Generation using gas-fuelled engines in South Africa – an overview

Information from Agaricus

Most gas engines are Otto cycle spark ignition internal combustion reciprocating engines using natural gas as the primary fuel. Smaller models utilise stochiometric combustion while the larger engines are lean burn engines with pre-chamber ignition systems. The engines are coupled with packaged generator sets, cogeneration and, even, trigeneration units to optimise energy utilisation in the fuel being burned. Engines are modular and multiple units may be installed in power houses or housed in individual containers, such as standard ISO containers, which facilitates relocation particularly in the case of landfill gas to energy projects.

Over the last five decades, gas engines have evolved into variants which are able to utilise a wide range of fuels including natural gas, biogas (landfill gas and sewage gas), as well as coal seam gas (coal mine gas and coal bed methane). Some machine manufacturers, e.g. GE Jenbacher are able to use furnace gases (steel, ferrochrome, ferromanganese, calcium carbide production) in their engines to generate electricity. The power outputs of commercially available units range from 20 kWe to 18 MWe. The smallest units are generally based on modified diesel engines retro-fitted with spark ignition systems, whereas the larger units from approximately 250 kWe upwards are purpose-built as gas engines.

Gas engines for power generation delivered over the last 20 years represent a capacity of approximately 50 GW [1]. GE's gas engine division is among the world's leading manufacturers of gas-fuelled reciprocating engines with more than 20000 engines delivered representing a total capacity of over 20 GW. Most gas engines are used as base load units, run grid parallel and operate continuously but significant numbers are being used in island mode. In some cases power may be wheeled through the grid to the end user from the power producer.

There are significant advantages to the generation of on-site power particularly where high-efficiency combined heat and power (CHP) or trigeneration systems are employed to recover engine block and exhaust heat which is often wasted [2]. Power generated locally, i.e. distributed power (DG) has more value to society than centrally generated (CG) power [2]. Recent research in the USA has demonstrated two game-changing conclusions:

- 1 MWh generated near users with a DG plant can, depending on grid location, displace 1,2 to 1,45 MWh of CG power.
- Each peak MWh from DG can displace 2 MWh to 2,25 MWh of peak transmission and distribution (T&D) and CG power.

Fig. 1: MTN Campus GEJ320 engine/genset trigeneration unit being installed.

At the time of writing no gas engine based gensets are associated with the Department of Energy's REBID program. Gensets currently producing electricity for own use at various facilities have been installed because of the strategic necessity to avoid expensive outages that have severely negative impacts on production or service. In many cases these installations are already producing lower cost power as Eskom's tariffs increase.

Applications in SA

Natural gas engine based gensets

Sasol Gas currently supplies most of the natural gas in South Africa but will lose that monopoly during 2014. Sasol markets both natural and methane rich gas. Sasol operates and maintains a gas supply network of 2500 km of pipeline, including the 865 km cross-border pipeline linking the gas fields in Mozambique to the Sasol Gas network. The network delivers more than 150-million GJ of pipeline gas a year to about 550 industrial and commercial customers. Pipeline gas is a convenient and reliably supplied energy source, that is cost effective and ideally suited to a wide range of applications including electricity generation. Customers are established in the industrial regions of Gauteng, North West, Mpumalanga, KwaZulu-Natal and Northern Free State provinces in South Africa. The pipeline gas supplied by Sasol Gas is in two forms [3]:

- Natural gas with an energy content of 39,0 MJ ±5% at 101,325 kPa @ 15°C
- Methane rich gas with an energy content of 33,89 MJ ±8% at 101,325 kPa @ 15°C

Natural gas in South Africa is piped in from the Mozambique gas fields whilst methane rich gas is a blend of synthesis gas produced by Sasol. Sasol has limited the sale of gas in South Africa because it is using most of the natural gas for the Fischer-Tropsch synthesis of hydrocarbon fuels and its monopoly seriously constrains opportunities to use pipeline gas as fuel alternatives in the short term.

Year	Client organisation	Units installed	Recovery
2008	Thos Begbie Middelburg	GE Jenbacher – 4 x 620 @ 2676 kW ea. natural gas engine/gensets	Electricity
2010	ABSA Towers	GE Jenbacher – 4 x 620 @2887 kW ea. natural gas engine/gensets	CHP
2010	MTN	GE Jenbacher – 2 x 320 @ 1063 kW ea. natural gas engine/gensets	Trigen

Table 1: Natural gas engine/gensets installed in South Africa.

Fig. 2: Dutch tomato tunnel system using GE's Jenbacher Ecomagination innovation.

Electricity generated by gas engines using natural gas costs R0,75 to R 1,00 per kWh depending on the negotiated price of the pipeline gas whereas diesel-generated electricity currently costs R2,80 to R3,00 per kWh. Natural gas generated power is subject to long term agreements so the cost is more stable compared with diesel generated power, where the price of fuel changes frequently and is generally increasing. Gas engines are more suitable for base-load applications than diesel driven gensets which have their prime application in emergency power systems.

South Africa has recently lifted the 2011 moratorium on shale gas exploration in the semi-arid Karoo region, where the extraction technique of "fracking" might be used to tap into some of the world's potentially largest stocks of this energy source. Collins Chabane, a Minister in the President's office, stated on Friday, 7 September 2012 that the Cabinet had decided to lift the moratorium, after a study eased safety concerns related to the controversial method [4].

According to an initial study commissioned by the US energy information administration, South Africa has 485-trillion ft^3 of technically recoverable shale gas resources, most of which are located in the vast Karoo basin. The reserves could be a long-term solution for the energy problems of Africa's largest economy, which relies on coal to produce 85% of its electricity. The Eurasia political risk consultancy believes that lifting the moratorium could be "a game changer" for South Africa's economy. There are serious concerns relative to the impact of "fracking" on regional groundwater systems and each project will require careful evaluation which may include the implementation of significantly expensive environmental mitigation measures .

Large reserves of natural gas have been discovered off Namibia, Northern Mozambique and Southern Tanzania. According to the Department of Energy the development of regional gas-fields will lead to natural gas becoming a more important fuel in South Africa. With the availability of natural gas in neighbouring countries, such as Mozambique and Namibia, and the discovery of offshore gas reserves in South Africa, the gas industry in South Africa is undergoing rapid expansion. In addition to coal gas and Liquid Petroleum Gas (LPG), South Africa produced about 930 000 t of natural gas and 104 860 t of associated condensate in 2003. The entire gas and condensate output is dedicated to Petro SAs liquid-fuel synthesis plant, and accounts for about 1,5% of total primary energy supply. Gas manufactured from coal accounted for 5% of net energy consumption, while LPG accounted for about 6% [4].

Year	Client organisation	Units installed	Recovery
2007	Petro SA Mosselbay	GE Jenbacher – 3 x 420 @ 1413 kW ea. natural gas engine/ gensets	Electricity

Table 2: Biogas engine/gensets installed in South Africa.

Year	Client organisation	Units installed	Recovery
2006	DSW La Mercy	GE Jenbacher – 1 x 312 @ 637 kW landfill gas engine/ genset	Electricity
2006	DSW Mariannhill	GE Jenbacher – 1 x 320 @ 1063 kW landfill gas engine/ genset	Electricity
2008	DSW Bisasar Road	GE Jenbacher – 4 x 320 @ 1063 kW ea. landfill gas engine/gensets	Electricity
2009	DSW Bisasar Road	GE Jenbacher – 2 x 320 @ 1063 kW ea. landfill gas engine/gensets	Electricity

Table 3: Landfill gas engine/gensets installed in South Africa.

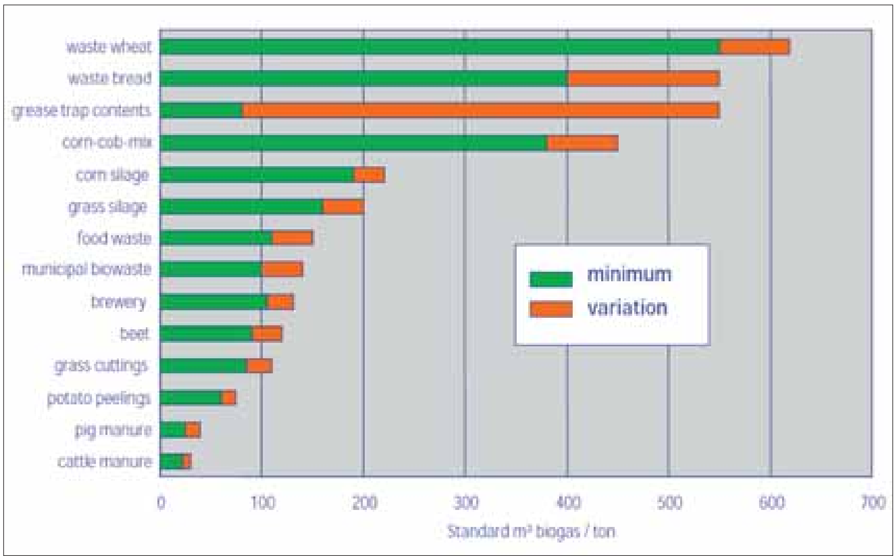

Fig. 3: Biogas generation from various waste streams [6].

There is also potential to extract methane from South Africa's deep gold mines in order to generate electricity to supplement the power used by the mines. Coal measures also hold methane gas but most of the coal deposits east of the Waterberg have low gas yields. A number of projects have already been established in South Africa using Sasol pipeline gas as can be seen in Table 1.

- The Thos Begbie project uses methane enriched gas to generate electricity in a grid parallel system.
- The ABSA Towers engines run on methane rich pipeline gas in a grid parallel system and use the engine block heat (nominally at 80°C) to provide hot water to the building housing the gensets which are located in the basement. The ABSA Towers project was elegantly presented by Ken Gafner in Energize of May 2012.[5]
- The MTN project uses natural gas to generate electricity independently of the grid. The engine block heat provides hot water and the exhaust heat (nominally 460°C at full load) provides air conditioning for the MTN campus through absorption chillers.

In Holland and Belgium intensive tunnel farming projects use natural gas with trigeneration and carbon fertilisation to produce cut flowers and vegetables – the electricity provides light, the engine block heat warms the tunnels, the exhaust gas heat provides cold storage through absorption chillers and the exhaust gas itself is processed to remove unburned hydrocarbon residues prior to being fed into the tunnels where the enriched CO_2 accelerates the growth rate of the crops. More than 600 GE Jenbacher units with CO_2 fertilisation with a total electrical output of 1500 MWe have been supplied in the EU. Preliminary investigations are taking place into the deployment of this technology in intensive agriculture in South Africa.

Biogas engine/gensets

Biogas is one of the final by products of anaerobic biodegradation of waste effluents derived from local authority waste water treatment, industrial effluent and agriculture waste stream processing and treatment plants when these installations are managed correctly. Table 2 lists the Petro SA plant.

Whilst the Petro SA plant does not include CHP, many waste water treatment plants in Europe make use of both the engine block heat and the exhaust heat through heat exchangers to optimise the operating temperatures of the anaerobic digesters.

Fig. 3 shows that biogas yields are relatively low for sewage. Better yields may be obtained from food wastes. This is so because animals, including mankind, are actually quite efficient in extracting energy from the food that they ingest so there is less energy in their faeces than might be generally supposed.

Biogas typically consists of methane (CH4) at 65% and carbon dioxide (CO_2) at 35% by volume and is saturated with water vapour. Notable impurities include siloxanes and hydrogen sulphide (H_2S). Siloxanes result in the formation of silicate residues in the combustion chambers of the engines which necessitates decoking during the servicing of the engines. If siloxanes are present in excessive concentrations the decoking intervals may be too frequent for the efficient operation of the engines. It will then be necessary to remove siloxanes in the conditioning of the gas stream prior to its being used in engines.

During combustion H_2S converts to SO_x which form sulphurous and sulphuric acids. The acids accumulate in the engine oil and, if excessive, will increase the need to change the oil more frequently than is recommended by the engine manufacturer. If the H_2S concentration in the gas exceeds the limits recommended by the manufacturer it can be removed in a biogas conditioning process prior to being used in the engines. It may also be necessary to remove condensate from the biogas.

The decision to condition the biogas is always a matter of economics and in many cases more frequent decoking and oil changes may be tolerated because of favourable cost-benefit analyses. There is no one solution that fits all circumstances and plants must be engineered to meet client's individual needs.

It may be necessary to use gas holders to minimize the impact of negative pressure

Fig. 4: A biogas farmer installation with Gas holder storage in Austria.

Fig. 5: DSW bisasar road landfill energy compound.

Year	Client organisation	Units installed	Recovery
2009	IFM	GE Jenbacher – 10 of 620 @ 1700 kW ea. furnace gas engine/gensets	Electricity
2011	SA Calcium Carbide	GE Jenbacher – 4 of 620 @ 1700 kW each furnace gas engine/gensets	CHP

Table 4: Furnace Gas Engine/Gensets installed in South Africa.

on anaerobic digesters as these may implode if the suction pressure being applied to extract biogas is excessive. Gas holders assist in the management of a steady fuel supply to the gensets.

Landfill gensets

Landfill gas is derived from the breakdown of municipal solid waste and is similar in many respects to biogas as it is one of the final byproducts of the anaerobic biodegradation of waste and it is also saturated with water vapour. Residual gas in active landfill sites where the gas has never been extracted is similar to biogas extracted from a waste water treatment works having a CH_4 concentration of 65%. However, when the gas is being extracted for electricity generation it typically consists of methane (CH_4) at 50% and carbon dioxide (CO_2) at 50% by volume.It may contain siloxanes and H_2S and may require conditioning before being used in gas engines. The decision to condition the landfill gas is always a matter of economics and in many cases more frequent decoking and oil changes are tolerated because of favourable cost-benefit analyses outputs.

Bisasar Road landfill is the largest landfill in Southern Africa. The landfill is surrounded by a residential area to the South and a high density informal settlement to the North West. Due to the proximity of the site to the surrounding neighbourhood, it is vital to reduce odours and mitigate health and safety concerns related to landfill gas. Gas cannot be stored in the landfill and continuously vents into the atmosphere. To manage the release of gas, Bisasar Road established a landfill-gas-to-electricity project.

A combination of vertical and horizontal gas wells are installed in the waste body of the landfill and the gas is extracted by two blowers that create a negative suction to draw the gas to the energy compound, where it is compressed and delivered to seven GEs Jenbacher gas engines at 110-millibar. Delivery pressure to the engines is controlled by a Hofstetter flare that combusts any surplus gas at temperatures in excess of 1000°C with retention times in excess of 2 s. The six GE J320 engine gensets and one GE J312 engine genset are capable of generating a combined total of 6,9 MWe / h, which is exported to the Ethekwini power grid.

Bisasar Road extracts and combusts an average of 4200 Nm^3 /h of gas and provides power to the equivalent of 7000 households. This may seem like a drop in the ocean considering our current power crisis but this is power from a waste gas that would otherwise be entering the atmosphere.

CH_4 is a greenhouse gas with a global warming potential 21 times greater than CO_2 and Bisasar Road thus qualifies under the Kyoto Protocol as a Clean Development Mechanism project. Each Certified Emission Reduction (CER) is the equivalent of 1 t of CO_2 not emitted into the atmosphere. Up to December 2011 Bisasar Road had accumulated just under 700 000 CERs (worth about R94-million) as well as an additional R44-million through the sale of electricity provided to the local eThekwini electricity grid.

Furnace gas engine/gensets

South Africa is one of the larger producers of ferro-alloys in the world. The furnace gases produced by smelting processes vary quite considerably from one process to another but consist mainly of carbon monoxide (CO) and hydrogen (H_2) which were historically flared to atmosphere.

In each situation the gensets are engineered to use the furnace gas produced by the client's particular furnaces. Of particular concern is the particulate size and concentration in the gas stream and particulates are extracted using a variety of specialised filtration systems. The concentration of H_2 is also a problem as this gas causes knocking in gas engines which can lead to serious damage.Allowance must be made for gas mixing related to furnace tapping and recharge cycles to facilitate stability in the gas quality. Moisture in the gas feed may also require management. These potential problems are all managed through

Fig. 6: International Ferro Metal's MooiNooi furnace gas to electricity plant.

appropriate gas conditioning systems. Electricity production from furnace gas using correctly configured engines with conditioned fuel gas has been shown to be viable. Table 4 lists current furnace off gas generation plant in South Africa.

International Ferro Metal's (IFM) plant is currently producing 16 MWe on a continuous basis which equates to 11% of the power consumed by the furnaces at this plant. If Eskom were to enforce the 10% capping of power consumption on IFM, this operation would be unaffected.

The men in the right hand top corner of Fig. 5 illustrate the scale of the plant.

The SA Calcium Carbide plant is currently being installed in Newcastle and two of the engines will be configured for CHP.

The potential for power generation using "waste'" gas sources in SA

Biogas and landfill gas

The capacity building in energy efficiency and renewable energy study completed for the Department of Minerals and Energy in 2004 demonstrated that landfill gas alone could contribute 80 MWe to South Africa's power requirements [7]. Although biogas from municipal waste water treatment plants wasn't studied its potential contribution is considered to be of a similar magnitude.

Significantly, these sources of power could be quite rapidly deployed within a 12 to 14 month project realisation cycle. Further, since the major landfills and large waste water treatment facilities are all associated with metropolitan developments in South Africa the power would remain under the control of the metropolitan authority grid structures and would all show the benefits of distributed generation. Durban Solid Waste, the eThekwini Metro's waste management agency, in cooperation with the eThekwini Metropolitan Electricity Department has demonstrated that this approach is viable.

There is also substantial potential for smaller projects located at intensive agricultural production units to either contribute to the grid or satisfy their own electricity requirements. Several countries in the EU have chosen to develop distributed electricity production this way and there are over 1750 small scale biogas to electricity projects operating where state subsidies are offered to "biogas farmers" producing <1 MWe. A major constraint to the implementation of this approach is the provision of entry points into the grid infrastructure. Consequently projects that are initiated in the short term will be associated with power for own use and, where convenient and cost effective entry points exist, power wheeling may be considered.

Furnace gas

The gases that make up furnace gas provide a relatively low energy fuel supply but there is potential to produce a substantial contribution to South Africa's electrical power supply from these sources alone and some estimates suggest the following [7];

- 60 Open Furnaces – 1,64 GWe
- 42 Closed Furnaces – 1,98 GWe

The furnace industry alone uses 10% of the country's entire electrical generating capacity of 40 GW at full production. As IFM has shown it will be possible for significant numbers of furnace operators to meet Eskom's cap restrictions if these are applied in the future. Instead, Eskom is offering financial incentives to furnace operators to shut down their plants. This has negative consequences on the mines supplying ores, coal and other raw materials which diminishes the capacity of a significant sector of the economy relative to growth and employment opportunities.

REBID

In 2009, South Africa's National Energy Regulator (NERSA) announced the REFIT schedule for a range of technologies [8]. The REFIT process appeared to stall and in July 2011, the Department of Energy announced that there would be a competitive element to the award of power purchase agreements.

At the time of writing the successful bidders under the first round of the REBID process have yet to achieve financial closure. The process appears to be ponderously slow and is causing delays which can be expected to systematically exacerbate delays in the implementation of the next REBID cycles. A nine month delay has already been announced relative to the third REBID cycle, i.e. from October 2012 to May 2013.

The relationship between electricity supply and job creation has been established quite clearly [8], and many of the potential waste gas projects would create employment opportunities in the operation of the plants themselves whilst contributing efficiently to the electricity supply through distributed generation. Irrespective of the current situation and the associated impediments, small scale independent power producers will become economically viable as the price of electricity rises and more of these facilities will become established in South Africa. However, this should be happening sooner rather than later.

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