovative, flexible financing solutions that help ensure project success.

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