Fuel-flexible, efficient generation using internal combustion engines (ICEs) to meet growing demand in Myanmar

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1.0 Summary

The total generation capacity in Myanmar is 4,581MW, of which 3,044MW (66.4%) is from hydropower. Only 33% of the population has access to electricity. Myanmar needs substantially more generating capacity since its socio-economic development is hampered by lack of electricity. Myanmar is mapping a National Electricity Master plan to meet increasing demand, setting its sights on boosting capacity from 4,581MW to over 27,000MW in 2030.

Myanmar plans to shift the focus from hydropower to other energy sources, including coal, natural gas, solar, and wind power by 2030. High reliance on hydropower causes unstable supply, as the storage in reservoirs shrinks during the hot season. The paper proposes an optimum energy mix for Myanmar in line with common practice in developing countries. Flexible internal combustion engines (ICEs) based power plants offer excellent fuel efficiency and reliability. These gas based power plants are quick to respond, efficient and, can make optimum use of available gas. The dual-fuel combustion engine power plants can be optimized to initially run on cheap liquid fuel (HFO or crude oil) and later use natural gas when it’s eventually tapped from the proven reserves of 11Tcf. Such generating units have proved their worth in meeting peaking and reserve requirements and in providing necessary back-up for renewable energy that tends to be intermittent.

The optimal technology for each project must be chosen based on a feasibility study specific to the project. This paper analyzes the life cycle costs of a dual fuel combined cycle gas turbines and ICEs plants separately. Based on the feasibility study, combustion engines based dual fuel plant has lower total life-cycle cost than gas turbine power plant. Total saving in base load operation is 92 Million USD over 4 years of liquid fuel operation and 217 Million USD over project lifetime.

The dual fuel combustion engine plants provide the best possible efficiency on HFO & gas mode, as well as the lowest life cycle costs when compared to gas turbine technologies. Greater efficiency of ICE plants would also allow the same amount of fuel to produce more electricity as gas turbines, thus reducing the impact of restricted gas supplies in Myanmar.
2.0 Electricity Market – Overview

Myanmar is one of the upcoming economies in Asia. The recent lifting of international sanctions due to economic and political reforms in the country, along with its strategic location as a land bridge between south and south-east Asia, has brought the country into the spotlight of international investors.

The total generation capacity in Myanmar is 4,581MW. Hydropower is the dominant constituent of the power mix of Myanmar. It represented 66% of the country’s total installed capacity in 2014. While thermal power contributed to 34%. Gas-based capacity was the largest contributor at 29% of the total installed capacity in 2014, followed by coal-based capacity at 3% and oil-based capacity at 2%. The remaining was together contributed by renewable technologies such as wind, solar, biopower and small hydropower.

![Figure 1: Myanmar Installed Capacity (MW) – 4581 MW](image)

Electricity access in the country is extremely limited, with the national average being around 33%. In urban areas, the highest access rate has been recorded in Yangon City at 67%, while in rural areas this is around 16%. Most of Myanmar’s people reside in rural areas. Myanmar energy consumption is among the lowest in the world. The consumption per capita is 160 kWh per annum – twenty times less than the world average.

On the other hand, Myanmar has abundant power generation resources. Its hydropower potential has been estimated at around 108GW. More than 300 sites have been identified by the government, with a total generation capacity potential of around 46 GW. The country also has large natural gas reserves, estimated at 11 trillion cubic feet (tcf). This gas is, however, mostly...
extracted for export. Oil and gas mining and extraction are the largest activities in the country’s industrial sector, although labor employment is low.

Electricity consumption is growing fast in Myanmar. The peak load demand reached 2,100 mega-watts (MW) in 2014, growing on average 14 percent per annum in the past five years. Electricity shortages and supply disruptions remain prevalent in the country. Accumulated delays in investments in power infrastructure, over-reliance on seasonal hydropower production, together with a rapid increase in electricity demand, which tripled over the last decade, results in large electricity shortages in the country.

3.0 Ongoing Development: “Framing New Energy Plans for 2030”

The government is coming up with a new national development plan. Coupled with the fact that international sanctions are being partially or fully lifted, this is expected to create an environment for increased investment in the energy sector, possibly in combination with the private sector.

3.1. Myanmar Electricity Master Plan

Until now Myanmar has lacked a detailed long-term master plan that would address strategic issues of the future energy mix in power generation, demand forecast and transmission expansion are being addressed. However, such long-term electricity master plan is reportedly being currently prepared by MOEP with support from JICA. The interim results of the master plan seem to indicate that Myanmar power demand will reach 9,100MW by 2030 in low demand growth scenario and over 14,500MW in high demand growth scenario. A large variation between scenarios is explained by a lack of past statistics and reliable forecasts for GDP growth and electricity growth in industrial and consumer sectors.

In addition to meeting the peak demand, the total installed capacity needs to have sufficient reserve margin, and sufficient surplus to meet the reduction in hydro power availability during the dry season. In addition, Myanmar is planning to utilize its abundant hydro resources to export some of its excess electricity to neighboring countries. Overall, the interim reports of Myanmar electricity master plan indicates total requirement of over 25GW of installed power capacity.
3.2. National Electrification Plan
With help from the global Sustainable Energy for All initiative, led by the World Bank and the UN, the Government (through the Ministry of Electric Power and the Ministry of Livestock, Fisheries and Rural Development) is preparing a National Electrification Plan (NEP) which includes recommended geospatial, least cost grid rollout plan for achieving universal access to electricity by 2030, and an Investment Prospectus for the phased financing of the investment needs. The NEP also proposes institutional reforms required to ensure alignment of funding sources and accountabilities for effective and timely implementation of the electrification program. The development of NEP is coordinated with the government’s ongoing effort for the preparation of the Power Sector Master Plan (funded by JICA) in which related strategic issues of the future energy mix in power generation and transmission expansion are being addressed.

**Approach:** NEP is envisaged to be a comprehensive action plan for developing, financing, and implementing electricity access scale-up program nationwide, with the target of achieving universal access by 2030. Its aims to align support from different stakeholders with the implementation program for achieving national access targets and syndicates financing on a timely, ongoing and programmatic basis.

**Key components of NEP**
1) Geospatial Least Cost Electrification Rollout plan (grid and off-grid): First component consists of a high level geospatial rollout plan comprising of a systematic grid network rollout connection plan and complementary spatial plans for mini-grids and individual systems.

2) Road Map and Investment Prospectus: Second component looks at the long-term and intermediate targets for 2015-2030, investment financing framework for the first 5 years, action plan to address enabling policy and institutional framework, as well as the capacity strengthening initiatives for key institutions and agencies.

4.0 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 the below Figure 2, the possible primary sources of power and fuel options are evaluated from Myanmar’s perspective.

**Figure 2: Possible options for the generation mix:** *HFO represents the optimal fuel for immediate temporary use before additional domestic gas is available*
Looking at all possible options for the generation mix presented above (Figure 2), hydro power will be the top priority for Myanmar’s power generation in the long term. However, due to high seasonality of hydro power and due to its longer development cycle, thermal plants will also be required in Myanmar. First, due their faster development and construction time, thermal power plants will be required to provide the bulk of base load electricity until sufficient hydro capacity is online. Even after that, thermal capacity will be needed for a back-up during dry season and longer than usual draughts.

Such thermal generation would most likely come in the form of gas or coal. Sufficient additional domestic gas will not be available before 2021 or later, depending on the commercialization of offshore gas fields in exploration phase. LNG infrastructure will not only take several years to implement, but will also be expensive. Therefore it is likely to be a feasible solution only in mid-to long-term. Coal is frequently discussed as a good option for low-cost base load in Myanmar, but environmental concerns and the lack of high quality coal in Myanmar have slowed down development. Even if coal would be accepted for power generation by the country of Myanmar, a coal plant would take several years to develop, permit, finance and construct. In the meanwhile, the lack of gas is driving commercial and industrial users as well as households to use expensive diesel in small-scale gen-sets at high cost to keep business running.

As for the non-thermal energy sources, wind and solar power are needed in Myanmar but their scale is too small to provide the constant reliable power for base load demand that is needed for economic growth. Therefore, they can only provide a part of the solution. **Hence, the optimal and most practical solution for the country would be to use low-sulphur heavy fuel oil (HFO).** Heavy fuel oil is widely used in power generation and in ship bunkering, is substantially cheaper (25-35%) than diesel, and can be utilized for an interim period in power generation before additional gas is available. When utilized in dual fuel power plants, the same power plants can immediately switch over to gas once available. There are private companies (from Singapore) who have initiated importing HFO to Myanmar and making it locally available for power generation. Lower cost than diesel is the key reason that it is widely used as fuel in power generation in various countries like Brazil, India, Bangladesh, Philippines, Cambodia, etc. 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.
5.0 Best technology option for Myanmar: “Dual fuel power plants- Liquid fuel in short term and Gas in long term“

As mentioned in the Section 4, 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. Therefore, it is important to invest upfront in a technology that can operate efficiently on both gas and liquid fuels.

Today’s modern combustion engines are excellently suited for various stationary power generation applications. They cover a wide capacity range, and have the highest simple cycle efficiency in the industry. These are dual fuel plants which are typically based on modular 4–17 MW internal combustion engine (ICE) units. Dual fuel ICEs are designed for continuous operation on natural gas or in multi-fuel mode (gas/oil). Dual fuel plants can run in the following operation modes, and switch between them seamlessly without interrupting the power supply:

- **Gas only** (with liquid pilot fuel): Natural gas, LNG, biogas, associated gas (GD only). Insensitive to gas quality

- **Liquid fuel only**: Heavy fuel oil, crude oil, diesel, residual oil, fuel-water emulsions, liquid biofuel

- **Fuel sharing mode** (in GD plants): Gas and liquid fuel simultaneously. Fuel switch without power decrease, automatic and instant trip to liquid fuel mode in alarm situations

Figure 3: Engine hall of ICE power plant
Considering the gas availability in Myanmar a few years from now, **dual fuel medium speed engines** represent the optimal solution to increase the power generation capacity in the short term (till 2021 or until more natural gas is available) due to its ability to efficiently burn HFO, capability to switchover to gas online, extremely fast construction period and performance on liquid fuel as well as gas mode. These plants can burn HFO instead of 30 – 40% more expensive diesel before domestic gas or imported LNG is available, and will later be switched to burn gas efficiently, as soon as it is available.

World-class operational flexibility with uniquely fast starts, stops and restarts, ensures perfect control over daily load fluctuations. And as energy demand grows, the high modularity of ICEs makes it easy to expand the power plant to meet any future changes. We can upgrade the plant at any time without risking operational reliability.

Operational flexibility is especially important when Myanmar installed capacity grows in the long-term to include more and more hydro capacity. As low cost hydro takes an increasing share of the total capacity mix, thermal plants that provided base load energy using natural gas and heavy fuel oil during early years are not needed in base load duty anymore. Due to their superior flexibility, dual fuel ICE plants are well suited to support the Myanmar power system also in the long-term by providing seasonal back-up capacity to hydro, peaking energy and secondary reserves.

The gas and multi-fuel power plants are designed for optimal performance in a wide variety of decentralized power production applications: baseload, peaking power and combined heat & power plants. The plant can be situated whether in the midst of a densely populated area or in a remote area with minimal infrastructural resources. Regardless of the plant’s location, it will be just as lean, clean and quiet as it should be.

### 6.0 Some of the other features of Dual Fuel Internal Combustion Engines

#### 6.1 Highest simple cycle efficiency

The combustion engine’s high efficiency is enabled by the characteristics of the combustion process. Combustion takes place in the cylinders at high pressure and high temperature. Modern engines operate at up to 200 bar (2900 PSI) peak cylinder pressure during every combustion
cycle. The combustion temperature is optimized for high efficiency and low NOX emissions. In an idealized thermodynamic process, a combustion engine would be able to achieve an efficiency rating in excess of 60%. As engine development proceeds, various losses and deviations from the idealized process are minimized, and today modern combustion engines have 45-48% simple cycle efficiency, measured at generator terminals. Modern combustion engines use turbochargers to increase the output and improve efficiency. Turbochargers typically operate at up to 20,000 rpm.

6.2 Superior part load efficiency
Typically in actual operations, plants are not continuously operated at full-output due to varying nature of demand. Part-loading has significant impact on plant efficiency, especially when the size of generating unit is large. By operating more number of smaller units in a modular manner to suit the demand, the efficiency can be kept high at all plant loads. Therefore, average efficiency should be defined based on expected generation profile. In proposal evaluation annual average efficiency should be deployed, instead of using full load efficiency.

![Figure 4: Load range & Part load Efficiency (Net) comparison](image)

6.3 No start cost
Small diesel or HFO power plants are typically utilized as peaking units in power systems. Consequently, even daily starts are required to meet fluctuating system demand. Continuous starting and stopping cause additional cost for less flexible generation technologies, which should be considered in power plant feasibility evaluations.
### 6.4 Small units enabling high availability

In off-grid solutions, continuous and reliable power supply requires additional back-up units. Typically, the reserve capacity required is equal to twice the size of the largest generating unit in the system. When plant(s) are built of smaller units, investments on reserve capacity would reduce. Moreover, smaller capacities allow better flexibility in needed maintenance window (one engine at a time), better utilization of manpower, as well as higher availability. From these several perspectives, combustion engine plant with 10-18MW unit size is superior choice for small off-grid solutions.

### 6.5 Flexicycle operation

Traditionally, the baseload generation capacity has consisted of large, centralised coal and/or nuclear power plants alongside combined cycle gas turbine (CCGT) plants, with long ramp-up and ramp-down times. The intermediate load is often handled by combined cycle gas turbines, while the reserve and peaking capacity is often based on smaller, less efficient generating units, which are expensive to operate. The introduction of the ICEs Flexicycle power plant solution makes the concept of using different dedicated power plant technologies for different load ranges and operation profiles obsolete.

The Flexicycle power plants are based on gas or dual-fuel internal combustion engines (ICEs) and a steam turbine combined cycle. Each engine is equipped with a waste heat recovery steam generator. The power plant has a common steam turbine with condenser. The power plant cooling is typically arranged so that the ICEs are cooled with closed loop radiators, and the steam cycle with cooling towers, other cooling options are also available.
Dual Fuel Internal Combustion Engine benefits:

- Plant electrical efficiency around 48% in simple cycle mode
- Low gas pressure requirement
- Fast start-up: 2-5 min from hot standby to full plant load
- Maintenance schedule independent of the number of starts, stops or trips
- Combined heat and power as an option
- Full plant output at high altitudes and in hot and dry ambient conditions
- Excellent plant availability and reduced need for back-up capacity due to multi-unit installation
- Minimal water consumption due to closed-circuit radiator cooling
- High part-load efficiency
- Stepwise investment with smaller risks and optimized profit generation.

Figure 6: Dual Fuel Internal Combustion Engine benefits

7.0 Feasibility Study: Combined Cycle Dual Fuel Power Plant

In this section, we evaluate feasibility of a 100MW dual fuel project in Myanmar with two technologies, combined cycle gas turbine and internal combustion engine in combined cycle (Flexicycle) mode. For the first 4 years the plants are operating on liquid fuel. In the case of CCGT, the liquid fuel is diesel fuel, whereas in ICE power plant heavy fuel oil (HFO) can be used. Starting from year 5, it is assumed that gas is available for use.

We have calculated the life-cycle costs of dual fuel combustion engine plant and dual fuel gas turbine plant is calculated. The common assumptions are listed in Figure 7 below.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project lifetime</td>
<td>Years</td>
<td>30</td>
</tr>
<tr>
<td>Natural gas cost</td>
<td>$/MMBTu (LHV)</td>
<td>12.1</td>
</tr>
<tr>
<td>HFO cost (&lt;2% Sulphur content)</td>
<td>$/Ton</td>
<td>487</td>
</tr>
<tr>
<td>Diesel cost</td>
<td>$/Ton</td>
<td>655</td>
</tr>
<tr>
<td>Years on liquid fuel</td>
<td>Years</td>
<td>4</td>
</tr>
<tr>
<td>Years on natural gas</td>
<td>Years</td>
<td>26</td>
</tr>
<tr>
<td>Water cost</td>
<td>$/m3</td>
<td>0</td>
</tr>
<tr>
<td>----------------</td>
<td>------</td>
<td>---</td>
</tr>
<tr>
<td>Lube oil cost</td>
<td>$/kg</td>
<td>2.8</td>
</tr>
</tbody>
</table>

**Figure 7: Common assumptions for Dual Fuel Power Plant**

Both diesel and HFO price reflect the current market price in Singapore and include estimates for the cost of transportation and applicable taxes and duties in Myanmar.

As discussed earlier in Section 5.0, the need for thermal base load capacity in Myanmar is mainly for the short to mid-term. As large-scale hydro capacity and high-voltage transmission infrastructure continue to be developed, the operating profile of liquid fuel and natural gas based capacity will gradually change from base load into providing peaking power, secondary reserve and seasonal back-up to hydro. As these early base load plants are predominantly constructed close to load centers in Yangon and Mandalay they also support system stability through frequency and voltage control.

Although the exact timeline for the change in operating profile is not known, we conduct a 2 feasibility comparison for both technologies, using liquid and gas fuel. In the first analysis, we assess the feasibility in base load operation with capacity factor of 85%. In the second analysis we take a long-term view and assess the feasibility with capacity factor of 30%.

### 7.1 Feasibility Comparison for Base Load Operation

#### 7.1.1 Dual Fuel Combustion Engine Power Plant

Sufficient additional domestic gas will not be available immediately, so the plant needs to operate on HFO for the first 4 years. LNG infrastructure will not only take several years to implement, but will also be very expensive. Hence, the optimal and most practical solution for the country would be to use HFO, which is substantially cheaper than diesel (25-35%), for an interim period before additional gas is available; and switch over to gas, once available.

Considering the gas availability in few years from now, the Dual Fuel combustion engines is the optimum solution to increase the power generation capacity in short-term. Dual Fuel combustion engine based plants, which can burn cheaper HFO for temporary period, before domestic gas or imported LNG can be already designed and manufactured in a way that same plants can burn gas as soon as it is available. Such Dual Fuel power plants which can be constructed in less than 1 year, can burn HFO with very high electrical efficiency of ~ 45%. Also, this technology can seamlessly switch over to back-up fuel should there be any interruption in gas supply.
Key performance figures and tariff calculation of engine based dual fuel plant can be seen in the table below.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>HFO</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant configuration</td>
<td></td>
<td>6x18V50DF + ST</td>
<td>6 x 18V50DF + ST</td>
</tr>
<tr>
<td>Estimated total investment cost (EPC,</td>
<td>M USD</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>development, financing fees, working</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>capital</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contracted capacity</td>
<td>MW</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>Net efficiency</td>
<td>%</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td>Base load capacity factor</td>
<td>%</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Peak load capacity factor</td>
<td>%</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 8: Key performance assumptions for Engine based dual fuel CC plant

![Figure 9: Tariff of Dual Fuel Combustion Engine Power Plant](image)

**7.1.2 Dual fuel Gas Turbine Power Plant**

In the second case combined cycle gas turbine technology is considered for dual fuel IPP. The typical model for 100MW range CCGT plant would be LM6000 in 2-2-1, and such configuration is already in operation in Myanmar. As combined cycle gas turbine technology is not capable of operating on HFO, in absence of gas, it would have to operate on diesel oil. The efficiency of combined cycle gas turbine plant when running with liquid fuel is negatively affected and
maintenance costs increased drastically, due to more frequent maintenance. Key performance figures and tariff calculation of dual fuel gas turbine plant can be seen in the table below:

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Diesel</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant configuration</strong></td>
<td></td>
<td>LM6000 2-2-1</td>
<td>LM6000 2-2-1</td>
</tr>
<tr>
<td><strong>Total development cost (inc. EPC +</strong></td>
<td>M USD</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td><strong>Development and financing expenses 20%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Contracted capacity</strong></td>
<td>MW</td>
<td>108</td>
<td>110</td>
</tr>
<tr>
<td><strong>Net efficiency</strong></td>
<td>%</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td><strong>Base load capacity factor</strong></td>
<td>%</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td><strong>Peak load capacity factor</strong></td>
<td>%</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

**Figure 10: Key performance assumptions for dual fuel power plant with gas turbine**

The life cycle cost analysis shows that dual fuel combustion engine plants in combined cycle mode provide the best possible efficiency on HFO mode, as well as the lowest life cycle costs when compared to dual fuel combined cycle gas turbine. 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.

**Figure 11: Tariff of Dual Fuel Gas Turbine Power Plant**

The life cycle cost analysis shows that dual fuel combustion engine plants in combined cycle mode provide the best possible efficiency on HFO mode, as well as the lowest life cycle costs when compared to dual fuel combined cycle gas turbine. 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.
7.2. Feasibility Comparison for Peak Load Operation and back-up electricity provision

Figure 12 below illustrates the tariff comparison for both technology types in peaking operation.

Figure 12: Comparison of dual fuel engine plant and dual fuel CCGT plant tariff in peaking mode

The tariff comparison in peaking operation shows that as the plant utilization factor decreases, the benefits of investing into flexible dual fuel engine capacity become more pronounced. High flexibility, low capital cost, and ability to burn heavy fuel oil make dual fuel engine power plant a feasible solution for intermediate and peaking applications.

7.3 Life-cycle savings

Figure 13 below summarizes the life-cycle savings with combustion engine option both in base load and in peaking operation.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Liquid fuel</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BASE LOAD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCGT tariff</td>
<td>c/kWh</td>
<td>16.6</td>
<td>13.1</td>
</tr>
<tr>
<td>Dual fuel engine tariff</td>
<td>c/kWh</td>
<td>13.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Difference</td>
<td>c/kWh</td>
<td>3.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Annual saving</td>
<td>M USD / Year</td>
<td>23.0</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>PEAK LOAD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCGT tariff</td>
<td>c/kWh</td>
<td>23.0</td>
<td>19.4</td>
</tr>
<tr>
<td>Dual fuel engine tariff</td>
<td>c/kWh</td>
<td>19.0</td>
<td>17.8</td>
</tr>
<tr>
<td>Difference</td>
<td>c/kWh</td>
<td>4.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Annual saving</td>
<td>M USD / Year</td>
<td>11</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Figure 13: Savings with HFO-capable dual fuel engine plant in comparison to diesel-capable CCGT

* Generation 778.9 GWh / Year
** Generation 274.9 GWh/Year

The results indicate that:

- Based on the feasibility analysis, combustion engines based dual fuel plant has lower total life-cycle cost than gas turbine power plant.
- In base load operation, total saving is 92 Million USD over 4 years of liquid fuel operation and 217 Million USD over project lifetime.
- In peaking operation, total savings are 44 Million USD over 4 years of liquid fuel operation and 156 Million USD over project lifetime.
8.0 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 or a functioning LNG infrastructure becomes available. 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 natural 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 optimal technology for each project must be chosen based on a feasibility study specific to the project. This paper analysed the life cycle costs of a dual fuel combined cycle gas turbines and ICEs plants separately. Based on the feasibility study, combustion engines based dual fuel plant has lower total life-cycle cost than gas turbine power plant. Total saving in base load operation is 92 Million USD over 4 years of liquid fuel operation and 217 Million USD over project lifetime.
The dual fuel combustion engine plants provide the best possible efficiency on HFO & gas mode, as well as the lowest life cycle costs when compared to gas turbine technologies. Greater efficiency of ICE plants would also allow the same amount of fuel to produce more electricity as gas turbines, thus reducing the impact of restricted gas supplies in Myanmar.