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Low Emissions Development Program

CASE STUDY

Moving towards carbon neutral wastewater treatment plants: the case for combined heat and power

The SA-LED Program, launched in 2015, has strengthened the capacity of the public sector to plan, finance, implement and report on low emissions development projects and to accelerate the adoption of low emissions technologies in South Africa.

Wastewater treatment plants (WWTPs) require electricity for operation of pumps, mixers, dosing equipment, aerators and other process equipment, as well as for ancillary services including lighting and offices. Those WWTPs that have anaerobic digestion (AD) systems to treat water also require heat for the digesters (heating improves digester efficiency and ensures optimal volatile solid stabilization) and sludge drying. Electricity, diesel and/or gas is typically used to provide the necessary energy inputs. Wastewater treatment facilities often account for more than 20% of municipal electricity consumption[1] and are among the top three users of energy (and associated costs) in municipal operations.

At the same time, WWTPs generate methane from the process of AD. Methane is an energy source that can be recovered to provide some or all of the plant's energy requirement. In combined heat and power (CHP) processes, the methane gas can be combusted to generate electricity in a turbine. The residual heat can also be recovered for use in the plant (heating of the digesters). CHP thus provides an efficient way of recovering the maximum energy value from the methane stream, which may otherwise be vented (released into atmosphere) or flared (burnt with an outside flame). Most WWTPs in South Africa that have digesters generally vent the biogas without any treatment. Through providing on-site heat and power, CHP can result in energy and associated cost savings, improve the reliability of the plant and minimise the impacts of power

Photo Credit: USAID/SA-LED
An anaerobic digester located at the City of Tshwane's Zeekoegat Wastewater Treatment Plant (WWTP)

[1] https://www.sustainable.org.za/userfiles/wastewater%20biogas(1).pdf

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outages on plant operation, which is particularly relevant in South Africa. There is the potential for WWTPs to gain energy neutrality, generating up to 100% of the plant energy needs, although in practice they tend to produce less than 60% of energy demand[2]. This potential, however, depends on the plant configuration, treatment processes and the capacity of the CHP unit.

REDUCING THE CARBON INTENSITY AND COSTS OF WWTPs

There is a growing interest among municipal entities operating WWTPs to improve the energy and operational efficiency of these facilities. This is prompted by the need for municipalities to cut costs and contribute to global and national efforts to reduce greenhouse gas (GHG) emissions. Many municipalities are therefore seeking to make WWTPs net carbon and/or energy neutral. CHP has the benefit of reducing greenhouse gas (GHG) emissions that contribute to global warming, both through reducing emissions of methane to the atmosphere and through reducing demand for fossil fuel-based energy. A recent review study has suggested that anaerobic digestion with CHP is the most economically attractive proven technology for energy recovery from sludge within South Africa[3].

Carbon and energy savings can also be achieved using various other options, including process changes, installing or improving the efficiency of methane flares, installing wind, solar and other renewable energy technologies, adopting energy efficiency measures, and planting trees to act as emissions sinks. These options are presented in Table 1, which summarises whether the options contribute to carbon neutrality, energy neutrality or both. In all cases it is **best practice to implement energy efficiency interventions prior to more capital-intensive developments**, such as CHP or renewable energy systems.

TABLE 1: CARBON AND ENERGY SAVING OPTIONS FOR WWTPS

Intervention/ Technology	Energy Neutrality	Carbon Neutrality
CHP Systems	Yes	Yes
Process Changes	Yes	Yes
Methane Flaring	No	Yes
Energy Efficiency	Yes	Yes
Solar PV	Yes	Yes
Wind Technology	Yes	Yes
Tree Plantation	No	Yes

In addition to the generation of methane, AD assists with sludge management by reducing the final volume of sludge and helping ensure the sludge is of good quality to enable it to be used as fertiliser. Since sludge disposal can release both methane and nitrous oxide emissions, proper sludge disposal practices will also help to reduce the overall carbon footprint of the WWTP. Direct landfilling of sludge (which is the option used at many South African WWTPs) results in almost 40% more methane emissions than sludge that is anaerobically digested and then applied to land as a fertiliser. Sludge management is also an important economic consideration for municipalities, as sludge management infrastructure can account for 50% of total WWTP capital costs[4]. Energy recovery or the sale of compost/fertiliser manufactured from the sludge is therefore important for the economic sustainability of WWTPs.

[2] https://www.sustainable.org.za/userfiles/wastewater%20biogas(1).pdf; http://www.engineeringnews.co.za/article/chp-plants-at-water-treatment-works-capable-of-knocking-60-off-elec-bill-2015-11-13
[3] http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20752-18.pdf
[4] http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20752-18.pdf

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CHP GHG CALCULATOR

Whilst a number of tools are available for calculating the energy and emissions savings potential of other renewable technologies such as solar and wind; for implementing energy efficiency measures and for calculating emissions savings from broader application of CHP, there are few tools available to understand the potential for savings from CHP in WWTPs. In response to this gap, SA-LED has developed a free calculator to support municipalities in South Africa to assess the potential of CHP. The calculator is available here[5].

The user enters either the volume of biomass generated, or wastewater being treated, along with selected other details about the plant, including current sources of energy being used. The calculator provides as output:

- Electricity generation/savings potential
- Fuel savings for heating
- Greenhouse gas emissions savings potential

The tool can be used as a complement to financial analysis tools and ultimately help provide information on the potential cost savings associated with CHP.

INTERNATIONAL EXPERIENCE IN CHP AT WWTPs

The use of CHP at WWTPs is a well-established practice internationally, with the United States Department of Energy reporting 231 installations across the country[6]. Sweden has 140 CHP systems[7] and one in eight plants in Germany utilise CHP[8]. The total savings achieved from installation of CHP varies widely between installations. Some examples from the United States are shown in Table 2 below.

TABLE 2: AMERICAN WWTP ANAEROBIC DIGESTION AND CHP SYSTEM EXAMPLES[9]

WWTP	Plant capacity (ML/day)	CHP generation capacity (kW)	Percent of energy needs
Albert Lea Treatment Facility	47	120	25%
Allentown Treatment Plant	121	360	26%
Budd Inlet Treatment Plant	44	335	10 to 15%
Burlingame Treatment Plant	21	177	20%
Gresham Treatment Plant	76	790	17%
Southside Treatment Plant	416	4320	4%

An example of a WWTP that has achieved net zero energy use[10] is that of the Gresham WWTP in the United States. The plant has a treatment capacity of about 75 megalitres per day and receives 49

[5] https://www.climatelinks.org/resources/greenhouse-gas-emissions-reduction-calculator-combined-heat-and-power
[6] https://doe.icfwebservices.com/chpdb/
[7] https://energiforskmedia.blob.core.windows.net/media/24303/more-efficient-use-of-biogas-at-waste-water-treatment-plants-energiforskrapport-2018-476.pdf
[8] https://www.interregeurope.eu/policylearning/good-practices/item/78/power-self-sufficient-sewage-wastewater-treatment-plant/
[9] http://www.chptap.org/projects
[10] http://www.chptap.org/Data/projects/Gresham_WWTF-Project_Profile.pdf

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megalitres per day of wastewater, as well as fats, oils and grease (FOG)[11] collected at a drop-off facility. To achieve net zero energy use, various energy efficiency interventions were implemented to reach a 17% reduction in plant energy consumption. A 420 kW solar PV installation further reduced energy consumption by 8%, with a 790 kW CHP system producing the remaining energy for the plant.

CHP IN WWTP IN SOUTH AFRICA

Anaerobic digesters are used at many WWTPs across South Africa; however, the digesters have typically not been designed to capture biogas for use. In some cases, digesters are fitted with flares, which reduces the greenhouse impact of emissions from the digesters through burning methane (which has a high global warming potential) to produce carbon dioxide, which has a lower climate impact. However, the flaring systems do not reduce plant energy demands and are still contributing to the production of greenhouse gas via carbon dioxide emissions. As mentioned previously, biogas recovery and use has been considered by local and national government in recent years due to the potential economic benefits. The systems are more economical on larger WWTPs, with plant that treat more than 15 megaliters per day considered feasible for CHP systems[12].

Biogas recovery implementation has however been slow, with the first municipal WWTP anaerobic digestion and CHP system beginning operations in 2012. Johannesburg's Northern Wastewater Treatment Works treats 430 megaliters per day and initially had a 1.1 MW CHP system installed, which produced 10-15% of the WWTP's electricity demand[13]. The heat is used to preheat sludge, resulting in increased biogas generation and improved sludge management. The system was designed to produce lower volumes of high-quality sludge, for sale as agricultural compost[14]. The success of the initial phase meant that further anaerobic digesters were upgraded, and CHP engines installed, to reach a total capacity of 4.5 MW. This system was designed to provide 56% of the WWTP's electricity needs[15]. Due to numerous issues, however, the system is not generating the expected amount of electricity, with remedial action necessary to increase biogas production[16].

Although there are few local public examples of the use of CHP at WWTPs, there are numerous examples of private sector facilities in South Africa with anaerobic digestion where CHP systems are utilized to treat other waste streams and produce electricity. Some examples of these are presented in Table 3 below to demonstrate the AD and CHP capability already established in South Africa.

TABLE 3: SOUTH AFRICAN COMMERCIAL ANAEROBIC DIGESTION AND CHP SYSTEM EXAMPLES[17]

Project	Feedstock	Generation capacity	Percent of energy needs
Bronkhorstspruit Biogas Project	Manure, along with abattoir and food waste	4,600 kW supplied to BMW's Rosslyn plant	25-30% of plant's electricity demand
Uilenkraal Biogas Project	Manure, urine and wastewater slurry	500 kW	95% of farm's electricity demand

[11] Anaerobic digestion of fats, oils and greases (FOG) results in increased biogas production due to an increase in COD loading

[12] https://www.crses.sun.ac.za/files/research/publications/SAGEN%20Job%20Pot%20-%20Digital%20(low-res).pdf; https://www.sustainable.org.za/userfiles/wastewater%20biogas(1).pdf

[13] https://www.crses.sun.ac.za/files/research/publications/SAGEN%20Job%20Pot%20-%20Digital%20(low-res).pdf

[14] https://www.sustainable.org.za/userfiles/wastewater%20biogas(1).pdf

[15] https://www.crses.sun.ac.za/files/research/publications/SAGEN%20Job%20Pot%20-%20Digital%20(low-res).pdf;

[16] http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20752-18.pdf

[17] https://www.crses.sun.ac.za/files/research/publications/SAGEN%20Job%20Pot%20-%20Digital%20(low-res).pdf

Elgin Fruit Juice Biogas Project	Pomace and fruit waste	500 kW	Unknown (both electricity and heat generated are used for on-site processes)
Morgan Springs Biogas Project	Abattoir waste	400 kW	50% of abattoir's electricity demand 90% of abattoir's heat and warm water demands

CHP AT CITY OF TSHWANE'S ZEEKOEGAT WWTP

It is estimated that the implementation of biogas systems at the Zeekoegat WWTP would result in electricity consumption reductions of 32%. If simple measures, such as process optimization and control, are implemented alongside biogas systems, it is estimated that electricity consumption could be reduced by 50%. The implementation of new technology, such as new aeration technology and advanced process control, alongside biogas systems could result in estimated electrical savings of up to 78%[18].

To demonstrate the potential for biogas offsetting some of the energy requirements of a local WWTP, SA-LED used the CHP calculator referenced previously to determine the electricity and heat generation potential at the Zeekoegat WWTP. The model outputs are shown in Table 4, and demonstrate potential electrical savings of 2,356 MWh/year (19% of plant demands). It is assumed that all heat will be used to heat the AD system, which currently does not occur (the AD system is designed to be heated using flared biogas but this system is out of operation). Overall, the CHP system is anticipated to reduce GHG emissions by almost 16,000 tonnes CO_2e per annum. These savings are very similar to those found in other analyses of this plant's potential[19], demonstrating the robustness of the calculator model. It was noted that the Zeekoegat has a very low organics loading in the incoming wastewater (0.37 kg COD/m^3 as measured in laboratory testing, in comparison to the calculator default of 0.79 kg COD/m^3).[19]

TABLE 4: MODELLED PERFORMANCE OF A CHP PLANT AT ZEEKOEGAT WWTP

Parameter	Values
Sludge produced from WWTP (tonnes solids/year)	3,706
Methane produced in AD system (tonnes CH_4/year)	482
Electricity produced (MWh/year)	2,356
Heat produced (GJ/year)	10,716

FURTHER READING ON CHP POTENTIAL IN SOUTH AFRICAN WWTPS

- Biogas Potential: A Survey of South African Wastewater Treatment Works - http://www.biogasassociation.co.za/wp-content/uploads/2016/08/WWTW-survey.pdf
- Biogas Industry in South Africa: An Assessment of the Skills Need and Estimated Job Potential - https://www.crses.sun.ac.za/files/research/publications/SAGEN%20Job%20Pot%20-%20Digital%20(low-res).pdf

[18] http://www.wrc.org.za/wp-content/uploads/mdocs/PB_2377_energy%20use%20and%20BNR%20plants%20(005).pdf
[19] https://www.sagen.org.za/publications/44-summary-of-the-biogas-feasibility-study-for-zeekoegat-wwtw

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