Country Study Myanmar: Sustainable increase in power generation capacity – a review of effective options

Power-Gen Asia, Kuala Lumpur, September 2014
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1. Abstract

Myanmar has a huge potential for fast economic development and growth. However, the growth is very much dependent on the country’s capacity to develop a reliable power infrastructure to increase access to electricity and to support industrial development. For that matter, it is crucial that the country conducts a comprehensive evaluation of the appropriate fuel mix and different generation technologies that are available for power generation both in short and long term. This paper provides a review on Myanmar’s power system today, assesses the fuel and technology options available, and makes some recommendations for both short and long-term power generation options. The paper recommends dual-fuel medium speed internal combustion engines capable of running on HFO initially and switching to natural gas when available as a practical and feasible solution for increasing Myanmar’s permanent power generation capacity quickly. Furthermore, the paper reveals that dual fuel combustion engines prove to be the optimum solution keeping in mind short-term constraints as well as long-term needs of the country. Medium speed combustion engines have considerably lower life-cycle cost of generation than alternative technologies.

2. Myanmar – general overview

A few decades ago, the Republic of the Union of Myanmar, formally known as Burma, was considered to be the "Pearl of Asia". It was one of the region's leading economies, with a per capita income more than twice that of its neighbour, Thailand. After decades of isolation and stagnation, the political and economic reforms in the recent years have caused the world to closely focus on Myanmar. Isolation has kept the progress of the country at a very slow pace, hence providing massive potential to grow. Currently, Myanmar has one of the lowest GDP and electricity consumption per capita in the region.

With its remarkable natural reserves, untapped oil and gas potential, promising demographics with 62% of the population in working age, and its strategic location, Myanmar has potential to become one of Asia’s leading economies. A huge domestic market of approximately 60 million people, the potential to become a low-cost manufacturing hub and a leading position in oil & gas industry have undoubtedly attracted vast foreign interest to Myanmar.

Oil and gas have together been the largest source of the country’s foreign income for more than two decades. Gas exports were valued at USD 3.3 billion, accounting for almost 40% of all exports in financial year 2013. Compared to other ASEAN countries, Myanmar’s hydrocarbon reserves are quite significant: proven gas reserves are estimated at 283 billion cubic meters and proven oil reserves at 50 million barrels. Potential gas reserves are expected to be ~ 2.2 trillion cubic meters.

Institutions like World Bank, ADB, JICA, and IFC are active in the country and trying to support the development of the Myanmar at a faster pace.
### 3. Electricity market – overview

With a measly 29% electrification ratio, more than 2/3 of the Myanmar population lacks access to electricity. With a forecasted GDP growth of ~7–8%, the country has kept electricity on the top of its agenda.

The current installed power generation capacity of Myanmar is ~3800 MWe. 68% of it comes from hydro, 29% coming from gas and one coal plant of 120 MW. For the sake of comparison, the neighbouring Thailand, with a similar population as Myanmar, has ten times higher installed power generation capacity. There is a notable difference in available capacity: in the wet season, the available capacity in Myanmar is about ~ 2500 MWe, while in the dry season it can be as low as 1800 MWe due to reduced generation from hydro power plants. Some of the installed plants, for example the gas- and coal-fired ones, cannot run at its rated capacity and efficiency due to ageing and a sub-optimal maintenance history.

With forecasted increase of ~15% per year, the annual demand is forecasted to reach ~ 15000 MWe by 2030 in a high growth scenario. To match this, the country will need on average 800 to 1000 MWe additions to its power generation capacity every year.

The existing subsidies on electricity tariff are putting pressure on governmental budget. With the hike in April 2014, tariff is ranging from 35 Kyat (~3.5 USD cents)/Kw h to 150 Kyat (~15 USD cents) /Kw h depending on type of consumers and units consumed.

Feeble transmission and distribution (T&D) network are causing very high losses – of about 26%. It is almost impossible for the county to rely on national grid for 24/7 power, especially during the dry season or in areas outside of the former capital Yangon. Alternate source of electricity is the only solution for reliable power, which in most cases are diesel-fired, high-speed generators. At many places, these are the only sources of electricity available, which may cost ~ 30-40 USD cents /Kwh or even more.

The entire power sector in Myanmar is under the responsibility of the Ministry of Electric Power (MOEP). In its existing structure, MOEP is the sole player in-charge of transmission, distribution, off-taking, regulation and system planning. Until very recently, all the generation capacity was also owned by MOEP. Keeping in mind the rapid growth, huge need for investments, country’s current fiscal situation and scarcity of in-house resources, Myanmar is aggressively looking at external funding and Independent Power Producers (IPP). With a lack of IPP history, readily available project financing, or a bankable framework and contracts, attracting foreign investments is a challenge that the country is trying to overcome. While the country has attracted significant foreign interest from IPP developers, the journey to implement project financed IPP projects has just began.
4. Load demand and transmission & distribution network

Due to the availability of hydropower mainly in northern and eastern part of the country and the majority of power demand being around the Yangon region (as illustrated in Figure 1); there is a need to transmit the power from north to south. The power demand in the Yangon region is also expected to remain substantially higher as compared to other parts of the country. Central Myanmar, around Mandalay and the surrounding region, is also coming up as a high demand area. However, the mismatch in demand & supply due to the location difference of generation capacity and load pockets requires a robust, reliable and efficient transmission and distribution system in the country.

The country has transmission lines of 230kV, 132kV and 66kV, and it lacks interconnection with neighbouring countries. Power flow from north to south is reaching its capacity limit, especially in the eastern route of the country. There are several single-circuit segments, causing the system to be unreliable. Overall, the capacity and conditions of the T&D network needs substantial improvement. The Government of Myanmar is in the process of making upgrades to the transmission and distribution system. It is envisaged to build several new transmission lines and introducing a 500 kV system and reduce the T&D losses from the current 26%.

Figure 1: Myanmar: Power source and Load distribution 2012
5. ‘Quick fix’ power generation solutions – implemented
To cater to the rising demand and to meet immediate shortfall, MOEP has awarded a few IPP projects that will use domestic natural gas supplied to MOEP by Myanmar Oil and Gas Enterprise (MOGE), a national oil and gas company under the Ministry of Energy. On the tariff structure, fuel cost is settled between Myanma Electric Power Enterprise (MEPE is the off-taker) and MOGE while the IPPs receive a tariff excluding fuel price. There are three IPPs of 25 to 50 MWe each, using high speed gas engines, with unit sizes ranging from 1 MW to 4.3 MWe each. There are a couple of projects above 100 MWe range, using gas turbines to be initially started on open (single) cycle mode and later to be converted to combined cycle. The government has also implemented some short-term rental power plants as temporary solutions to fill the gap between supply and demand, until more efficient and sustainable power plants come up in future.

Such plants have been implemented to cater to the ‘immediate requirement of power’. The IPPs implemented so far, are not project financed, but mostly equity financed. Also some of these IPPs had to sacrifice on electrical efficiency due to choice of technologies e.g. high speed gas engines. However, such plants have supported the county with quick power through private investments in a critical time of electricity shortage.

Clearly, these are short-term focused solutions to cater to an immediate need. Going forward, the country would look at implementing high efficiency and sustainable power plants with lower lifecycle costs through long-term focused solutions. The government has already initiated a couple of power plants in 100 to 200 MW range, with international practices and standards to bring Myanmar to a level playing field with other countries in the region. Going forward, it is important for the country to explore and evaluate various fuel and technology options to be able to meet power demand at lowest life cycle cost in the years to come.

6. Possible fuel options to meet future electricity demand
Fuel mix is not only one of the most critical resources but also one of the main constraints while planning power generation capacity, and Myanmar’s case is no different. Though the fuel types being used for utility-scale power generation are not too many, it is of utmost importance to evaluate each option in the light of benefits and challenges attached to it, considering local perspective. In this section, the possible primary sources of power and fuel options are evaluated in Myanmar’s perspective.

6.1 Hydro Power: Myanmar is one of the few countries blessed with tremendous natural potential of hydro power. Myanmar has developed only ~2.6% of its overall hydro potential of ~108 GW. The IPPs developed by its neighbours China and Thailand dominates the future hydro power development and about half of such electricity is expected to be allocated to these countries. Overall, hydro is expected to remain the dominant source of electricity for Myanmar in years to come.
Along with its benefit, hydro power is also prone to seasonal variations. Myanmar has two distinct seasons: Dry season is prominent in the country, typically lasting from April to June and affecting the hydro power. Hydro power generation in dry season can be as low as 60% of the generation in the wet season. This being a big variation, the country faces even bigger challenge to meet the power demand during the dry season.

Large hydro plants take several years, sometimes more than a decade to develop before coming into operation. Also, the environmental and social impact of developing hydro power makes it difficult to implement potential projects in the most effective and timely manner. The mismatch between dam locations and demand hubs of the country also means that Myanmar needs robust T&D network to transport the electricity from such hydro power plants to where it is most needed. The additional cost, time and power losses associated with such T&D network are not to be forgotten.

Hence, due to the long development cycle, seasonal variation in power output and the dependence on weather conditions, Myanmar cannot rely solely on hydro power, especially in the dry season and in the near future. The country must look at fossil fuels to complement hydro power. Thermal power plants are reliable irrespective of weather conditions, can be developed faster, and are easier to install closer to power demand.

6.2 Natural gas: Myanmar has gas reserves; however, currently supply is insufficient to meet local demand, due to existing long-term export contracts with Thailand and China. Recently, the country has awarded more than 35 offshore and onshore blocks for further exploration. However, it will take several years before these blocks will come into production. On the positive side, the government has announced that future gas will be used domestically before any export. Currently available gas is planned to be consumed by existing power stations, plants under construction or development. Additional gas is expected to come online around 2021, if no delay occurs in the exploration and development schedule. This means that, although in the longer run Myanmar will have additional domestic gas, for short- to medium-term it will have to rely on other fossil fuel for power generation.

6.3 Coal: Myanmar’s only coal plant is running at 50% of its rated capacity of 120 MW. The county has stalled the development of big coal power plants in past, on the basis of ‘environmental impact’. The future policy of the Government on coal plants remains to be seen. Even if the country decides to pursue coal plants due to cheaper generation cost, implementing coal plants will be challenging, especially in the short term.

There is less than 1 million ton/year domestic coal available; however, the quality is poor, and reserves are not significant. Hence, relying on imported coal is mandatory. In addition to logistic infrastructural development for importing the coal, other challenges like the longer
development and construction period required by coal power plants and unwillingness of multilaterals to finance coal power projects, make it challenging for coal to be considered as a short-term solution for Myanmar. Going forward, cheaper hydro power will remain as the first priority to get dispatched. Coal plants are typically used for baseload operation and are not operationally flexible enough to provide load following or perform quick start-and-stop cycles.

This means that even if coal plants are chosen as part of the generation mix by the government of Myanmar, sufficient capacity of such plants may not be operational in near future. Hence, liquid fuels need to be considered as part of the short-term solution.

6.4 Liquefied natural gas (LNG): LNG is an option to supplement gas supply where gas is either not available or not sufficient in the right location. LNG is more often used, either to reduce the cost of generation as compared to an alternate fuel or to reduce emissions. Some countries also consider using LNG for fuel security or diversity.

In the context of Myanmar, if the country imports LNG, the cost of gas along with its transportation, storage and re-gasification, could be as high as 16–18 USD/MMBTU, depending on the size of the terminal, number of tanks and the location of power plants. This is 35 to 45% expensive as compared to the commercial price of domestic gas, which is in the range of ~12 USD/MMBTU. It is noteworthy that the real cost of gas to various ministries may be much lower than 12 USD/MMBTU. And already MOEP has heavy subsidy in existing tariff with prevailing fuel prices in the country.

LNG import terminals and storage tanks take several years to develop and construct. For Myanmar, where the key motive to have LNG is to make gas available for immediate use, the expensive LNG may not be available before 3–5 years after the decision to import LNG is made. Keeping in mind the country’s gas reserve, the imported LNG may be useful only for a limited period. And if the LNG is not available at the right time, the value of expensive LNG may not yield benefits to Myanmar. However, if the power tariff from the use of expensive LNG can be accepted by the country and imported LNG may be a part of the long-term solution, it may be considered for future perspective; but certainly not in the short term.

6.5 Liquid fuels (diesel, HFO and crude oil):

6.5.1 Diesel: Currently, most of the diesel used in Myanmar is imported. Using diesel in back-up generators to ‘keep the lights on’ is widely seen in Myanmar. For any country, using diesel in utility-scale power plants, especially on baseload, is the least preferred solution, mainly due to its cost (see figure 2). In addition to small back-up generators, diesel can also be used in medium speed combustion engines as well as gas turbines.
6.5.2 Heavy fuel oil (HFO): Historically, HFO is average ~35% cheaper than diesel, and it can be shipped to Myanmar for example from Singapore.Lower cost than diesel is the key reason that it is widely used as fuel in power generation in various countries like Brazil, Dominican Republic, India, Bangladesh, Philippines, Cambodia, and several countries in Africa and Middle East. Many of these countries use HFO, even in utility scale power plants, where liquid fuel is the practically most feasible option. It is possible to use a commercially available HFO quality which is compliant with World Bank’s Emission guidelines, which are applicable in Myanmar currently.

![Figure 2: Evolution of spot prices of HFO and diesel in Singapore hub, including the spread between them](image)

There are private companies who have initiated importing HFO to Myanmar and making it locally available for power generation.

6.5.3 Crude oil: Myanmar not only has proven crude oil reserves of 50 MMbbl but also has a current production of about 20000 bbl/day, which will be increased in the years to come. Currently, sufficient crude oil is not available locally in Myanmar and there is a huge shortfall between demand and supply. However, as more and more onshore and offshore blocks will start to be explored, crude oil may be available, which can be used in power generation. Most of the prime movers that can burn HFO (boilers, combustion engines, etc.) can also burn crude oil.

6.6 Wind and Solar power: In recent years, renewable energy like wind and solar power are being looked at, especially in developed countries, due to its minimum impact on the environment. Myanmar is in a very early stage of evaluating the potential of such renewable energy in the country as well in its mix.

Wind and solar power cannot be used for baseload power generation due to its intermittent nature depending on the weather. Typically, such renewable capacity also requires backup power from alternate back up sources that makes it more expensive for baseload power. Hence, looking at the current plans on wind and solar power development, accounting for the higher cost of generation and the intermittency, it may not be practical for Myanmar to implement large-scale wind or solar power plants in the short term.
**SUMMARY OF FUEL OPTIONS FOR MYANMAR IN SHORT TERM**

So, what is the most optimal fuel choice for Myanmar between 2016 and e.g. 2021?

Looking at all possible options for the generation mix presented above, hydro power will be the top priority for Myanmar’s power generation. In the absence of sufficient hydro power in the dry season and due to its longer development cycle, thermal plants will also be required in Myanmar.

Sufficient additional domestic gas will not be available before ~2021. Even if coal would be approved for power generation by the Government of Myanmar, a coal plant would take several years to come online. LNG infrastructure will not only take several years to implement, but will also be very expensive. Wind and solar cannot provide standalone, constant reliable power for base load demand. Hence, the optimal and most practical solution for the country would be to use HFO, which is substantially cheaper than diesel, for an interim period before additional gas is available; and switch over to gas, once available.

**Figure 3:** HFO represents the optimal fuel for immediate temporary use before additional domestic gas is available
7. Technology options based on gas and liquid fuel

The focus for the country is to implement additional power generation capacity in next ~5-7 years, which is not only affordable, but also sustainable and provides the cheapest lifecycle cost of generation. Different prime mover technologies which can burn liquid fuel and gas are briefly analysed here. The inland transportation of heavier equipment to many parts of the Myanmar can be a challenge due to existing road and bridge conditions. For many locations river transportation is to be considered and this also needs to be evaluated while selecting the optimum technology.

The following commercially available and well-accepted technology options that can use liquid fuels and/or gas are reviewed here.

1) Choice between open and combined cycle plants
2) High speed diesel generators and high speed gas engines
3) Gas turbines on open cycle as well as combined cycle
4) Medium speed gas engines on open cycle as well as combined cycle
5) Dual fuel power plants based on combustion engines or gas turbines.

7.1 Open cycle vs. combined cycle power plants:

Combined cycle (CC) power plants are a well-accepted solution to increase the plant output, without additional fuel consumption and hence increasing the electrical efficiency, and are typically used for baseload. CC power plant needs additional investments in equipment like waste heat recovery boilers and steam turbines and hence, requires much higher capital investment in USD/KWe compared to an open cycle power plant. CC power plants are the most efficient solutions for baseload applications where the plant is not expected to be running at lower/partial load or started/stopped frequently. However, if the power plants are expected to be running on variable/lower load or starting-stopping frequently, it is important to evaluate if the improved efficiency is worth the additional capital investment.

Looking at the current load pattern, there is as high as 40% variation between peak and off-peak load demand in Myanmar.

For each plant, the decision of whether the plant should be open cycle or combined cycle depends on several factors listed below:

a) the electrical efficiency of the plant on open cycle
b) additional investment needed to make the plant combined cycle and corresponding increase in electrical efficiency and output
c) cost of fuel
d) expected operating and load profile of the plant
e) other relevant factors like availability of water, plant construction time etc.
In summary, a detailed feasibility study on lifecycle cost of generation for each plant will indicate the optimal solution between open cycle and combined cycle solution. The key aspect here is that the feasibility study should be made based on an expected running profile for a specific plant and fuel (including running on possible backup fuel). An inaccurate forecast of the load pattern may result in sub-optimal selection.

7.2 High speed diesel engines or gas engines:

High speed diesel engines are widely used in Myanmar for back-up power, and also a couple of IPPs implemented based on high speed gas engines. These engines typically run at 1200 to 1500 rpm and are available in a range from less than 1 MW to ~ 5 MW, each. The benefits of these engines are low CAPEX and faster construction time.

However, such engines are generally not used for baseload application due to its poor electrical efficiency and shorter equipment lifetime. Hence, when compared with other available solutions based on lifecycle cost including fuel, high speed engines are not optimal solutions for long-term applications.

High speed engines are not used in combined cycle mode considering the additional CAPEX and incremental improvement in performance. In most cases, high speed engines are used for backup or short term power generation, where efficiency is not of prime importance.

7.3 Gas turbines on open cycle and combined cycle

This is one of the most widely used technologies in power generation industry. Open cycle gas turbines provide net lifecycle efficiencies of ~30–40%, at typical Myanmar ambient conditions, depending on type and size. Due to such lower efficiencies, most applications use combined cycle gas turbines to enhance electrical efficiency. Latest bigger-sized combined cycle gas turbine power plants, of >400 MW, provide the highest possible efficiency. Combined cycle gas turbine plants typically take 24 to 36 months to construct; and provide optimal efficiency when running at full load.

However, the efficiency drops substantially when operating at part-load, which is typically the case for most grid-connected plants that ramp their capacity down during low demand hours e.g. at night time. Especially, in countries like Myanmar where baseload power generation may be met with hydro or other cheaper source of power, for example coal, if available. The load on some of the gas power plants may be reduced in different times of the day or during wet seasons.

7.4 Medium speed combustion engine power plants

These are power plants based on internal combustion engines, typically in the range of 500 to 750 rpm. The size of these engines may vary from 4 MW to 20 MWe each. Medium speed engines can burn a variety of liquid fuels, like HFO, crude oil, diesel, liquid biofuel etc. in
addition to natural gas. These engines provide a best-in-class ISO efficiency of >48% on open cycle and on combined cycle even higher efficiency of >52%.

In recent years, the plant sizes based on medium speed engines have increased to more than 600 MWe, with multiple modular units. The higher efficiency and operational as well as fuel flexibility makes it a competitive solution. Some of the most attractive characteristics of such power plants are that it can maintain high efficiency even on partial load (Figure 4), its fuel flexibility to burn multi fuels efficiently, higher availability and reliability due to multiple units, low gas pressure requirement of 6 barg and operational flexibility. It has the capacity of starting from hot standby mode and reaching full load in mere 2 to 5 minutes, and can be stopped in 1 minute. Furthermore, starts and stops do not affect the maintenance cost of the plant. Faster construction time is one of the important benefits of such plants. An open cycle plant based on medium speed combustion engines can be constructed in less than 12 months, whereas a combined cycle plant can be constructed in ~18 months.

![Graph showing efficiency vs. plant load](image)

Figure 4: Performance comparison of engine- and gas turbine-based technologies on part-load

7.5 Dual fuel power plants – liquid fuel first and gas when it is available.

Dual fuel power plants can burn different types of fuels, namely natural gas as well as various liquid fuels. The benefits of such power plants are best recognised when they need to rely on alternate fuel in the absence of its intended primary fuel. For example, certain gas power plants can temporarily run on liquid fuel in the absence of a to-be-developed, malfunctioning or temporarily unavailable gas supply.
Depending on the technology, some gas-based power plants can use liquid fuel as a backup. For example, medium speed combustion engine power plants can use even HFO or crude oil in addition to diesel, minimizing the running cost by making use of the cheapest fuel available at any given time. Once gas becomes available, the plant can seamlessly start to consume gas as primary fuel, without any modification. The ISO efficiency of combustion engine based dual fuel plants on liquid fuel mode can be as high as 44–47% on open cycle and > 51% on combined cycle, including at partial loads.

Gas turbine technology can also burn diesel oil in addition to gas but considering the high price of diesel, this option is not economical. It is not common to use HFO in gas turbines. The turbine efficiency when running on liquid fuel is affected and maintenance schedule as well as costs are negatively and drastically affected.

**SUMMARY OF TECHNOLOGY OPTIONS FOR MYANMAR**

As mentioned in the summary of Section 6, liquid fuel will have an important role to play in Myanmar. It is crucial to note that plants will not be running on liquid fuel for a long time, but only for a temporary period when Myanmar is facing the gas shortage.

Considering the gas availability in a few years from now, dual fuel medium speed engines represent the optimal solution to increase the power generation capacity in the short term due to its ability to efficiently burn HFO, capability to switchover to gas, faster construction period and performance on liquid fuel as well as gas mode. These plants can burn cheaper HFO instead of diesel before domestic gas or imported LNG is available, and will later be switched to burn gas efficiently, as soon as it is available.

![Figure 5: Typical 200 MW open cycle power plant based on dual fuel combustion engines.](image)
8. Centralized vs. decentralized power plants

Myanmar has implemented or initiated a few power plants in the range of 50–250 MWe in the last couple of years. Also going forward, at least in short-term the planned project sizes are also in similar range. There are some discussions on the possibility of implementing bigger gas-fired and coal power plants of e.g. 500 MW or even bigger, but such plans seem to be rather long term. The government’s focus on mid sized plants is rightfully addressing some of the challenges linked to implementing bigger power plants in Myanmar. Some of these challenges are described below:

1) Readily available, competitive and reliable fuel supply for bigger power plants
2) Development and construction of bigger power projects takes 3–5 years, whereas country needs immediate power.
3) Strengthening and developing the T&D network to evacuate the power. This will require not only additional time, but also finance.
4) Raising the finance for bigger power plants, especially in the absence of IPP framework and bankable project agreements would be challenging.

It is important to look at the impact of transmitting the power using the existing T&D infrastructure and the associated losses. The following figure 6 illustrates the possible effect on electrical efficiency of having power plants closer to the load pocket. If the electricity needs to be transported from a bigger and high efficiency plant (e.g. 55% net, lifecycle electrical efficiency at site conditions), considering the losses, the net efficiency at the point of consumption will be substantially lower.

![Figure 6: Simplified view of impact of power system losses on net efficiency](image)

On the other hand, installing a power plant with a smaller capacity (e.g. 50–200 MWe) closer to the load demand is not only faster to construct, but also easier to finance and would avoid ‘putting all the eggs in one basket’. Not only the T&D losses, but also the additional time and cost needed for developing the required T&D network are reduced to a great extent. Such smaller, de-centralized plants that can provide net efficiency of ~ 50% are valuable considering the net electrical efficiency at point of consumption.
9. Preliminary feasibility case studies

In this section, life-cycle costs of different dual fuel and gas power plants using combustion engine and gas turbine technologies are evaluated. Two scenarios are considered for preliminary feasibility study. The cost of capital is assumed as 11.7%. And the fuel costs assumed in the study are indicated below.

- Gas-12USD/MMBTU
- HFO-770 USD/Ton
- Diesel-1060 USD/Ton
- Lube oil- 3USD/Litre

9.1 Scenario 1: Using liquid fuel for temporary period, until gas is available – 50 MW open cycle plant & 100 MW combined cycle power plant

Life-cycle costs of two different power plant sizes are being compared in this section. It is assumed that plant will run on liquid fuel for first 4 years and later on use gas as primary fuel.

→ **Comparison 1**: 50MW open-cycle plant using dual fuel combustion engine and dual fuel gas turbine technology

→ **Comparison 2**: 100MW combined cycle plant using dual fuel combustion engine and gas dual fuel turbine technology

Feasibility study yields the following conclusions:

- Combustion engines can use cheaper HFO during the initial operating years when gas is not available. However, gas turbines would need to use more expensive diesel/light fuel oil because of its inability to use HFO efficiently and optimally.
- In the case of a 50 MW open cycle power plant, the average tariff of the power generated from a dual fuel gas turbine plants is more than 19% higher than the same power generated from a dual fuel combustion engine based plant. The tariff will in both cases be high for the initial 4 years, due to the high fuel cost i.e. HFO/diesel, but the average tariff for the 20 years reduces, due to the lower cost of gas during the later years. Combustion engines have higher efficiency both in liquid fuel and gas mode. The calculated achievable savings are 7 MUSD per year, adding up to a total of ~140 MUSD savings for a 20-year project lifetime by using dual fuel combustion engines.
- Similar results are obtained for the 100 MW combined cycle power plant. Savings of 7.15 MUSD per year can be obtained by choosing dual fuel combustion engines over similar CCGT, resulting in ~143 MUSD savings for a 20 years project lifetime.
- Brief details can be found in the table 1, table 2 and figure 7 below.
Table 1: 50 MW open cycle dual fuel power plant: key figures for dual fuel combustion engines (DF) and gas turbines (GT) based power plants

<table>
<thead>
<tr>
<th>Assumptions/Results</th>
<th>50MW DF Engine plant - HFO mode (1-4 yrs)</th>
<th>50MW DF Engine plant - Gas mode</th>
<th>50MW GT – Diesel mode (1-4 yrs)</th>
<th>50MW GT – Gas mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>6x20V34DF</td>
<td>6x20V34DF</td>
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<td>1xLM6000PG</td>
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<td>EPC cost (MUSD)</td>
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<td>46</td>
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<tr>
<td>Construction Time (months)</td>
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<td>12</td>
<td>12</td>
<td>12</td>
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<tr>
<td>O&amp;M cost (USD/MWh)</td>
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<td>9.3</td>
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<td>Lube Oil Cons. (kg/h)</td>
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<td>Net life-cycle output (MW)</td>
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<td>57.1</td>
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<td>40.9(^1)</td>
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<td>Net life-cycle efficiency@ 80% (MW)</td>
<td>41.3%</td>
<td>44.3%</td>
<td>36.8(^1)</td>
<td>37.9(^1)</td>
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<td>Power generation (MWh/year)</td>
<td>397354</td>
<td>400157</td>
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<td>286389</td>
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</tbody>
</table>

1) Based on GT Pro software (including degradation factor of 0.5% for Engine plant / 2% for GT plants & part load impact of 80% capacity factor) Site conditions ambient temp 30C, relative humidity 60%, 20masl. Gas MN >80.

Table 2: 100 MW CC dual fuel power plant: key figures for combustion engines (DF) and gas turbines (GT) based power plants

<table>
<thead>
<tr>
<th>Assumptions/Results</th>
<th>100 MW DF Engine plant-HFO mode (1-4 yrs)</th>
<th>100 MW DF Engine plant - gas mode</th>
<th>100 MW GT - diesel mode (1-4 yrs)</th>
<th>100 MW GT - gas mode</th>
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<td>Configuration</td>
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<td>Construction Time (months)</td>
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<td>18</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>O&amp;M cost (USD/MWh)</td>
<td>9.3</td>
<td>9.3</td>
<td>13.5</td>
<td>8.1</td>
</tr>
<tr>
<td>Lube Oil Cons. (kg/h)</td>
<td>35</td>
<td>26</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Net Life-cycle output (MW)</td>
<td>105</td>
<td>106</td>
<td>108(^2)</td>
<td>111(^2)</td>
</tr>
<tr>
<td>Net Life-cycle efficiency@ 80% (MW)</td>
<td>45.2%</td>
<td>48.0%</td>
<td>45.2(^2)</td>
<td>47.7(^2)</td>
</tr>
<tr>
<td>Power generation (MWh/year)</td>
<td>735840</td>
<td>742848</td>
<td>803956</td>
<td>824570</td>
</tr>
</tbody>
</table>

2) Based on GT Pro software (including degradation factor of 0.5% for Engine plant / 2% for GT plants & part load impact of 80% capacity factor). Site conditions ambient temp 30C, relative humidity 60%, 20masl. Gas MN >80.
9.2 Scenario 2: Using only gas – 50 MW open cycle plant & 200 MW combined cycle power plant

In this analysis, we compare the life-cycle costs of the following technologies. It is assumed that gas is available for the entire 20 years under study.

→ **Comparison 1:** 50 MW open-cycle gas engine and 50 MW open-cycle gas turbine
→ **Comparison 2:** 200 MW combined cycle gas engine plant and 200 MW combined cycle gas turbine plant

The following conclusions could be drawn:

- In the case of a 50 MW open cycle power plant, the average tariff of power generated from the gas turbine plant is ~14% higher than the same power generated from combustion engines. Engines have a higher net efficiency of 44.8% on open cycle as compared to 37.9% with gas turbines. The calculated achievable savings by using combustion engines are 4.6 MUSD per year, for a total of ~92 MUSD savings for 20 years life cycle.
- In the case of a 200 MW combined cycle power plant, the average tariff of power generated from the gas turbine plants ~ 111.6 USD/MWh, whereas that of combustion engine is ~ 108.7 USD/MWh. The calculated achievable savings by using combustion engines are 3.9 MUSD per year, for a total of ~78 MUSD savings for a 20 year lifecycle.
- Brief details can be found in the table 3 and figure 8 below.
Table 3: 50 MW open cycle and 200 MW combined cycle gas-fired power plant: key figures for combustion engines (SG) and gas turbines (GT)

<table>
<thead>
<tr>
<th>Assumptions/Results</th>
<th>50 MW SG Gas Engine plant</th>
<th>50 MW open cycle GT</th>
<th>200 MW SG Gas Engine plant</th>
<th>200 MW combined cycle GT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>6x20V34SG</td>
<td>1xLM6000PG</td>
<td>10 x 18V50SG CC</td>
<td>Frame 6FA 2-2-1</td>
</tr>
<tr>
<td>EPC cost (MUSD)</td>
<td>45</td>
<td>42</td>
<td>200</td>
<td>243</td>
</tr>
<tr>
<td>Construction Time (months)</td>
<td>12</td>
<td>12</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>O&amp;M cost (USD/MWh)</td>
<td>8.5</td>
<td>6.1</td>
<td>8.1</td>
<td>7.3</td>
</tr>
<tr>
<td>Lube Oil Cons. (kg/h)</td>
<td>18</td>
<td>-</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td>Net Life-cycle output (MW)</td>
<td>57.2</td>
<td>40.9</td>
<td>195.2</td>
<td>202.1</td>
</tr>
<tr>
<td>Net Life-cycle efficiency@ 80% (MW)</td>
<td>44.5</td>
<td>37.9</td>
<td>49.6</td>
<td>49.1</td>
</tr>
<tr>
<td>Power generation (MWh/year)</td>
<td>400858</td>
<td>286389</td>
<td>1367962</td>
<td>1416550</td>
</tr>
</tbody>
</table>

3) Based on GT Pro software (including degradation factor of 0.5% for Engine plant / 2% for GT plants & part load impact of 80% capacity factor). Site conditions ambient temp 30C, relative humidity 60%, 20masl. Gas MN >80.

**Tariff comparison – 50MW & 200MW**

![Tariff comparison chart](chart.png)

Figure 8: 20 Year average tariff in $/MWh of 50 MW open cycle and 200 MW combined cycle gas-fired power plant based on gas engines (SG) and gas turbines (GT)

**SUMMARY OF PRELIMINARY FEASIBILITY STUDY**

Based on the feasibility analysis, medium speed combustion engines have lower total life-cycle costs both in dual fuel and gas based applications.
10. Long-term outlook
In the long run, when enough hydro plants have been constructed, enough domestic gas is available or Myanmar considers additional renewable energy, the operating profile of some of the thermal power plants which are being installed now, will change.

Dual fuel power plants would be running on gas mode. Hydro and coal power plants, if installed, would be running on baseload because of their low generation cost. However, gas power plants, due to their higher cost of generation, would be performing the ‘load following’ to match the supply and demand during the different times of the day and different days of the year. Especially, if the country installs renewable energy, the flexibility in the grid is of utmost importance to respond quickly to the sudden power demand variations when wind is not blowing or sun is not shining. It is important to note the capability of gas power plants to respond to such situations in long term and run on partial load or ‘quick start’ mode.

Combined cycle gas turbine plants, when run on load following mode/partial load, have a substantially reduced efficiency. Due to their ‘minimum stable load’ requirement, these plants cannot run at a very low load on combined cycle, and are forced to run on inefficient open cycle. The higher capital investment made in the ‘combined cycle’ of the plant may not benefit much, if the plant is not run on higher load. Inability of combined cycle plants to carry out quick starts and stops, and huge impact on maintenance costs for every start and stop, make combined cycle gas turbines plants rather in-flexible in nature as compared to medium speed combustion engines.

Medium speed combustion engines, which provide best-in-class efficiency in open cycle mode, are also capable to run on combined cycle, if needed and provides grid stability by providing operational flexibility and quick start-stop as described in Section 7 earlier.

11. Conclusion
Myanmar faces major challenges for its power sector in the near future, headlined by the need to increase its power generation capacity. Many of the traditional solutions are not suitable in current situation: hydro and coal power plants take too long to develop and construct, a shortage of domestic gas is expected to last until further exploration yields results in ~2021 or even later, time is needed to develop a functioning LNG infrastructure and the high cost of imported LNG increases the cost of gas-fired generation dramatically. Considering these challenges, Myanmar will have to consider liquid fuel for power generation to meet the load demand in the immediate future. Being much cheaper than diesel, HFO should be the fuel of choice for Myanmar in the short term. However, when cheaper gas is available, such HFO fired plants should be switched to use gas.

This paper demonstrates that medium speed engine based dual fuel power plants can run efficiently on HFO for a given period of time; and can later seamlessly switched to consume gas when available, without any modifications. This will make it possible to not only burn the
cheapest liquid fuel when it is absolutely needed but also to provide an immediate solution for today’s problems and hedge for tomorrow, making the best possible use of the country’s indigenous hydrocarbon resources.

The optimal technology for each project must be chosen based on a feasibility study specific to such project. According to preliminary feasibility study, it is important to select the most suitable technology for every project through technology-neutral tenders/requests for proposals. This will be the only way for the optimal solution to be selected for each specific power plant project.

Some of the important criteria that must be considered in such feasibility studies are expected realistic running profiles of the power plants, efficiencies at various operating loads (and not only at full load) and performance parameters on both liquid fuel & gas mode, including the long-term impact on performance that may occur at the given site conditions.

The life cycle cost analysis performed as part of this paper shows that medium speed combustion engine plants provide the best possible efficiency on HFO mode, as well as the lowest life cycle costs when compared to alternate technologies. In addition to this, the life cycle cost evaluation demonstrated that combustion engine-based power plants also provide lower life cycle costs when running on gas.

In the long run, hydro or coal power plants would be running on baseload, and some of the gas power plants could run to cater to intermediate or peaking load. Hence, it is also important to consider the possibility to run gas and dual fuel plants ‘flexibly’ in terms of their technical ability to do so, as well as the impact on the cost of generation. In that sense, the unmatchable operational flexibility of combustion engines, paired with their near-constant efficiency at any load, make them once again the optimal solution in long run.