MUNICIPAL WASTE WATER TREATMENT WORKS - BIOGAS TO ENERGY (CO-GENERATION)

City of Johannesburg

Project:

Northern Works Biogas to Energy

Generators at Northern Works
Image courtesy of *Jason Gifford*

With ever-increasing electricity prices, Johannesburg Water identified the need to cut back on its R100-million-a-year electricity bill for its waste water treatment works (WWTW)[1]. The biogas to energy project implemented at the Northern Works Waste Water Treatment plant produces electricity from biogas using cogeneration (or combined heat and power, CHP) gas engines. The electricity produced will reduce the need to purchase more expensive power from Eskom and soften the impact of rising electricity prices. The heat produced will also improve sludge management and increase biogas production. The project showcases the City's commitment to renewable energy.

Project Overview

Northern Works, which treats about 430-million litres of sewage a day, is Johannesburg's biggest WWTW and the site of its first biogas to energy project. As the plant was developed within an existing waste water works, involving the refurbishment of existing biogas digesters, no environmental impact assessment was deemed necessary.

The completed installation at Northern Works is owned by Johannesburg Water. It was built by WEC Projects, a private project developer, who also operates and maintains the plant. The plant has an installed capacity of around 1.1 MW electrical (MWe) using three CHP engines

The electricity produced is for own-use within the WWTW and runs in parallel with the incoming Eskom grid. It is capable of producing approximately 10% of the plant's power requirement. Currently, the biogas is collected from four digesters (additional digesters are being refurbished to allow maximum capacity). Once the balance of the existing digesters at NWWTW have been upgraded and all of the available sludge is treated anaerobically, the CHP plant will be able to produce up to 4.5MWe, covering approximately 56% of the power requirement. Provision has already been made to accommodate the additional gas engines at the CHP plant.

The heat energy produced by the CHP engines is used to pretreat the sludge which increases biogas production. Additionally, the heat improves sludge management, producing lower volumes of waste, and of far higher quality. This digested sludge (also known as digestate), is a valuable organic compost that could be sold to the agricultural sector by Johannesburg Water, even though this is not yet happening at this stage. The combined production and use of heat and power leads to an extremely high overall efficiency of the plant, in excess of 80% overall efficiency.

1 These were expected to rise to over R300-million a year within the next seven to ten years.

Key Project Data

Location

Northern Works

near Diepsloot, Gauteng

Technology

Anaerobic digestion of sludge through 4 digesters. Combined Heat and Power (CHP)

Key Actors

Owners

Johannesburg Water

Developers

WEC Projects (Pty) Ltd

Financers

City of Johannesburg capital expenditure

Some Indicators

Powered mid income households

(based on an average monthly consumption of 500 kWh)

830

(when biogas production optimised)
- **270** at the moment

Average output per MW installed

Not available

Capacity factor

[= ratio of actual output to potential output at full capacity, over the same period of time]

Not available

Capital cost per MW installed

(MZAR/MW installed)

R 32 million

(also includes some investment costs for the projected upgrades)

Operational cost per MW installed

(ZAR/MW installed/month)

Not available

Operational costs per MWh

(ZAR/MWh)

R 300

The calculations are high level based on average data and limited available information. Comparaison between projects is risky and should not be done without full understanding of the projects and their particularities.

These values reflect the electricity generation only without taking the co-benefits of heat production into account. They also include some costs for the planned upgrades, even though the numbers are calculated only for the current installed capacity of 1.1 MW. They should thus be used with caution and should not be compared to other technologies without full understanding of the details.

Technical Description

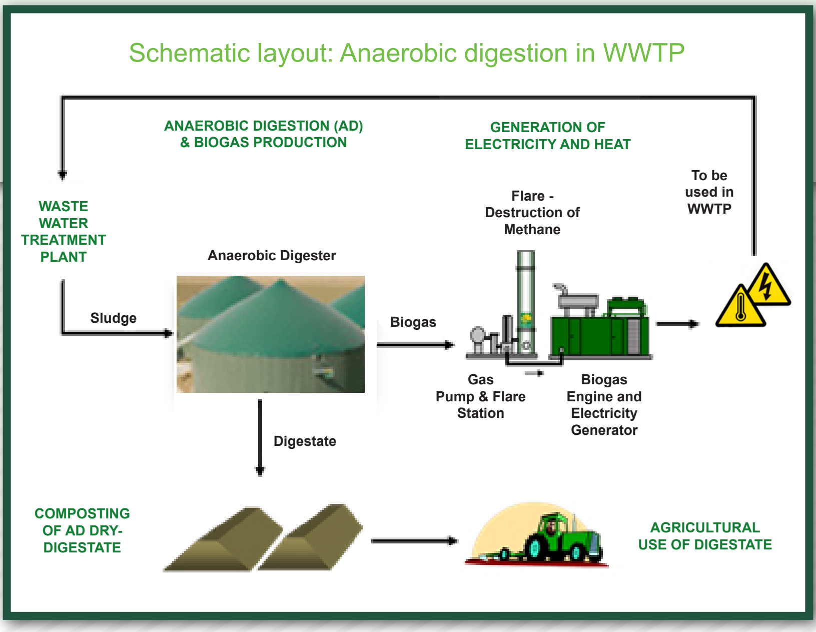
Anaerobic digesters are commonly used in South African WWTW to stabilise sewage sludge before dewatering and disposal. The destruction of volatile solids in the sludge by anaerobic bacteria produces methane rich biogas. At the Northern WWTW, the biogas is harvested from the four digesters (additional digesters are being refurbished to allow the treatment of more sewage sludge) and fed to the power plant.

The plant is made up of three 376kWe CHP engines (gas generator sets), with a total installed capacity is 3 x 376kWe, or 1,128kWe. The initial feasibility study conducted by the Northern WWTW estimated approximately 300Nm³/hour[2] of biogas and the CHP plant was sized on this basis. In the first phase of the project, the plant was expected to achieve an average output of 600-700kWe (roughly 5,000MWh/year at 95% mechanical availability), running two engines at 80% and leaving a third engine as standby.

The CHP engines can only produce electricity with the available gas produced by the WWTW. The plant has been mechanically available to run for over 95% since the start of operations. However, the average gas production since October 2012 has been between 100 and 150Nm³/hourfor 27 months of operation.

Due to these major challenges with sludge production (half the expected volume produced from the digestors, with an average of 62% methane content), the electricity produced has been lower than expected. At these gas rates, the engines could only generate an average output of 200kWe. To date, the CHP plant is running at an average of 18% of its installed capacity. The average electricity production has been 1,600MWh/year, roughly a third of the forecasted value.

If gas was produced as predicted, the payback period for the project would have been 9 years. However, at current production rates the project is in danger of not being able to recover the costs and achieve the savings it had hoped for. Johannesburg Water aims to improve the sludge processing to ensure adequate volumes and quality of gas are produced. They are in the process of refurbishing two additional digesters and expect that the six refurbished digesters will be able to produce biogas for the full-sized power plant. Additional generating capacity will only be pursued when this bottle neck in the sludge processing and biogas production has been resolved.



Project Business Model

The completed biogas-to-energy installation is owned by Johannesburg Water (a municipal-owned entity, run as a separate company, but wholly owned by the City of Johannesburg), who undertook the investment and owns the asset. The project is a design, build, operate and manage model, whereby a private company, WEC Projects, was appointed by Johannesburg Water for an 8-year period. Phase 1 included the design and build of the biogas scrubbing and CHP engine installations through a 1-year contract. Phase 2 covered the operation and maintenance of the installation through a 2-year defects liability period contract (a set period after construction whereby a contractor as the right to remedy any defects on site) and a 5-year operation and management contract.

It is the responsibility of Johannesburg Water to produce the biogas which is fed into the power plant, where it becomes the contracted company's responsibility to produce power and heat. This challenge of performance and risk sharing has been addressed by a contract fee with two billing components, based on a reward and penalty structure. Johannesburg Water therefore pays the following operational costs:

2 Nm³ means cubic meters of gas under normal (N) conditions (temperatures, pressure). This allows for comparability between measures.

a. A fixed monthly operation and maintenance fee linked to the mechanical availability of the power plant, which covers the fixed costs of the site such as insurance and operators - this component does not depend on the quantity of biogas or power produced.

b. A variable operational cost which accounts for the actual running cost of the power plant based on the units of power produced each month. The charge rate in Rand per kWh is constant, but the number of kWh's produced varies per month. This depends on the quantity of biogas Johannesburg Water produces and supplies to the power plant and as such represents a risk for the contractor.

This contract relates only to the operation of the plant, with no buying of gas or selling of the power. There is thus no need for a power generation license as the power is produced by Johannesburg Water for their own consumption on site.

Biogas is produced when any type of organic matter decomposes in the absence of oxygen – an anaerobic digestion process (AD). Biogas consists of methane, CO_2 and trace gasses. Pre-treating the sludge with heat produced from the CHP plant helps break down stronger chemical bonds and makes protein in organic matter more accessible for biological decomposition. As it contains methane, biogas can be used as an energy source for generating electricity just like Natural Gas or LPG.

Benefits of using biogas to generate electricity and heat include buffering the municipality against steep retail electricity price increases while displacing the need to purchase power for the plant's thermal needs (heat use). It also improves sludge quality and facilitates sludge management while increasing the municipality's green power portfolio, in line with local and national targets relating to greenhouse gas emissions reduction.

Anaerobic Digestion Reactor — Source: *Mark Tiepelt*

Project Timeline

2004 - 2009

Research and exploration into potential technical and business models for biogas to electrical energy generation by Johannesburg Water internal champion.

2009

Johannesburg Water undertook a feasibility study at their WWTW to establish WWTW to energy potential and developed a project proposal and associated tender specifications.

2010

The project proposal was approved by the City of Johannesburg council, with budget allocated from Capital Expenditure.

September 2011

the specialist contractor WEC Projects was appointed by Johannesburg Water to design, build, operate and maintain the pilot biogas plant.

August 2012

Plant construction was completed and first power was produced.

1 November 2012

Formal sign off on construction phase with the Johannesburg Water Northern WWTW biogas-to-energy plant handed over to the client (Johannesburg Water) and first year of the O&M entered into.

Challenges, enablers and lessons learnt

The project was delivered on time, within budget and quality requirements. Johannesburg Water has since proceeded with the second plant at its Driefontein WWTW, and has announced that it envisages similar installations for its Olifantsvlei and Bushkoppie WWTWs. These facilities have the combined potential to produce 8.5MW of electrical energy. According to WEC Projects, CHP solutions are more financially viable for WWTW that process at least 25 million litres of waste water per day – this is based on a financial payback of 7 years or less.

Permit and licensing processes

The project was facilitated by the fact that it involved the refurbishment of biogas digesters within an existing plant, and therefore did not require environmental permitting. In addition, the power generated is only used on-site, for municipal "own-use" (i.e. with no net-generation, or grid feed in), thus no generation licensing application procedure with NERSA was necessary.

Procurement

In large capital investment projects, long term contracts are important. This involves engaging with the procedures of Section 33 of the Municipal Finance Management Act (MFMA), including a public participation process, which can make the contracting process more lengthy and complex, but is an important check and balance in the spending of public funds. The total contracted O&M in this instance (7 years), was set to cover the anticipated lifespan of the plant. This means it is in the interests of the company to maintain the plant, which they must refurbish and return to Johannesburg Water in the original condition.

While the MFMA steps were not problematic, structuring the contract to ensure a fair and balanced contract (optimising performance and mitigating risk for the contracting company), involved a lengthy process of research and negotiation. It also required a high degree of legal and financial competence in order for the municipality to be able to engage with the business complexity.

Operational challenges

As noted, despite 95% mechanical availability of the plant, poor gas yields meant that, the electricity produced has been lower than expected. The average electricity production has been 1,600MWh/year, roughly a third of the forecasted value. This points to the need for very accurate gas production feasibility calculations to be done. This could include keeping a record and thoroughly assessing gas production volumes and gas quality, in order to estimate power generation potential. Where gas production is lower than anticipated this can result in the engines not operating optimally and higher than expected costs for the electricity produced, thus decreasing financial viability.

Enablers and successes

Project development: A pioneering project of this nature required research and an exploration of other models around the world; this took time and commitment – having a dedicated champion within Johannesburg Water enabled the project to make progress. The model is structured so that WEC Projects operate and maintain the plant for Johannesburg Water. Performance is ensured through structuring the contract to be partially based on power output (variable cost) and partially on fixed charges, because the biogas (fuel stock) production is not in WEC Projects' control. Concluding the contract required a high level of business and legal expertise. Other municipalities, where such skills might not be readily available, could benefit from the experience of Johannesburg Water in this regard.

Operational process: The physical electricity generation unit is fenced off from the rest of the WWTW, so that the management boundaries between the two plants are very clear.

The improved sludge management, which included the use of heat from the cogeneration power plant and the anaerobic digestive process, produces sludge that is of better quality, less volume and more stable, with less heavy metals and other problematic chemicals. This has resulted in a sludge that meets the standards for organic compost.

A visit of Tlokwe City Council, \\Khara Hais Local Municipality and SALGA officials to the Northern Works Biogas to Energy plants.
Picture: *Pieter C. Labuschagne* (manager community services, Tlokwe City Council)

Key Project Data

Start of operations

August / November
2012

Capacity

1.1 MWe
(only electrical output, i.e. without taking heat production into account), plans to upgrade the project to **4.5 MWe**

Average electrical output

1 600
MWh/year
(5000 MWh/year is anticipated once gas production is optimised)

Business Model

Project delivery model

Municipal project, built and operated by a project developer on behalf of the municipality

Electricity production

On-site, own use in the waste water treatment works

Cost

Capital cost

R 36 million
(includes some of the costs for the **4.5 MWe** upgrade)

Operational cost

R 0.30/kWh

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Key Resources: Time lapse video of installation can be viewed at: http://vimeo.com/45515427
Installation video's and time lapse available on: http://www.wecprojects.co.za/media_videos.asp

Sources:
Jason Gifford, WEC Projects
Reggie Makoane, Johannesburg Water
Mark Tiepelt, Biogas SA
http://www.purebalticsea.eu/index.php/gpsm:good_practices
http://www.epa.gov/region9/organics/ad/Why-Anaerobic-Digestion.pdf

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