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GAS TO POWER

TECHNOLOGY OPTIONS AND RECOMMENDATIONS
An African Perspective

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Background

Economic growth in Africa is spurring the demand for more electricity. Markets which have access to natural gas and where electricity is in short supply are best suited to implement gas to power technologies to convert the energy within the gas to electrical power. There are essentially two technology options; either to use gas turbines in combined or open cycle mode or to use gas engines in combined or open cycle mode.

The decision on which technology to choose and the configuration within that technology choice depends on numerous technical, economic and commercial attributes but probably the most influential driver is the demand from the off-taker. i.e. Is it necessary to operate the power plant as a baseload, mid-merit or as a peaking plant?. Sasol has facilities in South Africa and Mozambique that use both gas turbine and gas engine technologies, in both open cycle and combined (or even combined heat and power) cycle mode.

This paper describes a number of factors that affect the technology choice and specifically highlights some of the factors that may be more relevant to building gas to power facilities in Africa. In instances where process heat and electrical power are to be produced simultaneously, the required steam quality dictates the technology to a large degree as gas turbines allow for the production of high pressure (ca. 38 barg) steam whilst standard gas engine configurations are limited to the production of medium pressure (ca. 17 barg) steam.

In all other scenarios, the main aspects to consider are the site ambient conditions and altitude, the degree of flexibility and availability required by the electricity off-taker (baseload, mid-merit, peaking), the remoteness of the site, delivered gas price, gas volume profile, water availability and capacity of the plant. Sometimes social-economic factors may also be important, particularly in areas which lack infrastructure and relevant skills. Either training programs need to be put in place to address the gap or one needs to consider technology options which do not utilize specialized equipment.

A number of Sasol and non-Sasol examples are highlighted to show that in Africa, depending on the business needs and location, any technology option can be viable.

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Approach and Method

The first approach adopted was to look qualitatively at the typical factors that influence gas engine or gas turbine selection and to contextualize these factors within the African environment. The second stage takes notes of factors that don't affect technology selection per se but are most relevant to constructing and operating gas to power plants on the African continent. Specific examples are referenced to support the technology selection decision made.

Technology Comparison

Technology Landscape

The landscape of technologies suitable for conversion of gas to power is listed below:

1. Standard frame gas turbine technologies (high combined cycle efficiency)
    a. Open cycle (OCGT)
    b. Combined cycle (CCGT)
2. High-efficiency gas turbine technologies (higher efficiency in open cycle than standard frame gas turbines) - typically aeroderivative.
    a. High efficiency open cycle (AOCGT)
    b. Highest efficiency combined cycle (ACCGT)
3. Gas engine technologies (high efficiency in open cycle)
    a. Open cycle (OCGE)
    b. Combined cycle (CCGE)

Of these, only those operating in a combined cycle mode, have the ability to produce steam and electrical power. Steam is produced in the Heat Recovery Steam Generator (HRSG) which can then either be used as process heat for downstream users or be sent to the steam turbine where additional electricity may be produced.

Technology influences

Capacity

The intended capacity and future capacity increments, and nature of energy services to be offered to the market by the power plant, has a strong influence on selection of gas power plant technology. For gas turbine selection, larger capacity (over 400 MWe) is likely to favour the use of large, more efficient units ("F" or "H"-class type gas turbines) versus multiple smaller and less efficient gas turbines. Before the advent of the large gas engines (ca. 20 MWe), the capacity cut-off between gas engine and gas turbine selection, would have been a plant of around 200 MWe; now the options to include gas engines is viable for plants up to around 400MWe in capacity pending electrical off-taker requirements, inter alia.

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Nature of electricity market.

In a baseload based market, there is no ramping (ability to incrementally increase electricity generation capacity) required as the plant operates at or near 100% load when the units are available. Options which have the highest efficiency (gas turbines in combined cycle) are best suited to this type of operation. In peaking or mid-merit markets, portions of the plant are expected to be shut down to follow the load requirements. Peaking usually means operating at part-load with the ability to respond quickly to changing demand whilst mid-merit is a mode of operation where the plant follows the load demand. For a combined cycle configuration (gas turbine or gas engines), this results in more thermal stress on the HRSG and steam turbine and increases the maintenance cycles on these units. In addition, both aero-derivative and industrial gas turbines undergo accelerated degradation when they are required to stop-start more frequently than planned. It is also important to note that the time to start-up and shut-down is longer for a combined cycle gas turbine or combined cycle gas engine plant which means lost production vs. an open cycle gas turbine or gas engine plant.

High efficiency aero-derivative or hybrids with industrial gas turbines, operating in open cycle mode, are becoming increasingly competitive against open cycle gas engine configurations. However, they are generally 30% or so more expensive, due to the more exotic materials used, the cycle time between maintenance is far shorter and they have lower tolerance to upsets. They also suffer a number of mechanical related issues. Low pressure air-compressor vibration and corrosion problems have been reported in nearly all gas turbine models, and there have been reports of frame cracking and bearings related issues. Maintenance may require the use of specialised equipment for mandatory bore-scope inspection after any stall (particularly at the high-pressure air-compressor). Aero-derivative gas turbines are also prone to pitting of the rotor shaft and hence permanent loss in performance. Vibration analysis and monitoring are vital to avoid excessive dynamic loads, damages and premature failure which all adds to the cost of maintenance.

A gas turbine (aero-derivative or industrial) also undergoes significant derating when operated at part load (less than 70-80% of design load).

Flexibility comes at a compromise to efficiency (and hence gas consumption per MWe produced) [Figure 1]

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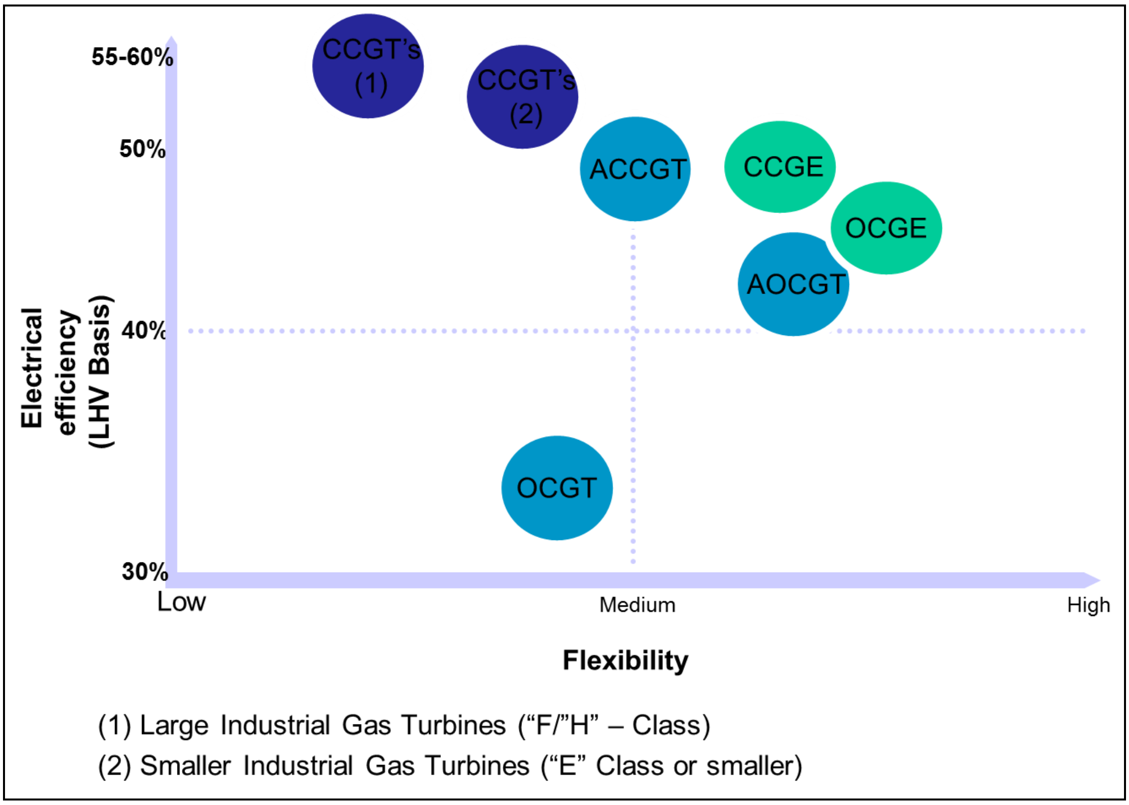

Figure 1. Qualitative comparison between various gas turbine and gas engine configurations.

In general though, open cycle industrial frame gas turbine configurations have the lowest efficiency of all the options above and therefore will consume more gas per MWe production. Even though there are higher efficiency large standard frame gas turbines (ie. F and H -Class machines) on the market, this comes at the sacrifice of plant availability and flexibility, especially if the overall plant capacity (read: capacity <400MWe) only calls for one or two of these turbines. High efficiency aero-derivative gas turbine options are ca. 30% more expensive than standard frame gas turbines and only become cost effective if the delivered gas price is high. Similarly, combined cycle gas engine facilities become attractive only when delivered gas price is high.

Availability and firm capacity

Gas engine facilities can be built with an n+1 or n+2 sparing philosophy with little additional expense. This allows these facilities to achieve availabilities >98% and to

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sustain high firm capacities throughout the life of the plant. In addition, one will only lose between 0-7% of power output if a single engine fails. In a gas turbine plant, availabilities are typically in the region of 91-94%. In general for sizes above 10 MWe per machine, it is not beneficial to install spare gas turbines since the cost of a single turbine is significantly more than a single gas engine. This means that one can lose anywhere between 25-100% of power when a gas turbine fails, depending on the gas turbine/HRSG configuration. Security of supply could be very costly if not met, especially if one has agreed to a certain reliability/availability as part of the power purchase agreement.

Site selection drivers

Ambient conditions

It is important to note that gas engine and turbine suppliers quote performance under ISO conditions. These are 15^{o}C, 1 barg and 60% relative humidity. Deviations from these conditions can lead to derating (lower power output per unit of gas consumed), especially when one looks at locating the facility at sites that are more humid than ISO conditions, that are higher than sea level or that have ambient temperatures on average warmer than 15 ^{o}C.

Gas turbines undergo significant derating at temperatures above 15 ^{o}C and where the plant is located above sea level[1]. Derating due to temperature is around 5% at 25 ^{o}C and 10% at 35 ^{o}C. Aero-derivative turbines can overcome this derating impact with the advent of intercoolers, but this comes at a sacrifice on net power output. For every 1000 m rise in altitude standard gas turbines derate by around 10%, the figure is greater for aero-derivative type turbines. It is important to note that the derating is only on the gas turbine, and not inclusive of the HRSG or steam turbine (where a combined cycle configuration is selected).

Gas engine units are relatively immune to any derating unless ambient temperatures are extreme (above 35 ^{o}C) or the plant is situated above 2500 m above sea level[2]. Gas

[1] "GE Gas Turbine Performance Characteristics", Brooks (http://www.muellerenvironmental.com/documents/GER3567H.pdf) and "Gas Turbines in Simple Cycle and Combined Cycle Applications", Soares (http://www.netl.doe.gov/technologies/coalpower/turbines/refshelf/handbook/1.1.pdf).

[2] For gas engines, "Gas Power Plants" pg 9, article from Wartsila (on www.wartsila.com). Heat rate derating: (https://www.wecc.biz/committees/BOD/TEPPC/External/E3_WECC_GenerationCostReport_Final.pdf).

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engines however do undergo derating in environments where the relative humidity is higher than ISO though this may be overcome if a drain is installed at the intercooler.

Water supply and Water quality

Combined cycle gas turbine configurations could use as much as 200 times more water than open cycle gas engine facilities, if wet cooling is employed[3]. If air cooling/dry cooling is employed, the volume of water needed reduces 10 fold but is still more than that required by an open cycle gas engine facility of similar capacity. Some gas turbine options use even more water to meet the low NO_x emission requirements set by environmental specifications. However, in this instance, one could also use dry low NO_x burners instead (slightly more capital). As most African countries have limited water supply, one would typically look at technologies that would minimise the use of water or pay the small capital penalty to put in dry low NO_x burners.

Combined cycle gas turbine and gas engine facilities need ultra pure water to prevent corrosion and erosion in the HRSGs and steam turbines. If the gas turbine is using water for NO_x suppression, then ultra pure water is also required. Open cycle gas engine and gas turbine plants only need water that has been filtered and undergone reverse osmosis treatment. This means less effluent needs to be handled and treated and cheaper water treatment facilities can be installed.

Available Infrastructure and Remoteness of site

Generally, gas to power plants need to be situated close to the source of the gas (wells or main arterial gas pipeline) as the cost of a gas pipeline is more expensive than the cost of a building a transmission line to the nearest substation. Gas turbine plants require high gas inlet pressures (>24 barg) and therefore ideally need to be situated close to compressor stations or the source of the natural gas. However, one needs to also factor in regulatory processes and understand whether the time and cost associated with obtaining permits and access to servitudes for either gas pipeline or transmission lines is a factor.

Typically in Africa, a gas to power plant may be situated in relatively remote areas where there is little infrastructure. This means that gas to power plants must generally be self-sufficient (i.e. provide their own utilities, waste and effluent treatment and have on-site maintenance workshops). The conditions of roads, bridges and ports may also impact on technology selection, though this may be off-set by a once off capital injection to allow heavy equipment to be transported to site. Large gas engines are very heavy (greater than 200 tons) and will typically require significant temporary infrastructure to transport to

[3] (a) "Cost and value of water use at combined cycle power plants", Maulbetch and DiFilippo (2006)) and
(b) http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/water-energy-electricity-cooling-power-plant.html#ftn1

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site; in some cases, a beach landing may be required if the road and bridge infrastructure is poor.

The level of specialised personnel available to maintain and operate the power plant can influence the decision on technology: Simpler/ more common technology and/or a modular plant design may better suit more remote locations. Gas engine maintenance, although more frequent than with a gas turbine, requires smaller/simpler parts and therefore it may be easier to upskill people to assist with onsite maintenance. This may be an important factor in technology selection especially where a country mandates the use of a percentage of local labour for operation and maintenance purposes.

Environment impacts

The allowable impact on the environment, in terms of hydrology and water use, soil and vegetation disturbances, dust pollution from continuous stream of trucks over un-surfaced roads, may influence aspects of the technology selection. However, for most locations this is not a determining factor. Generally, all technologies can meet the environmental specifications though gas turbine options, may specifically need the installation of more expensive dry low NO_x burners or the consumption of more water.

Gas volumes and delivered gas prices

Gas turbine configurations in combined cycle have higher thermal efficiencies than gas engine configurations (either in open or combined cycle) and will therefore consume less gas per MWe produced. If there are constraints on the volumes of gas available and there is a need to maximise electricity production, this could be a factor in which technology to choose.

Delivered gas price has a marked impact on technology selection. When prices are high (>$4/GJ), the more efficient process will typically result in the lowest levelised cost of electricity; however, there are exceptions pending electricity off-taker needs, site conditions, inter alia.

Other factors influencing technology selection:

- Quality of the natural gas – natural gas containing some heavy hydrocarbons is more suitable for gas turbines as some gas engines undergo derating if the methane number is below 80. Gas turbines are particularly susceptible to particulates in the gas feed. If the gas is not conditioned properly, particularly if sulphur compounds are not removed for example, soot can be formed in the burners and subsequently damage the blades of the turbine. It is very important that the plant is therefore designed to accommodate the gas quality expected throughout the lifecycle of the plant

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- Maintenance costs – On a per unit basis, gas engine maintenance costs are far lower than for gas turbines. Although individual parts are cheaper than for gas turbines, the overall maintenance costs for gas engine plants may generally be higher than similar gas turbine plants due to the number of pieces of equipment that need to be maintained and the more regular maintenance required.
- Lube oil consumption – gas engines consume more lube oil per hour than gas turbines do and therefore have slightly higher operating costs. For a facility of the same capacity, a gas engine power plant will require larger storage facilities.
- Operating personnel – gas engines require more people to operate per unit which leads to higher fixed cash costs. At the same time, this may be a strategic/social driver in a particular country.
- Construction schedule – the construction timeline to install gas engines can be some 10-12 months shorter than for a gas turbine plant of the same size but this ultimately depends on the market situation at the time. In fact, the period between financial close and start-up can be as short as 12 months in the case of a gas engine facility (reference: Kipevu power plant, Kenya).

Other Factors – Technology independent

The factors below, although not necessarily specific to Africa, are more pertinent to the construction of gas to power plants in Africa and could impact capital costs and schedules. These issues are independent of technology selection:

Landmines

Is the plant to be located in an area where there may be landmines? If so, an extensive demining exercise will be required. This must be planned for in advance as this will prevent access to site for environmental specialist studies and this could result in a delay of the environmental authorisation process. In addition, this will prevent access for geotechnical and other studies required for engineering of the works.

Land compensation

Where the servitudes for the gas pipeline, transmission line and the power plant itself run through land owned by others and/or where communities are using the land for farming; some form of compensation needs to be allowed for to relocate the communities and to compensate for loss of income. A process known as "blue carding" is necessary to identify all current land owners/land users to prevent others from making claims in the

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future. This can be quite an exhaustive exercise and needs to be done in advance of any major earthworks.

Geology

It is important to do a thorough examination of the geology where one wants to locate the power plant. Rocky areas will require blasting and add to the capital cost as well as schedule delays.

Unplanned for Strikes

Depending on the country; there may be a number of unplanned strikes that may delay construction. In addition, one must consider the likelihood of strikes in the country where one is sourcing material, not only in the country the likelihood of strikes where the plant is being built.

Work permits and restrictions on number of expats (regulatory factors)

It is important to understand the work permit requirements in a particular country and what the specifications are regarding the use of local labour vs. expats. Also take note that bureaucratic issues could take longer to resolve than in European or other developed countries.

Skills and labour productivity

Most African countries have limited semi-skilled and skilled labour and therefore one may need to train local labour in advance to upskill them. This also links to the requirements that some countries may have regarding the employment of local labour. Additional supervision may need to be provided to ensure productivity levels are sustained.

Lack of Infrastructure

Most (not all) African countries have limited infrastructure and this needs to be taken into account when designing a gas to power plant. Eg. Allowances for sewage and water treatment, roads and bridges upgrades, upgrades to substations (or construction of new substations), inter alia. Also communication and Information Technology could be limited in some parts of Africa thus many documents may need to be printed and hand delivered for signature.

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Local official language and culture

Be aware of the local official language to ensure all relevant documents are translated into the correct language in time, to prevent delays. Employing someone who is familiar with the ways and customs within that country could help facilitate the approval and expediting of official documents.

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Results

Qualitatively there are a number of factors that are both negative and positive to both technologies and the technology decision can vary from one African country to the next. One has to consider each case by itself and subsequent to the qualitative assessment; a techno-economic evaluation should also be completed, especially where the technology selection is not that clear.

In South Africa most power plants would generally be located in the Highveld area (close to the bulk of the consumers) which is around 1500 m above sea level and has high ambient temperatures on average. Gas turbines will undergo significant derating in this area. The opportunity in Sasolburg was limited to around 175 MWe which lent itself to using small gas engines (<10 MWe) in open cycle configuration at the time. Subsequent to this, HRSGs have been added to allow for the production of medium pressure process steam for use in the Sasolburg chemical plant. This was at the time, the largest gas engine facility in Africa. A similar size facility has recently been commissioned by Central Termica de Ressano Garcia at Ressano Garcia, Mozambique.

In Mozambique, most areas are generally warmer on average than ISO conditions and have high relative humidity. Water availability is often an issue though there are areas where underground water is available. The lack of infrastructure in some areas can make it challenging to transport large and heavy equipment to site and in almost all instances any roads and bridges will have to be upgraded. For mid-merit or peaking operation, it is generally more attractive (especially for capacities <200 MWe) to employ gas engines in Mozambique but this is by no means one hundred percent true in all cases.

In Kenya and Tanzania, Wartsila has commissioned a number of gas engine power plants ranging from 45 MWe to 116 MWe though these typically run on crude oil[4].

There are a number of smaller facilities throughout Africa employing gas engines (also primarily running on heavy fuel oil, biogas, inter alia) – these include the Kipevu plant in Kenya, Grand Cote in Senegal, plants at Chi in Nigeria (8 MWe) and the Akute Power plant near Lagos, Nigeria (12 MWe) and plants in Cameroon and Rwanda).

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[4] http://www.wartsila.com/en_KE/about-us/history

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However, where high pressure steam is required for process use, then a gas turbine configuration is more attractive – such as that which Sasol has constructed and operated in Secunda. It is operated as a combined heat and power plant producing ca. 220 MWe electricity and ca. 250 t/h high pressure steam. The high pressure steam is used by processes within the Sasol Secunda facility, primarily as heating medium.

Elsewhere in Africa, Nigeria has constructed and is operating a number of gas turbine facilities. In general the capacities of these plants are far greater than 400 MWe and therefore the selection of gas turbines over gas engines was quite clear. Also these plants are typically run as baseload facilities, again favouring gas turbines. What is interesting is that a number of the gas turbine plants are running in open cycle mode but with most having the option to convert to combined cycle later. The reasons are most likely two fold – (1) the capital required to install the combined cycle portion of the plant is significant and (2) if gas is cheap (<$4/GJ), then having a less efficient open cycle process would not impact the levelised cost of electricity significantly. Ambient conditions in Nigeria would indicate some derating on the gas turbine due to warm temperatures but the topography is mostly near sea level. There are a number of small scale power plants running with gas engines though (eg. At Chi (ca. 8MWe), Akute Power (12 MWe), inter alia).

In Tanzania, the state-owned energy provider Tanzania Electric Supply Company Limited (TANESCO) also operates gas turbine power plants to provide power to Dar es Salaam, the largest city in Tanzania, and there are a number of other gas turbine power plants throughout the country. The power plant in Tahaddart (Morocco) – 30 kilometers south of Tangiers on the Atlantic coast – is Morocco's first combined-cycle power plant. In these two countries, there is a need to be able to feed various types of fuels such as heavy fuel oil, distillate and natural gas and that is why gas turbines were considered, however, it should be noted that some gas engines vendors do offer multi-fuel configurations (reference: Grand Cote, Senegal).

For plants in the region of 400 MWe operating at mid-merit operation (Figure [2]) and factoring in the higher than ISO ambient temperatures generally prevalent in the sub-saharan region, large gas engine based plants are attractive. However, where gas is cheap (<$4/GJ), open cycle gas turbines (even though less efficient) start becoming attractive. The final decision would depend on a comprehensive techno-economic assessment with up to date market costs for the power plant.

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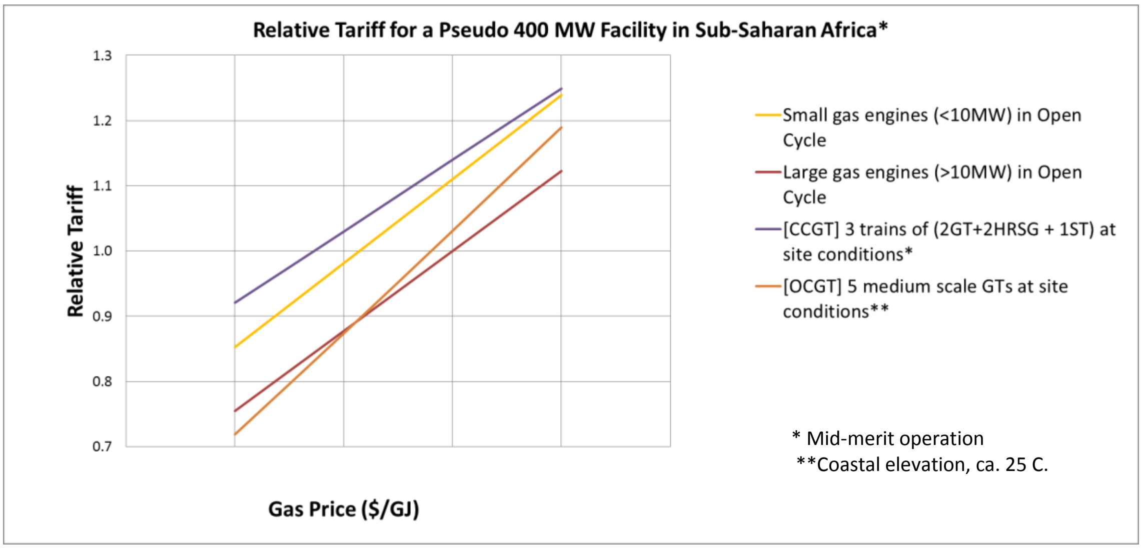

Figure 2: High level techno-economic comparison of gas to power configurations for a pseudo 400 MWe facility based in Sub-Saharan Africa*.

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Conclusions

Although the majority of new gas to power plants planned or commissioned in Northern Africa are based on gas turbine configurations, it is evident from Sasol's own experience, that one is not necessarily restricted to gas turbine based options only and that gas engines configurations can also be economic and do play an important role in supporting the growth in electricity demand forecasted for the continent. In the past, gas engine power plants were uncompetitive beyond 200 MWe capacity. However, with the larger gas engines now offered by Original Equipment Manufacturers, the landscape has changed such that even up to 400 MWe and pending electricity off-taker needs and site conditions, gas engine power plants can now be a force to be reckoned with at this increased capacity. Ultimately the decision on technology is primarily a techno-economic one. A detailed assessment taking into account site conditions, infrastructure and skill availability, operability (flexibility and availability) needs, amongst other things can alter the playing field. Where gas prices are high(>$4/GJ), a technology which shows the greatest efficiency will be the most attractive whilst for low gas prices(<$4/GJ), a technology which is primarily less capital intensive will be the most attractive.

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References

[1] "GE Gas Turbine Performance Characteristics", Brooks (http://www.muellerenvironmental.com/documents/GER3567H.pdf) and "Gas Turbines in Simple Cycle and Combined Cycle Applications", Soares (http://www.netl.doe.gov/technologies/coalpower/turbines/refshelf/handbook/1.1.pdf).

[2] For gas engines, "Gas Power Plants" pg 9, article from Wartsila (on www.wartsila.com). Heat rate derating: (https://www.wecc.biz/committees/BOD/TEPPC/External/E3_WECC_GenerationCostReport_Final.pdf).

[3] (a) "Cost and value of water use at combined cycle power plants", Maulbetch and DiFilippo (2006)) and
(b) http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/water-energy-electricity-cooling-power-plant.html#ftn1

[4] http://www.wartsila.com/en_KE/about-us/history

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