



## Overview

The organic matter in raw wastewater contains almost 10 times the energy needed to treat it. Some wastewater treatment works (WWTW) can produce up to 100% of the energy they need to operate, though more typically 60% of operational energy can be produced. Biogas is typically used to meet on site power and thermal energy needs. Export of gas to local industrial users, power producers or for use as a municipal vehicle fleet fuel is also possible.

In a wastewater treatment works (WWTW) biogas is produced when sludge decomposes in the absence of oxygen, in digesters. This process is referred to as Anaerobic Digestion. South Africa was one of the first countries in the world to utilise digesters as part of sludge management at WWTW. Digesters at WWTW were, however, not built to capture and use the biogas produced, but rather to assist in sludge management. In most cases, digesters can actually be refurbished to allow for biogas collection.

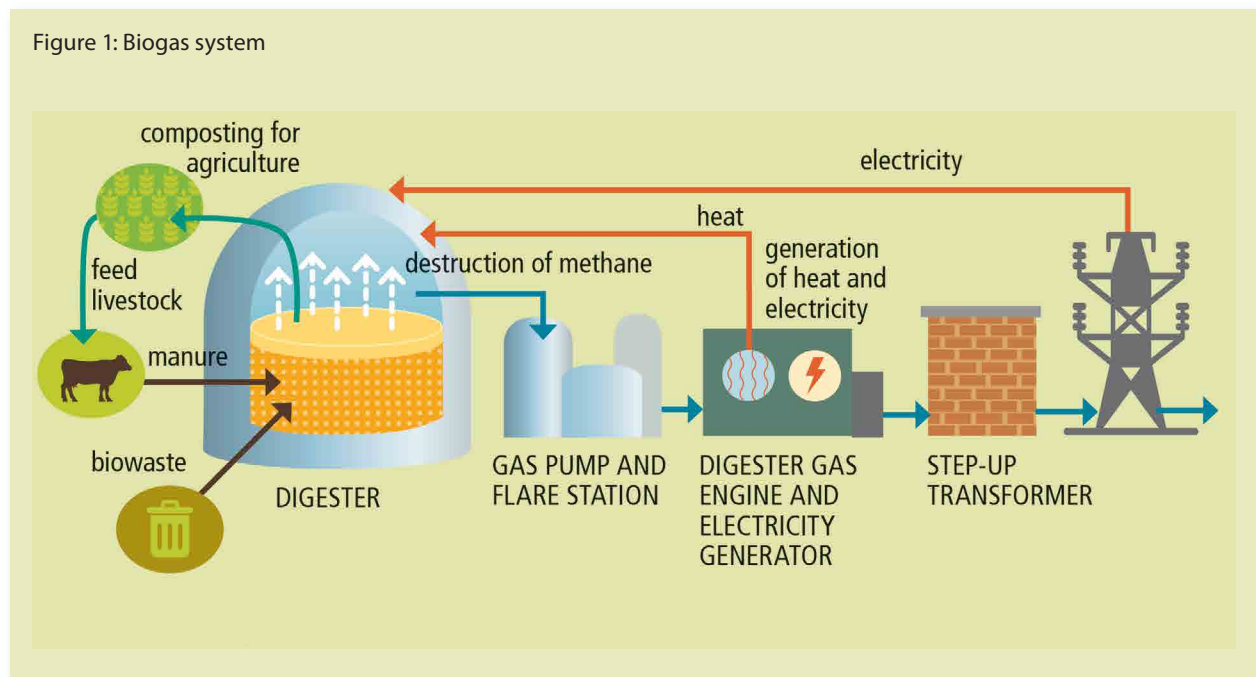
Biogas (a methane-rich natural gas) derived from anaerobic digestion and captured at WWTW plants provides a renewable energy source which can be used for electricity, heat and biofuel production. At the same time the sludge is stabilized and its dry matter content is reduced. This sludge, or digestate (remaining solid matter after the gas has been removed), contains valuable chemical nutrients such as nitrogen and potassium, and can be used as an organic fertilizer.

This intervention involves the installation of biogas digesters and CHP plants at wastewater treatment facilities to generate electricity from sludge digestion, which can be used on site to power lights, pumps, control etc. Excess heat can also be used to heat digesters or in the composting process. 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.

Technical aspects for consideration in a biogas to electricity project within a WWTW:

- Building or refurbishment of digesters to optimise them for biogas collection sufficient for viable electricity production.
- Gas scrubbing to remove impurities that can result in damage to the engine and affect electricity generation.
- Engine type: CHP, gas engine, fuel cells.
- Transformer selection – needs to be based on whether electricity generated will be used internally only (i.e. one-way transformer) or used internally and fed into the grid (i.e. two-way transformer).
- Heat exchange system: need an effective heat exchange system to ensure that waste heat energy from the gas engines is used to heat the digesters. This will assist in optimising biogas production and boost electricity production.

Figure 1: Biogas system



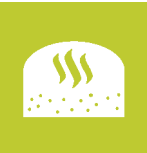
## Implementation

Wastewater treatment processes contribute some 20% plus to the total municipal electricity consumption – and bill. Wastewater to energy plants can potentially contribute 60% to site electricity, offsetting what is required from the national utility. Generation engines have a lifespan of 10 – 15 years and return on investment (ROI) is usually 7 – 9 years. Studies indicate that larger plants with in excess of 15ML/day inflow are more likely to be financially viable. However, biogas production is highly dependent on treatment processes and thus varies greatly, requiring site-specific detailed feasibility studies to be undertaken. Producing energy from biogas in WWTW has multiple benefits:

- Combined heat and electricity production which results in:
  - Operational cost savings: reduced electricity bill for WWTW, buffering the municipality against steep retail electricity price increases while displacing the need to purchase power for the plant's thermal needs (heat use)
  - Improved sludge management (reduce quantity, improve quality) though use of pre-treatment heating that improves biological decomposition
- Digestate is an organic compost, offering a potential revenue stream
- Reduced methane and CO<sub>2</sub> emissions / carbon footprint towards municipal and national targets
- Skills transfer and green economy development (introduction of new technology, new business development)

Implementation of a WWTW biogas to energy project includes the following aspects:

- Potential feedstock and viability assessment
- Project structure and development: Project ownership and municipal participation, electricity aspects and licensing arrangements
- Financial modelling and project financing



## Potential feedstock and viability assessment

Assessing viability is primarily done by looking at the anticipated Return on Investment (ROI) calculated by comparing the cost of establishing a biogas plant in relation to the potential income generated from replacing electricity bought from Eskom. Other indirect benefits such as efficient waste management, reduction in sludge, revenue from the sale of fertilizer, compliance with sludge quality requirements, carbon mitigation and local 'green' economic development provide additional motivation to the financial case within a cost-benefit analysis.

Determining the quantity and nature of sludge available is essential to determine the amount of biogas and resultant electricity which can be generated. This will provide an indication of the financial viability of such a project. The quantity of sludge produced is largely determined by the treatment processes employed by each specific WWTW. Each municipal WWTW has a unique water treatment process, which leads to highly variable biogas yields. This can result in biogas yields that are substantially different from a theoretical calculation based solely on the inflow of waste water in the WWTW. It is thus very important to understand in detail the waste water treatment processes and such expertise should be included in the project team of any biogas project in WWTW.

**As a guideline, there is a strong likely viability in larger plants with inflows in excess of 15 M litres/day; smaller plants with a flow of less than 15 M litres/day would most likely not be able to produce sufficient sludge for viable levels of electricity production under current financial conditions.**

The following information is important when assessing the potential to produce biogas:

- Design capacity and current daily flow rate of the WWTW
- Plant operational and sludge generation process: whether this is biological nutrient removal (BNR) trickling, or aeration, etc. Current quantity of sludge produced
- Current quantity of biogas produced, if any
- Existing biogas capture infrastructure, if any
- Sludge disposal procedures
- Status of existing digesters (number, size, mixed and/or heated, structural integrity, etc.).

### Plant treatment process, sludge management and biogas digestion

Each WWTW plant employs a different treatment process (or a combination thereof) and each process produces different quantities and quality of sludge. Sludge production is usually inversely proportional to electricity consumption, i.e. the more mechanically driven the process is, the less sludge is produced.

Figure 2: Electricity usage decreasing down the list; sludge potential increasing

LOWER ELECTRICITY NEEDS		HIGHER SLUDGE POTENTIAL
	PLANTS WITH PSTS (PRIMARY SETTLING TANKS)	
	TRICKLING PLANT	
	BNR (BIOLOGICAL NUTRIENT REMOVAL)	
	ACTIVATED SLUDGE	
	EXTENDED AERATION	
HIGHER ELECTRICITY NEEDS		LOWER SLUDGE POTENTIAL

## Municipal Initiatives

Many South African WWTWs have digesters. These are operated to optimise sludge management and not biogas production. Sludge management is integrally part of the operations of the WWTW and most municipalities have drying beds which function with varying degrees of success. There normally exists some arrangement with the private sector to collect the dried sludge that is then used as compost.

Fully functional digesters will benefit the WWTW by reducing the quantity of sludge going to the drying beds and improve its quality for organic composting. There are new regulations currently under development that will specify improved sludge management in future.

### *Additional Organic Waste, or “Co-digestion”*

A municipality may consider securing additional organic feedstock over and above the sludge from the WWTW. This could include the organic fraction of the Municipal Solid Waste or directly from agricultural or commercial organic waste. While certain benefits can be reaped through such co-digestion, including improved biogas productivity and more stable biogas production across the seasons, co-digestion can be complex and implementation of co-digestion activities would necessitate a separate, detailed assessment of sources of organic waste, necessary pre-treatment and related infrastructure, impact on retention times and operating capacities, proportions of substrate addition rates, etc.

More WTPs are adding post-consumer food waste to existing anaerobic digesters at their facilities. Food waste has up to three times as much energy potential as bio solids.

## Project structure and development

### *Electricity (and heat) usage*

WWTW use a lot of electricity for pumping and aeration. International reference indicates that around 60% of the electricity consumption of the WWTW can be offset by the electricity generated at the biogas plant. Combined with efficiency measures (enhancing pumping operations, pumping equipment, optimisation of processes and aeration equipment – see page 153 in the chapter on WWTW), offset can reach 80%. (SALGA GIZ Biogas potential, March 2015).

Although electricity could be fed into the grid, on-site consumption is preferable given that generation potential is generally less than on-site consumption and the “price” for the generation would be the full cost of the electricity purchase offset. Selling power to the private sector would only be attractive for a WWTW if the buyer was willing to buy electricity at a premium price, for example if the buyer wanted to promote its green profile. Such an option complicated and costly as long-term commitments have to be negotiated between the WWTW and the buyer as part of a Power Purchase Agreement and wheeling arrangements to transport electricity to the buyer must be concluded with the owner of the grid. Experience indicates that, given the complexity in ensuring the feedstock (e.g. if the downstream municipal WWTW breaks down), such arrangements would entail high levels of risk.

The heat produced by a combined heat and power (CHP) unit should also be used on-site, mainly to heat the digesters and thereby increase the biogas production. It could also be used for drying the sludge in order to produce fertilizer.

### *Business model*

The most common business model utilised to date in South Africa is one where the municipality owns the plant and all of the waste streams that provide the feedstock. The model includes:

- Full ownership of the plant by the municipality
- Investment by the municipality
- Appointment, through competitive tender, of a service provider to design, build, manage and operate the plant for a period of 7 – 10 years





## SAGEN-GIZ/SALGA Biogas Potential Assessment Toolkit

A Biogas Potential Toolkit has been developed to assist municipalities to determine the biogas potential of their WWTW and the viability of such a project at the early stage of decision making process. The Toolkit is intended for use by Water and Sanitation and/or Energy and Electricity departments of municipalities.

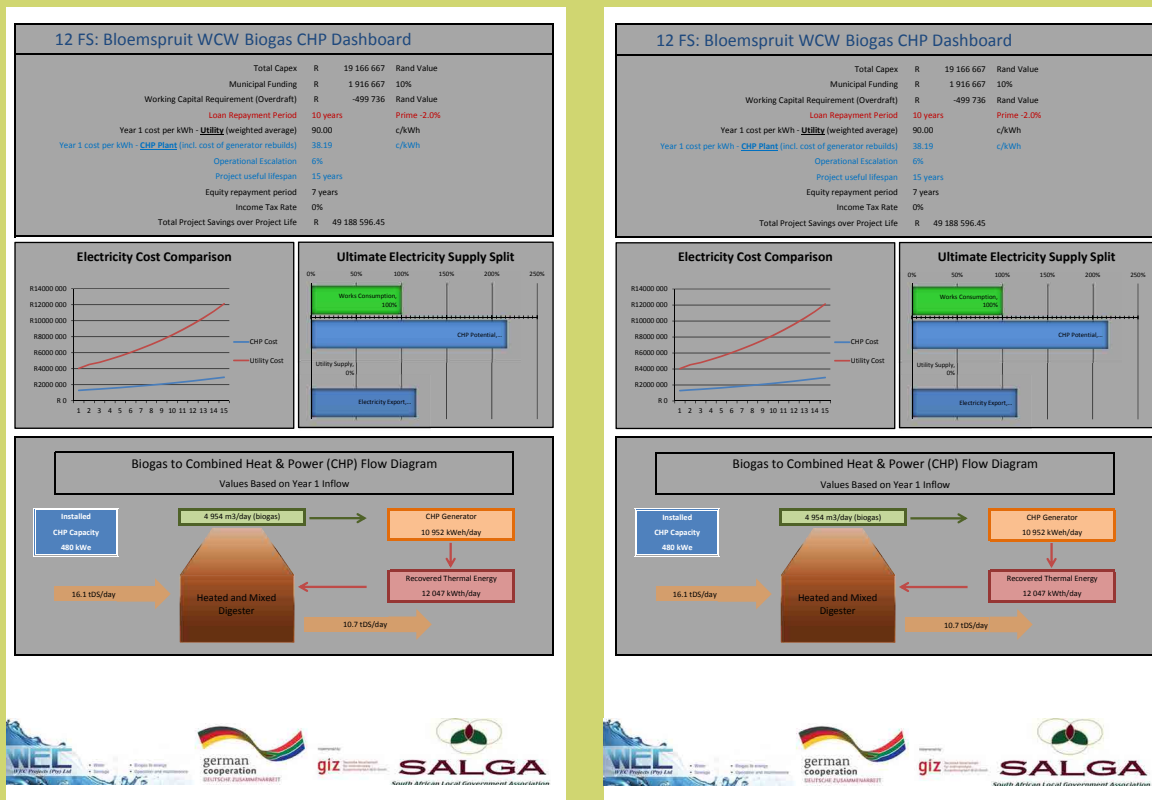
### The Biogas to Energy at Municipal Wastewater Treatment Works: Feasibility EXCEL tool

This calculation tool requires inputs from municipal officials' familiar with the WWTW processes used and from officials familiar with the municipality's finance requirements. The excel tool comprises 4 sheets:

**Notes:** this page if for information purposes and explains how to use the tool.

**Assumption Sheet:** this is the main user interface with the excel tool. Here the user inputs all process and financial information.

**Dashboard Sheet:** the Dashboard provides an Executive Summary of the potential project allowing the user to quickly assess the project's viability based on the information inputted in the Assumption Sheet.



**Generator CAPEX Sheet:** the model calculates an approximate capital cost of the complete CHP plant based on the cost of the generator set. These are rule of thumb assumptions and are for guideline purposes only. The cost of the generator set can be modified by the user.

The accuracy of the tool is only as good as the information it receives. It is also for indicative purposes only. Should the tool indicate viability, the municipality would still need to then appoint suitably qualified consultants to **undertake a full feasibility study**.

### **POWER POINT PRESENTATION and NOTES**

The presentation and accompanying notes have been developed to assist project initiators when presenting the project to management. The notes provide a better understanding of biogas as a technology and how it applies to WWTW. The presentation can be used to:

- Explain the technology
- Outline the multiple benefits associated with such a project
- Display the results of the Excel tool in a specific waste water treatment plant.

All Tools can be downloaded on: [www.cityenergy.org.za](http://www.cityenergy.org.za) / Renewable Energy / Tools and Guidelines.

*The tool was commissioned by SAGEN-GIZ/SALGA; the Excel tool was developed by WEC Projects (PTY) Ltd. The other parts of the toolkit were jointly developed by Biogas SA, CapEAPrac and WEC Projects (PTY) Ltd.*

This greatly simplifies the business of plant establishment and operation as there is no need for complex public private partnership agreements, wheeling agreements, generating license applications, etc. While this model may be considered optimal in terms of simplicity, it is still very important to clarify the roles and responsibilities of those in charge of development, operation and maintenance of the plant. Key actions include:

1. Appointing a dedicated champion within the municipality to drive the project. As this is a relatively unknown technology, new to most decision makers, this person will need to equip themselves with new skills and knowledge.
2. Setting up cross-departmental teams to steer the implementation of the project and appoint consultants with the necessary experience in the biogas field to undertake the viability assessment and draft the necessary tender documentation.
3. Appointing of service providers to design, build, operate and maintain the plant for 7 – 10 years.
4. Clarifying operation and maintenance responsibilities: feedstock to the plant and biogas production is reliant on the downstream feedstock, so coordination between these municipal responsibilities and/or the contractor, is critical. The more in-house capacity is built in relation to the new activities, the better the cooperation between facility managers and staff will be, ensuring a higher likelihood of success.
5. Once commissioned the risk sharing must be clearly delineated between the municipality and the service provider ensuring good performance while not penalizing the contractor where the municipality fails to supply adequate feedstock to the power plant. This can also be assisted by a clear delineation – marked through fencing off of the power plant – of the management boundaries between the parties. This process requires complex contracting and takes time and money.

### **Partnering with the private sector**

Private participation may be helpful to bring in specific project development expertise or to mobilise private capital. However, private capital is likely to only be interested where the ROI is high enough to make it attractive to invest. Such projects may be set up as a Public Private Partnership (PPP) or Energy Services Company (ESCO) model.

While establishing a PPP may mobilise expertise, share risk and reduce financial commitments, the process can be lengthy, cumbersome and costly. A Power Purchase Agreement (PPA) needs to be developed, either directly with the municipality or a private company, which in turn requires a comprehensive contract and possibly a wheeling agreement – all of which is time consuming and costly – requiring a high level of technical (financial and legal) skills that have to be contracted in.



### *Licenses*

The licensing requirements for a biogas project in a municipal WWTW are not clearly stipulated under current legislation, but the following would have a bearing:

- **Environmental Impact Assessment (EIA):** either a Basic or Scoping and “Full EIA” will need to be undertaken in terms of the NEMA (No.107 of 1998) – this depending on the scale and design of the existing WWTW facility and scale and design of the biogas digester proposed, and on existing licenses.
- **Various additional authorisations will need to be obtained:** Waste Management License, Water Use License, Atmospheric Emission License, Land Use Planning Authorisation, Major Hazard Installation Regulation may also be relevant.
- **Electricity/gas related authorisation:** while a generating license from NERSA is usually only required if the project sells the electricity into the national grid and is over 1MW (Schedule 2 Electricity Regulation Act, 2006), biogas is an exception. Section 28 of the Gas Act No.48 of 2001 stipulates that NERSA registers all small biogas projects not connected to the grid.

### *Financial modelling and project financing*

The primary financial viability factor is the potential revenue made, or cost savings derived from avoided purchases where consumption is on-site, through electricity generated from the available biogas. Secondary benefits include sludge management (reduction and improved quality), carbon mitigation and local economic development and related jobs. These secondary aspects may have a financial value that could be costed in.

The financial model will depend on whether the municipality retains sole ownership or enters a Public Private Partnership with the private sector. Private sector stakeholders may require a higher ROI compared to the municipality. Secondary benefits, such as sludge management, may also not benefit to them. Lengthy contract development processes (PPP, PPA, Wheeling agreements) in a PPP may impact on ROI due to the additional time and resources required to effect.

In general, biogas projects will require a long-term investment of 7 – 10 years or more. The initial indication is that larger WWTWs with an inflow in excess of 15ML/day show financial viability based on the amount of electricity they could generate. As emphasized, site-specific modelling would be required to confirm any estimation, given the variability of characteristics of each plant.

There are no strongly established typical costs for such projects. This was also depend on whether biogas digesters are in place and the capacity and functionality of these. The capital investment at Johannesburg Northern Works plant was in the region of R32 million/MW installed. This included investment for upgrading of existing biogas digesters. Operational costs are cited as R300/MWh. (SALGA-GIZ case study series: Municipal Wastewater Treatment Works: Biogas to Energy (Co-generation) at City of Johannesburg Northern Works: [http://www.cityenergy.org.za/uploads/resource\\_336.pdf](http://www.cityenergy.org.za/uploads/resource_336.pdf)).

Finance for project implementation may be sourced internally from the municipal fiscus, or externally, from a commercial bank, donor funder or through Public Private Partnerships. In order to motivate for finance the Project Business Plan needs to present a favourable financial feasibility for the project. Expected financial savings and other benefits need to be clearly articulated.

### *Barriers and opportunities*

Undertaking a sound feasibility analysis can be hampered by lack of information: an in-depth understanding of the actual operational processes at each WWTW is required in order to do a realistic analysis of the practical quantity of sludge available to serve as feedstock for the digesters at each WWTW (this informs the electricity

## Municipal Initiatives

generation potential and is thus the basis of the financial viability). This information is not readily available or recorded at municipalities.

Downstream management of the feedstock: poor gas yields due to issues relating to the sludge management component of the plant can result in lower gas production than anticipated. This aspect of the project is often managed by municipal wastewater treatment plant staff. The system they are operating within is not market related, or performance output related (for example obtaining supplies from stores for broken components may require lengthy public service procedures resulting in delays in production. This is important for spending of public money, but may not result in optimal efficiency of gas production). This can result in the engines not operating optimally and higher than expected unit costs for the electricity produced.

Opportunities and enablers that can facilitate biogas to energy projects at WWTW include:

- Many plants already have biogas digestors. While these may require refurbishment, they generally already have the requisite environmental permitting.
- If the electricity produced is under 1MW and largely used on-site, the municipality is likely to be exempt from generation license application processes, and if it is used entirely on-site, complex Power Purchase Agreement contract development will be avoided.
- Improved sludge management may result in an additional revenue stream where it meets the standards for organic compost.

### **Future developments**

Given that this is a rapidly changing technological space, it is important to remain attentive to developments and regularly investigate new possibilities. For example, the Netherlands has introduced the idea of the NEW Factory (nutrient, energy and water factory) for wastewater treatment works. This suggests considering wastewater as a resource of nutrients, energy and clean water, rather than a waste product. New areas of technological development include:

- High-load digestion: increased concentration of solids and microorganisms inside the anaerobic digester reducing necessary digestion volume and heat required which lowers investment and operation costs. For WWTPs without digesters, and for smaller plants, this may open up a cost effective solution;
- Hydrothermal carbonization, pyrolysis and gasification and fuel cells. In addition to utilizing the methane gas from waste for combustion or heat generation, the carbon dioxide found in waste streams may offer an important source of carbon dioxide for synfuel development. Hydrogen from water – through a hydrolysis process – mixed with carbon dioxide can form hydrocarbons that can be used as transportation fuels in the future. These technologies are in theory far more efficient, but require high quality gas and there are security concerns around hydrogen;
- Phosphorus recovery from sewage sludge for nutrient recycling.





## Case study 1: Johannesburg Water Northern Works Biogas to Energy\*

With electricity price increases set to triple Johannesburg Water's electricity bill from R100 million to over R300 million over the next ten years they identified the need to cut back on electricity usage. Northern Works treats about 43 ML of sewage/day. It is the City of Johannesburg's largest wastewater treatment works and the site of its first biogas to energy project.

The plant produces electricity from biogas using three 376kWe (KWh equivalent = heat and power) combined heat and power (CHP) gas engines. The electricity produced is consumed on-site. Currently it produces 10% of the treatment work's power requirement. However, once all of the digesters have been refurbished, and all of the sludge is treated anaerobically, the CHP plant should produce some 56% of the on-site power requirements.

The heat energy produced by the CHP engines is used to pretreat the sludge, which increases the biogas production. Additionally, the heat improves sludge management producing lower volumes of better quality waste. Sludge will now meet the standards for organic compost and can be sold into the agricultural sector.

**Business model:** The biogas plant installation was undertaken by Johannesburg Water (wholly owned by the City of Johannesburg). The project is a design, build, operate and manage model whereby a private company was appointed by Johannesburg Water for an 8-year period.

**Procurement and contracting:** 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 biogas plant through a 2-year 'defects liability period' contract and a 5-year operation and maintenance contract. As the latter is a contract of more than 3 years a public participation process was undertaken in accordance with the Municipal Finance Management Act (Section 33).

The greatest hurdle in the contracting arrangements was working out a fair balance of risk and responsibility between Johannesburg Water and the O&M Company. This was complex as power output (responsibility of the O&M Company) was reliant on feedstock (responsibility of Johannesburg Water). This was ultimately resolved through structuring the contract to include both a fixed (to ensure ongoing operations and maintenance despite potentially variable feedstock) and variable fee component, the latter based on actual power production (to ensure performance).

**Permitting and licensing:** the project was facilitated by the fact that it involved the refurbishment of existing biogas digesters within an existing plant and therefore did not require environmental permitting. In addition, as the power generated is only used on-site, for municipal 'own use', no generation licensing application procedure was required. However, registration with NERSA was required in terms of Section 28 of the Gas Act No.48 of 2001.

### Lessons learnt through the process:

- ◆ Complex contractual arrangements in terms of performance and risk sharing required substantial, and costly, legal time and knowledge. Despite mechanical availability of the plant, poor gas yields have meant lower than expected electricity production (a third of the forecast value), shifting the anticipated 9 year ROI back and severely affecting the financial viability of the project. This emphasizes the importance of detailed and accurate gas feasibility studies.
- ◆ A dedicated champion within the WWTW department was critical in driving the project through.
- ◆ Clear fencing of the electricity generation unit from the rest of the WWTW has assisted in clarifying the management boundaries between the two plants.
- ◆ Improved sludge management is considered an important additional benefit resulting from the project.

\* This case study draws extensively from the report: Municipal Wastewater Treatment Works: Biogas to Energy (Co-generation) at City of Johannesburg Northern Works: [http://www.cityenergy.org.za/uploads/resource\\_336.pdf](http://www.cityenergy.org.za/uploads/resource_336.pdf). Unless referenced otherwise, information is sourced from this document.



Figure 2: Generators at Northern Works



Source: courtesy of Jason Gifford, WEC

## Support Organisation

**Southern African Biogas Industry Association (SABIA)**

<http://www.biogasassociation.co.za>

