# An Objective Comparison of Small-Scale Remote Power Generation Systems

## CAPEX vs. Overall Life-Cycle Cost

A White Paper By
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## Abstract

Small-scale power generation can account for up to half of the total operating costs at remote mine sites. Even small percentage savings can amount to significant reductions in overall power generation costs. This document objectively compares the advantages and disadvantages associated with various power generation technologies and fuels in two scenarios utilizing real-world data. The conclusions of this paper clearly demonstrate significant cost savings by investing in the correct technology at the outset and benefiting from the reduced fuel consumption and maintenance costs as a result.


## 1.0 Introduction

Reliable power is critical for mining and heavy industry, which often operate in remote locations, where local power grids are either unreliable or non-existent. This white paper presents a comparison of some of the various fuels and engine technologies available for small-scale (5 to 30 megawatt (MW)) stand-alone power plants.

Three primary operational profiles for small-scale power plants include:

- Prime Power – Ongoing, 24/7 operation of a varying load (typical configuration of remote mining and industrial applications)
- Continuous Power – Ongoing, 24/7 operation of a constant load (typically tied to a utility grid in a supporting role)
- Stand-By Power – Intermittent emergency responses (installed to prevent long-term outages due to unstable prime power source).

This white paper focuses primarily on Prime Power configured power stations. We selected Diesel Fuel Oil (DFO) and Heavy Fuel Oil (HFO), along with High speed (1,500 rpm) and medium speed (750 rpm) reciprocating engines, for comparison. ISI has selected these fuels because of their prevalence in the markets where power plants of these sizes typically operate. Reciprocating engines were selected because they are more reliable to operate and maintain in remote, austere environments and they are more efficient than other available technologies (such as turbines).

This white paper will evaluate two real-world power plant scenarios (10MW and 30MW) to determine the costs and benefits of using each fuel and engine technology solution at varying scales.

# 2.0 Overview of Fuels

DFO and HFO are both refined products of petroleum crude oil. The term "Crude Oil" refers to a wide range of paraffinic, naphthenic, and aromatic hydrocarbon mixtures that can be thin and light colored (lower density, higher gravity) or thick and black (higher density, lower gravity). Thanks to modern refining and blending processes, both low- and high-gravity crude oils can be turned into high value products.[1]

## 2.1 Diesel Fuel Oil

DFO is a clear or straw-colored complex liquid mixture of several different individual compounds with a mild characteristic petroleum odor.[2] Different proportions of various compounds yield DFO with varying characteristics. Most of the individual hydrocarbon compounds that comprise DFO range from 10 to 22 carbons in length. DFO is separated from crude oil solutions through distillation; therefore, it is considered a "distillate fuel." Since compounds with different carbon numbers have different boiling points, the boiling range for DFO is from approximately 125° to 400°C.[3] DFO has a low vapor pressure, so it evaporates slow. DFO has a kinematic viscosity of approximately 3 centistokes (cSt) and a density between 830 and 860 grams per liter (g/l).[4] The caloric value of DFO is typically around 42,700 kilojoules per kilogram (kJ/kg).

## 2.2 Heavy Fuel Oil

HFO is a thick black liquid with a strong characteristic petroleum odor. HFO is categorized by its kinematic viscosity. Typically, either 180 cSt or 380 cSt HFO is utilized for small-scale power generation projects such as the ones detailed in this document. HFO is recovered from the "leftovers" of the distillation process; therefore, it is considered a "residual fuel." The initial boiling point for HFO varies widely and is between 150° and 750°C (or more). HFO typically has a density between 900 and 1,000 g/l at 15°C.[5] The caloric value of HFO is typically around 43,500 kJ/kg.

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[1] John Bacha, et al, Diesel Fuels Technical Review, (Chevron, 2007), 25.
[2] *Diesel Fuel*; SDS; Global Companies, LLC: Waltham, MA, May 2016. http://www.globalp.com/documents/files/SDS%20Diesel%20Fuel%20Final.pdf (accessed 02/27/2019)
[3] John Bacha, et al, Diesel Fuels Technical Review, (Chevron, 2007), 32.
[4] *Diesel Fuel*; SDS; Global Companies, LLC: Waltham, MA, May 2016. http://www.globalp.com/documents/files/SDS%20Diesel%20Fuel%20Final.pdf (accessed 02/27/2019)
[5] Heavy Fuel Oil; SDS; Neste Oyj: Neste, Finland, 08/01/2018. https://www.neste.fi/static/ktt/14359_eng.pdf (accessed 02/27/2019)

## 2.3 Energy Content

The energy content of the fuel is measured in kJ per unit, typically either kJ/kg or kJ/liter. In the two previous paragraphs the energy content was provided in kJ/kg. When we take the energy content and the density we can figure out the total energy of a fuel per volume, in this example per liter of fuel.

DFO at a density of 845 g/l with a calorific value of 42,700 kJ/kg has a energy content of 36,081 kJ/liter. HFO at a density of 950 g/l with a calorific value of 43,500 kJ/kg has an energy content of 41,325 kJ/liter. In this comparison the HFO has 15% more energy content per liter than the DFO, and thus will produce 36,081 kJ of work will only using .87 liters of fuel (13% less fuel per unit of power produced).

## 2.4 Advantages and Disadvantages of Each

The primary advantages of DFO are its availability and that it requires little or no treatment prior to utilization by power generation equipment. The primary disadvantages of DFO are higher cost and lower energy content per liter.

The primary advantages of HFO are its lower cost and higher energy content per liter relative to DFO. Disadvantages of HFO include having to process and heat it prior to utilization by power generation equipment. Maintenance intervals are typically more frequent for similar equipment running on HFO as compared to DFO.

Multi-year generation projects typically benefit from HFO-fueled generation while shorter duration projects see less benefit from utilizing HFO.

# 3.0 Overview of Engine Technologies

The following sections present a brief overview, along with advantages and disadvantages, for the three engine-generator configurations considered in this document.

## 3.1 High Speed DFO

The term "High Speed DFO" typically refers to power generation equipment that operates at 1,500 RPM or 1,800 RPM (for 50 Hertz (Hz) and 60 Hz systems, respectively). These generators are typically readily available in many sizes and configurations for rapid deployment. Additionally, high speed DFO power plants require very little ancillary equipment to operate since they usually have electric starters and DFO requires minimal ancillary equipment for handling.

Due to the higher operating speed, all maintenance intervals associated with these engines will have to be completed more frequently than those associated with medium speed engines. Typically, high speed generators require lube oil replacement every 300 to 500 hours of operation, and significant maintenance is required every 8,000 hours of operation. These engines/generators are usually due for replacement after 60,000 hours of prime operation.

High speed generators are best suited for short-term and emergency stand-by power needs. The lower capital cost for high speed power generation equipment per unit of energy production seems attractive; however, in prime operations, the long-term operation and maintenance costs associated with high speed power generation equipment quickly exceeds the initial capital savings.

## 3.2 Medium Speed DFO

The term "Medium Speed DFO" typically refers to power generation equipment that operates between 720 and 1,000 RPM (750 or 1,000 RPM for 50Hz systems and 720 or 900 RPM for 60Hz systems). These generators are custom built per project and have a longer procurement time than High-Speed DFO generators.

Since they operate at lower speeds (which translates to slower piston speeds and less overall wear), medium speed DFO engines consume less fuel per unit of energy produced, have longer maintenance intervals, and longer lifecycles compared to high-speed engines.

Medium speed engines can operate up to 3,000 hours between lube oil replacements. Significant maintenance intervals occur every 24,000 hours. With proper operation and maintenance practices, medium speed DFO engines can operate in excess of 200,000 hours (25 years).

Compared to high speed DFO generation equipment, the MS DFO generators use 10 to 12 percent[6] less fuel to produce the same amount of energy. This reduced consumption quickly offsets the additional capital costs of medium speed DFO power generation equipment. The typical return on investment (ROI) for the additional capital expense associated with medium speed DFO versus high speed DFO is approximately three to five years. Further details regarding anticipated ROI timelines for medium speed DFO versus high speed DFO will be provided in Section 4.

[6] Comparing 1,500 RPM High Speed to 750 RPM Medium Speed DFO.

## 3.3 Medium Speed HFO

The term “Medium Speed HFO” typically refers to power generation equipment that operates at 750 or 720 RPM for 50Hz or 60Hz systems, respectively. As with medium speed DFO, medium speed HFO power generation equipment are custom built per project and have a longer procurement time than High-Speed DFO generators.

Mechanically, medium speed HFO engines are very similar to medium speed DFO engines, with a few various components designed specifically for the different fuel.

HFO requires a significant fuel processing infrastructure compared to DFO. A multi-step heating and storage process is required to make the fuel usable by the HFO generators. A significant equipment infrastructure is required, making some smaller HFO plants cost prohibitive for shorter duration projects. Medium Speed HFO power generation equipment is best suited for longer-term projects because it allows customers to realize cost savings associated with lower fuel costs and greater caloric value as compared to DFO. Depending on its size, the typical ROI for the additional capital expense associated with medium speed HFO versus high speed DFO is approximately eighteen to thirty-six months. Further details regarding anticipated ROI timelines for medium speed HFO versus high speed DFO will be provided in Section 4.

## 4.0 Examples of Power Station Projects

The following sections briefly detail the comparison of High Speed DFO, Medium Speed DFO, and Medium Speed HFO power generation. These scenarios are based on real-world projects that ISI evaluated for our clients.

For consistency, each scenario was assumed to have an elevation of less than 200 meters above sea level (ASL), a maximum ambient temperature of 45C. Fuel costs (delivered to site) were assumed at $0.65 USD per liter for DFO and $0.50 USD per liter for HFO. Finally, each scenario was assumed to involve a 15-year life-of-mine.

## 4.1 Example 1: 10MW Continuous Demand

### 4.1.1 Overview

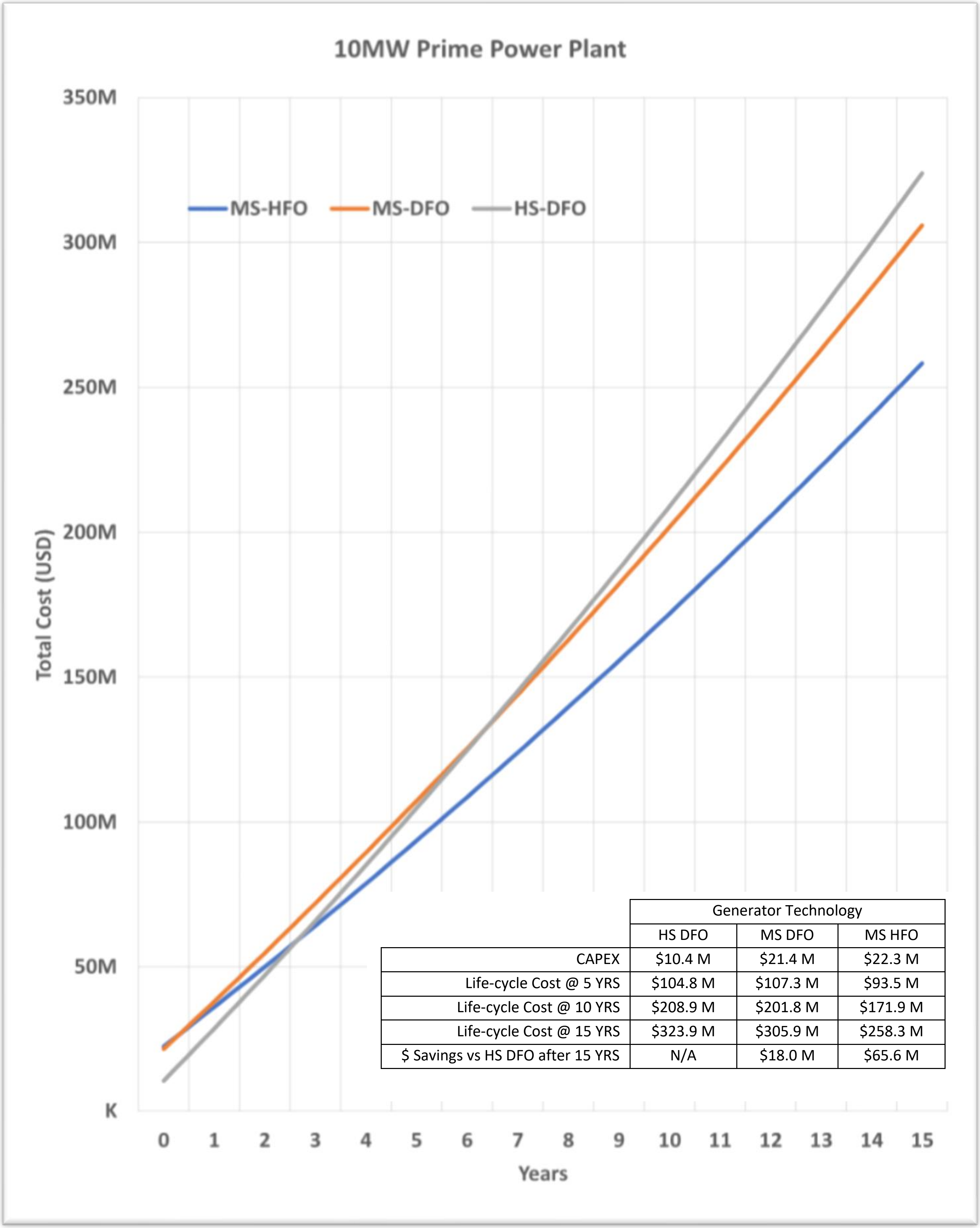
The first scenario involves power for a remote mine site with no utility power availability that has an average demand of 10MW. Due to the remote location of this project site, the client has requested that sufficient redundancy in power generation capacity be provided to have one spare unit available when another is down for routine maintenance (an N+2 configuration).

### 4.1.2 Technology Comparison

For this scenario, ISI evaluated three different approaches to power generation:

| Generator Type | Power (at site), per Generator | Total Installed Capacity | Operating Generators | Standby Generators |
|---|---|---|---|---|
| 1,500 RPM HS DFO | 1.55MW | 13.95MW | 7 | 2 |
| 750 RPM MS DFO | 2.56MW | 15.37MW | 4 | 2 |
| 750 RPM MS HFO | 2.55MW | 15.14MW | 4 | 2 |

These three scenarios were analyzed and the overall projected lifecycle costs for the first 15 years of operation (CAPEX + OPEX + Fuel + Overhauls) are depicted in the graph below.




| | Generator Technology | | |
|---|---|---|---|
| | HS DFO | MS DFO | MS HFO |
| CAPEX | $10.4 M | $21.4 M | $22.3 M |
| Life-cycle Cost @ 5 YRS | $104.8 M | $107.3 M | $93.5 M |
| Life-cycle Cost @ 10 YRS | $208.9 M | $201.8 M | $171.9 M |
| Life-cycle Cost @ 15 YRS | $323.9 M | $305.9 M | $258.3 M |
| $ Savings vs HS DFO after 15 YRS | N/A | $18.0 M | $65.6 M |

#### 4.1.3 Technology Selection

Although it requires a higher capital investment than the high speed DFO option, it is immediately apparent that the medium speed HFO option represents the lowest overall lifecycle cost option for this scenario. It is estimated that this option would result in a return of the initial additional capital investment approximately 28 to 30 months after commissioning versus the high speed DFO option. This represents a total potential savings of approximately $37 Million USD (17%) during the first ten years of operation and $65.6 Million USD (20%) after year fifteen as compared to a high-speed diesel scenario.

For projects where HFO is not available or shorter duration projects of less than five years, medium speed DFO is a great alternative to consider.

### 4.2 Example 2: 30MW Continuous Demand

#### 4.2.1 Overview

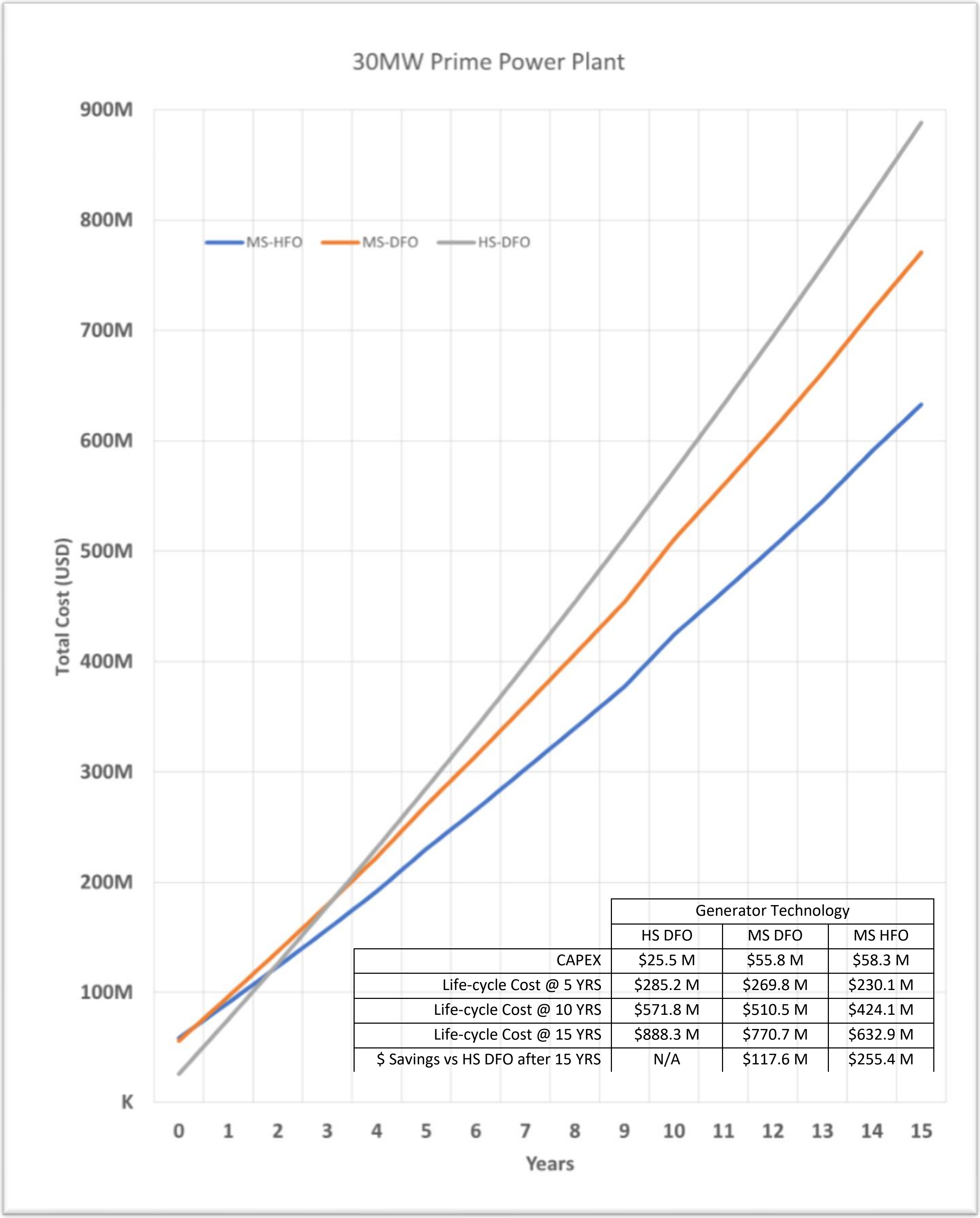
The second scenario involves power for a remote mine site with no utility power availability that has an average demand of 30MW. Due to the remote location of this project site, the client has requested that sufficient redundancy in power generation capacity be provided to have one spare unit available when another is down for routine maintenance (an N+2 configuration).

#### 4.2.2 Technology Comparison

For this scenario, ISI evaluated three different approaches to power generation:

| Generator Type | Power (at site), per Generator | Total Installed Capacity | Operating Generators | Standby Generators |
|---|---|---|---|---|
| 1,500 RPM HS DFO | 1.55MW | 34.10MW | 20 | 2 |
| 750 RPM MS DFO | 4.7MW | 42.30MW | 7 | 2 |
| 750 RPM MS HFO | 4.7MW | 42.30MW | 7 | 2 |

These three scenarios were analyzed and the overall projected lifecycle costs for the first 15 years of operation (CAPEX + OPEX + Fuel + Overhauls) are depicted in the graph below.




| | Generator Technology | | |
|---|---|---|---|
| | HS DFO | MS DFO | MS HFO |
| CAPEX | $25.5 M | $55.8 M | $58.3 M |
| Life-cycle Cost @ 5 YRS | $285.2 M | $269.8 M | $230.1 M |
| Life-cycle Cost @ 10 YRS | $571.8 M | $510.5 M | $424.1 M |
| Life-cycle Cost @ 15 YRS | $888.3 M | $770.7 M | $632.9 M |
| $ Savings vs HS DFO after 15 YRS | N/A | $117.6 M | $255.4 M |

#### 4.2.3 Technology Selection

Although it requires a higher capital investment than the high speed DFO option, it is immediately apparent that the medium speed HFO option represents the lowest overall lifecycle cost option for this scenario. It is estimated that this option would result in a return of the initial additional capital investment approximately 21 to 23 months after commissioning versus the high speed DFO option. This represents a total potential savings of approximately $147.7 Million USD (25.8%) during the first ten years of operation and $255.4 Million USD (28.9%) after year fifteen as compared to a high-speed diesel scenario.

For projects where HFO is not available or shorter duration projects of less than five years, medium speed DFO is a great alternative to consider.

## 5.0 Conclusion

This white paper presented a brief overview of small-scale power generation technologies and two fuels commonly utilized, along with an analysis utilizing real-world data considering both CAPEX and overall life-cycle costs for two common sizes of small-scale remote power generation systems (10MW and 30MW average demand).

The results of this analysis strongly suggest utilizing medium speed HFO Prime Power configured power plants constructed for projects which have durations of 5 years or greater yield ROIs that far exceed the initial CAPEX investments. In short, overall life-cycle costs can be reduced by 20 percent or more by utilizing medium speed HFO versus high-speed DFO power generation equipment.

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