Turn Emergency Engine-Generator Assets Into Revenue Sources

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The Miami-Dade Water and Sewer District (MDWASD) required new engine-generators at its South District Wastewater Treatment Plant (SDWWTP) facility. The new engine-generators would be located in a new electrical distribution building 3 (EDB3) that would replace existing engine-generators at the existing EDB1. The new engine-generators were to have a total capacity of approximately 20 megawatts (MW).

Additionally, MDWASD wanted to evaluate converting its seven existing diesel-fueled and low-speed engine-generators to have dual fuel capability. The seven existing diesel-fueled engine-generators are in EDB2 and they have a total capacity of approximately 20 MW.

Black & Veatch evaluated a total of nine different engine-generator alternatives for the facility, which included the evaluation of load curtailment or nonload curtailment operation; low- or high-speed engine-generators; and diesel, natural gas, and diesel-gas blend fueled units.

Plant staff has indicated the following preferences with respect to the new engine-generation equipment:

- The new engine-generators should have the ability to run when required. This includes early unit start-up to facilitate load transfer and the ability to run the units continuously for an extended period after a major hurricane. For this reason, the preference is for the continuous-duty and low-speed two-cycle engine-generator units, similar to the units in EDB2.
- The ability to continue operating the units if there is a shortage of diesel fuel after a major hurricane event. For this reason, a request was made to provide units capable of operating on either diesel or a diesel-natural gas blend (dual fuel).
- Maintain the same type of engine-generator equipment at the plant (EMD engines).
- Transfer the current Florida Power & Light (FPL) curtailment agreement in place at EDB1 to the EDB3 engine-generators to keep the benefits of the reduced electricity rate in the areas to be served by EDB3. Additionally, staff wants to add EDB2 engine-generators to the curtailment agreement.
- Convert the existing EMD units at EDB2 to dual fuel units to utilize cheap gas costs, while extending their runtime.

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Table 1. Engine-Generator Comparison Pros and Cons

Engine-Generator Comparison

Two-Stroke Low-Speed	Four-Stroke High-Speed
Pro: Longer life, less maintenance	Con: Shorter life, more maintenance
Con: Estimated cost = $1,000-1,300/kW	Pro: Estimated cost = $450/kW
Con: Higher capital cost	Pro: Lower capital cost
Pro: Available in two- and four-cycle	Con: Only available in four-cycle
Con: Only one manufacturer	Pro: More manufacturers
Con: Sole source	Pro: More manufacturers, competitive bid
Con: Physically larger package*	Pro: Physically smaller package*
Con: Require remote radiators	Pro: Unit-mounted or remote radiators available
Con: Generally nosier	Pro: Generally quieter

* Even though an engine technology may have a smaller or larger package footprint, it's the capacity of the engine-generator that will determine how many units are required to meet demand, which ultimately drives overall footprint.

Evaluation

There are several engine-generator options available on the market and the following is a discussion of curtailment agreements, the different regulatory requirements, and the engine-generator technologies available, including the challenges or advantages associated with each. These engine-generator options are the basis for the cost evaluation.

Curtailment Agreement

A curtailment agreement can be made between a power provider and a utility that requires a utility to use a portion of its engine-generators to offset peak power demands in the system, which in turn relieves the power provider. In exchange, the utility would receive a very favorable electricity rate.

Curtailment agreements typically require that an engine-generator be available for a certain number of hours of operation per year. Engine-generators classified as emergency units are limited to 50 hours of nonemergency operation per year. Operating an engine-generator for the power provider under a curtailment agreement is considered nonemergency use. If the utility exceeds the 50-hour limit, it's subject to fines. To avoid this, utilities should have nonemergency-rated engine-generators.

Entering into curtailment agreements is typically very favorable for water utilities; however, smart use of engine-generators could bring even more savings to the utility. Using natural gas is more cost-effective than using diesel fuel due to the substantially lower cost of natural gas. Depending on the location of the plant, natural gas units for emergency use have proven effective; however, most plants, especially those in coastal areas, do not want to rely on natural gas only and prefer to use diesel units to allow fuel storage for emergency events.

Regulatory Requirements

Emergency Versus Nonemergency

Given the plant's desire to continue the load curtailment agreement and prestorm operation, the new units would need to be classified as nonemergency units from an air permitting standpoint. This will likely trigger different requirements with regard to monitoring and recordkeeping with respect to new source performance standards and national emission standards for hazardous air pollutants (HAPs).

Dual Fuel Requirement

Diesel-fueled engines are a "compression" ignition type; therefore, the engine will need to meet the requirements of Subpart IIII from the New Source Performance Standards (NSPS). These are a set of standards defined by the U.S. Environmental Protection Agency (EPA) for a variety of emissions sources, such as engines, turbines, boilers, and many others, where the engine will need to be certified by the manufacturer and there is no option to purchase a "noncertified" engine. If the engine manufacturer does not certify the dual fuel engine to the Tier 4 standards (diesel engine standards that are the strictest EPA emissions requirement for off-highway diesel engines), it will not be possible to obtain an air permit for this type of engine.

Engine-Generator Technologies

Cycles

Two- and four-cycle (stroke) engines are available. Table 1 provides a comparison of the pros and cons of each type of engine.

Fast Starting and Load Acceptance

Plant staff prefers the two-cycle engines because of their rapid starting time and load acceptance. It was confirmed with manufacturers that four-cycle high-speed engine-generators have similar starting and load acceptance profiles as two-cycle low-speed engines.

Low-Speed and High-Speed Engines

Low-speed units last longer due to reduced wear; however, research indicates that there are very few wastewater plants using low-speed engine-generators, and the industry standard is the high-speed units.

Table 2. Engine-Generator Alternatives

ALTERNATIVES	SPEED	STROKE	FUEL	# of EGs	EG Size, kW	TIER	LOAD CURT.
Alternative 1	Low	2	DGB	8	2865	3	No
Alternative 2	Low	2	Diesel	8	2865	4	Yes
Alternative 3	High	4	Diesel	9	2600	2	No
Alternative 4	High	4	Diesel	9	2600	4	Yes
Alternative 5	High	4	Gas	10	2356	-	No
Alternative 6	High	4	Gas	10	2356	-	Yes
Alternative 7 (H)	High	4	Diesel	7	2600	4	Yes
	High	4	Gas	3	2356	-	Yes
Alternative 8 (H)	Low	2	Diesel	6	2860	4	Yes
	Low	2	DGB	3	2850	3	No
Alternative 9 (H)	High	4	Diesel	9	2600	4	Yes

Notes: EG – Engine-Generator; DGB – Diesel Gas Blend

Tier 2,3, or 4

Stationary emergency engine-generators are required to meet Tier 2 or Tier 3 emission limits (also governed by EPA), depending on the cylinder displacement of the engine; however, nonemergency engine-generators are required to meet Tier 4 emission limits based on the current air permit regulations. Certified Tier 4 diesel fuel units are available from manufacturers; therefore, these units can be permitted. Most Tier 4 units utilize diesel exhaust fluid for emission controls.

Natural Gas Engine-Generators

Natural gas-fueled engine-generators are available and they do have the inherent limitation of depending on the gas utility main for emergency conditions; however, their operational cost is substantially lower than diesel units due to the cost difference between diesel and natural gas. There are natural gas units that operate at 1800 revolutions per minute (rpm), or 1500 rpm with a gear box to operate the alternator at 1800 rpm. Natural gas engines comply with the air emission requirements in the south Florida area without the need for additional treatment.

Engine-Generator Availability

Based on recent research and experience, there is limited competition for specific categories of engine-generators. It should be noted that low-speed two-cycle units are limited to electromotive diesel (EMD) units, whereas high-speed diesel Tier 4 units seem to be limited to Caterpillar and Cummins, although Kohler has indicated that there is a high-speed Tier 4 product line coming out in the near future. It should be noted that Cummins does not have continuous-rated Tier 4 diesel units with capacities as large as Caterpillar or EMD and therefore may require additional units to match capacity.

Alternatives

Black & Veatch evaluated nine engine-generator alternatives for SDWWTP. For the evaluation it was assumed that the duty engine-generator total capacity is approximately 18 MW (with the addition of two redundant units) and each alternative is sized to meet this requirement. Any variation from the number of engine-generators and any variation in total capacity should have a relative impact on rankings of the alternatives.

The MDWASD requested 30 days of diesel storage onsite for EDB 3. For this evaluation it's assumed that six 50,000-gal tanks are needed, which would provide approximately 10 days of storage at peak demand.

The existing emergency engine-generators in EDB 2 were built prior to 2011, and therefore are grandfathered under the air permit regulations, such that the units can be reclassified as nonemergency engine-generators without the need to add Tier 4 emissions controls to the engines. The evaluation considered repurposing the existing emergency diesel units to dual fuel, but it was estimated that the cost to repurpose

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Table 3. Evaluation Input Parameters

Number of Engine-Generators		Total Number of Units
Engine-Generator Size	kW	Power output per generator
CAPITAL COSTS		
Equipment		
Engine-Generator Cost	$/gen	Unit cost of each generator
Tier 4 Adder	$/gen	Additional cost for adding SCR (emissions control equipment)
Spare Parts	$	Initial spare parts cost
Training	$	Training cost at installation
EDB2 DGB Adder	$	Adding DGB to EDB2 engines
Total Engine-Generator Cost	$	
Number of Fuel Storage Tanks		Number of units
Fuel Storage Tank Cost	$/tank	Cost per tank
Total Tank Cost	$	
Building		
Est. Building Cost	$/sq ft	Standard building cost for concrete masonry structures
Est. Building Size Increase	%	Size increase due to SCR equipment
Building Cost	$	Cost of building
Interconnecting	$	Cost of connecting the generator systems
Capital Cost	$	Total capital cost
OPERATING COSTS		
Engine-Generator Operating Hours		
Emergency Hours	hrs/year	Emergency hours operation
Maintenance Hours	hrs/year	Maintenance run time
Curtailment Agreement	hrs/year	Operating hours required by FPL per year
Total Hours	hrs/year	
Utility Cost		
Power Cost	$/kW-hr	Rate of electricity
AA Power Consumption	kW-hr/hr	Average power demand for the plant
Annual Consumption	kW-hr/year	Annual power demand for the plant
Annual Power Cost	$/year	Annual power cost for the plant
Maintenance Cost		
Service Agreement	$/year	Cost of service agreement
Cost per Hour of Operation	$/hr	Operating cost of each generator type
Annual Maintenance Cost	$	Annual maintenance cost
Fuel Cost		
Fuel Type		Diesel, natural gas
Cost of Fuel	$/gal, $/cf	Cost of diesel or natural gas
Fuel Consumption	gal/hr, cf/hr	Generator fuel consumption. Varies from average to max and min conditions
Annual Cost of Fuel	$	

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the existing units for dual fuel functionality would be $500,000 per unit. The repurposed existing units would consume 75 percent less diesel when running on a dual fuel blend than its diesel-only counterpart.

The cost associated with repurposing the existing diesel engine-generators for dual fuel functionality is included in the hybrid alternatives (7, 8, and 9), and operational costs for the repurposed engine-generator units are considered in alternative 9. Additionally, the cost associated with adding an additional dual fuel unit in the existing building was also considered in Alternative 9.

An additional eighth dual fuel engine-generator may be needed at EDB2 to meet new plant loads. The new dual fuel engine-generator emissions would not be grandfathered under air permit regulations like the existing units due to the year of manufacturing; therefore, the unit would be limited to emergency-only operation and would need to meet Tier 3 emission requirements.

The engine-generator alternatives evaluated for SDWWTP are described as follows:

Alternative 1: New Low-Speed Two-Cycle Diesel Emergency Engine-Generators

This alternative includes the use of new low-speed dual fuel units used as emergency generators for EDB3. Ten days of diesel fuel storage would be provided. No natural gas storage would be provided as it would be too costly from both a capital and operational expenditure standpoint, and impractical due to the storage volume required. The alternative assumes that the engine-generators will run only from the natural gas line.

Alternative 2: Low-Speed Two-Cycle Diesel Nonemergency Engine-Generators

This alternative includes the use of new low-speed units as nonemergency engine-generators for EDB3. These engine-generators require Tier 4 emission control and can be used for load curtailment. Ten days of diesel fuel storage would be provided.

Alternative 3: High-Speed Four-Cycle Diesel Emergency Engine-Generators

This alternative includes the use of high-speed diesel units as emergency engine-generators for EDB3. These engine-generators require Tier 2 or Tier 3 emission control and cannot be used for load curtailment. Ten days of diesel fuel storage would be provided.

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Alternative 4: High-Speed Four-Cycle Diesel Nonemergency Engine-Generators

This alternative includes the use of high-speed diesel units as nonemergency engine-generators for EDB3. These engine-generators require Tier 4 emission control and can be used for load curtailment. Ten days of diesel fuel storage would be provided.

Alternative 5: Natural Gas Units Emergency Engine-Generators

This alternative includes the use of high-speed natural gas units used as emergency engine-generators for EDB3. No natural gas storage will be provided, for reasons indicated in Alternative 1.

Alternative 6: Natural Gas Units Nonemergency Engine-Generators

This alternative includes the use of high-speed natural gas units used as nonemergency engine-generators for EDB3. No natural gas storage will be provided, for reasons indicated in Alternative 1.

Alternative 7 (Hybrid): High-Speed Diesel and Natural Gas Nonemergency Engine-Generators

This alternative includes the use of high-speed units, consisting of some diesel engine-generators and some natural gas engine-generators, used as nonemergency generators for EDB3. This requires Tier 4 emission control for the diesel engines so that they can be used for load curtailment. The natural gas engines can meet the air emissions standards without further treatment. No natural gas storage will be provided, for reasons indicated in Alternative 1, but ten days of diesel fuel storage would be provided. This alternative also includes the costs associated with modifying the existing diesel-only engine-generators to be duel fuel units for EDB 2.

Alternative 8 (Hybrid): Low-Speed Diesel Nonemergency and Low-Speed Dual Fuel Emergency Engine-Generators

This alternative includes the use of low-speed diesel nonemergency engine-generator units and low-speed dual fuel engine-generators used as emergency generators for the EDB3. This requires Tier 4 emission control for the diesel engines so that they can be used for load curtailment. The dual fuel engines can meet the Tier 3 air emissions standards and would be for emergency generation only. No natural gas storage will be provided, for reasons indicated in Alternative 1. This alternative also includes the costs associated with modifying the existing diesel-only engine-generators to be duel fuel units for EDB 2.

Alternative 9 (Hybrid): High-Speed Four-Cycle Diesel Nonemergency Engine-Generators and Interconnection With Existing Engine-Generators

This alternative includes the use of high-speed diesel units as nonemergency engine-generators for EDB3. This requires Tier 4 emission units that can be used for load curtailment. Ten days of diesel fuel storage would be provided. This alternative also includes an evaluation of an interconnection between existing EDB 2 and new EDB 3. This provides SDWWTP the flexibility to transfer electrical loads from EDB 3 to EDB 2 during a load curtailment period or other nonpeak conditions in which generator power is needed. This alternative also includes the costs associated with modifying the existing diesel-only engine-generators to be duel fuel units and assumes the addition of an eighth engine-generator at EDB 2. Operation and maintenance costs of the converted EDB2 units operating EDB3 loads are considered in this alternative.

For the purposes of this evaluation only, the eighth engine-generator is assumed to be included under Alternative 9 because interconnecting the generating facilities has the potential to require this added capacity at the existing facility. Conceptually, interconnection of EDB2 and EDB3 will require an additional switchgear section added to each bus. These electrical costs, as well as others, were included in the evaluation. This alternative will enable MDWASD to maximize the use of natural gas over diesel during engine-generator operation. Additional generator capacity is not required to allow implementation of the proposed interconnection between EDB 2 and EDB 3.

Table 2 summarizes the alternatives evaluated for EDB3.

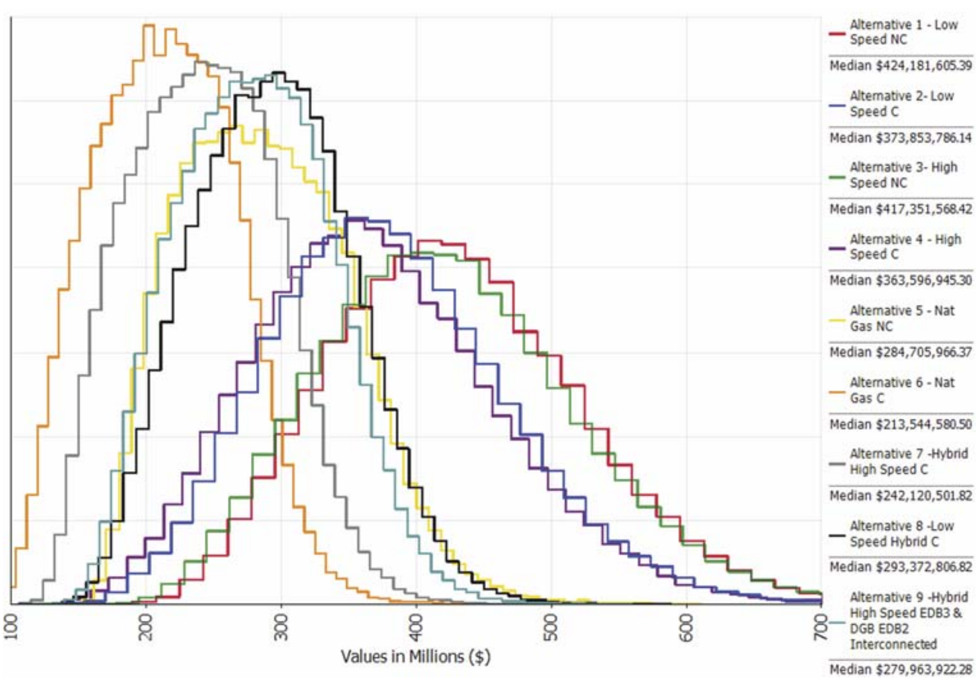

Figure 1. Probability Functions for All Alternatives Considered

Parameters

Different engine-generator alternatives were compared from a financial standpoint. Given the large number of input variables required to predict total cost (capital expenditures [CAPEX] plus operating expenses [OPEX]), a probabilistic sensitivity analysis was performed. In this evaluation, each of the main variables affecting the total cost of each alternative (CAPEX plus OPEX) was assigned a probability function specific to the variable. Then, a Monte Carlo-type simulation (a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making), with over 100,000 iterations, was run for each of the alternatives and the probability curve envelopes of the total cost for each alternative were generated. Figure 1 shows the probability functions for all alternatives considered.

Since the low-speed engine-generators are anticipated to last 50 years, the total cost of ownership was assessed over a 50-year period. No financial costs were included in any of the evaluations for simplicity. It was assumed that the high-speed engine-generators would need to be replaced once over the 50-year period.

Table 3 includes the input parameters considered in the evaluation.

Results

The evaluation included the results of a probabilistic present-worth analysis, with probabilities for the different variables affecting CAPEX and OPEX, as shown in Figure 1. It can be seen that there are substantial savings from moving from a diesel-only engine-generator alternative to a hybrid or natural gas solution (between $80 and $250 million in 50 years).

Findings

From Figure 1, the following were discovered:

- Natural gas alternatives represent the best business case; however, given their inherent risk of full dependency to the natural gas utility, these alternatives are not considered viable for SDWTTP's emergency engine-generator use.
- Diesel-only alternatives have the highest total cost of ownership.
- There is an obvious advantage to having a curtailment agreement with the local electric utility, as the total cost of ownership for the alternatives with the curtailment agreement are lower than alternatives without curtailment in every scenario evaluated (notwithstanding the fact that the curtailment agreement alternatives with diesel engine-generators have higher capital costs due to their need for Tier 4 compliance).
- The hybrid alternatives provide the best compromise, as their total cost of ownership is much closer to the natural gas only alternatives.

To further evaluate the alternatives, the annual operating hours were evaluated against the maintenance-only cost and maintenance-plus-capital cost for the generators. Given the conclusions, only curtailment and hybrid alternatives were evaluated further.

This evaluation was conducted to determine the operating-hour break-even point between the remaining alternatives. The annual costs were calculated based on maintenance costs per hours of operation and the capital cost of the units split over an assumed 50-year replacement period. This was done to evaluate the operation of the engine-generator technologies specifically.

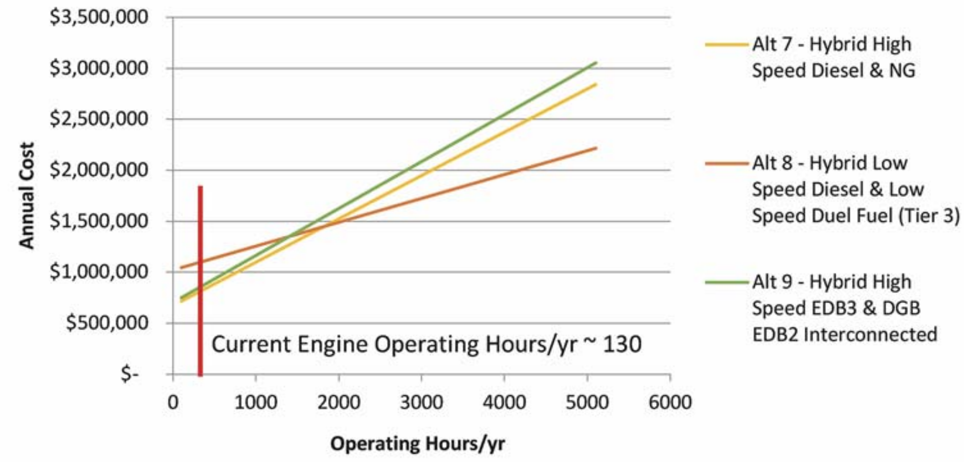

Figure 2. Annual Average Operating Cost of Alternative 7, 8, and 9 (Hybrid Alternatives) Versus Operating Hours (Capital and Maintenance Only)

Figure 2 compares the annual operating cost of Alternatives 7, 8, and 9 versus annual operating hours. Note that it's assumed that the high-speed units require a major overhaul at 25 years.

Alternatives 7 and 9 are the lower annual cost alternatives at the current average usage rate of approximately 130 hours per year. Additionally, the break-even point, in which the annual operating cost of Alternatives 7 and 9 are less than Alternative 8, is approximately 1500 hours per year. Therefore, Alternatives 7 and 9 are more cost-effective when operated less than 1500 hours per year.

Black & Veatch developed a revised future estimate of hours of engine-generator operation since the Tier 4 units will have more unrestricted operation, which should increase the running time of the engines. The revised estimate includes hours for emergency, maintenance, curtailment, and prestorm avoidance, and could conservatively result in the generators running up to 750 hours per year. Although this is significantly higher than the current usage (approximately fivefold), the conservative number of operating hours is still well below the break-even point between diesel-only and hybrid units, suggesting that a hybrid alternative is the best option for MDWASD.

Conclusion

To capitalize on the cost savings offered by natural gas alternatives, but not be dependent on a natural gas utility line, it's been proven that a hybrid solution of combining diesel and natural gas provides substantial total cost savings to utilities. The savings are even more pronounced if the utility enters into a curtailment agreement. Hybrid solutions can be achieved by either diesel-gas blend units or a combination of different fuel generators (diesel plus natural gas).

The hybrid engine-generator solution advantages are:

- Maximizes the use of lower-cost fuel.
- Extends the diesel fuel storage onsite by using natural gas, while reducing operating costs.
- Allows extended run time compared to diesel-only units under emergency conditions, if the natural gas supply is not impacted.
- Unrestricted engine operation, which allows the engines to be turned on for conditions, such as prestorm, or to provide completely flexible maintenance testing operation.
- Provides plant staff with more flexibility for operating the engine-generators.