

Building Puerto Rican Resiliency with LPG-Fueled Engines

After Hurricane Maria left the island of Puerto Rico in ruins, the ProCaribe liquefied petroleum gas (LPG) hub continued to operate, ensuring vital energy resources were available even in the wake of this major natural disaster. Still, the hurricane exposed risks, so to further enhance the terminal's capabilities, Empire Gas adopted a resiliency strategy that included the addition of a captive LPG-fueled engine.

Gabriel Craig

Just as significant damage caused by Hurricane Irma was being repaired in September 2017, the Category 4 Hurricane Maria made landfall in Puerto Rico. Bringing sustained wind speeds of more than 150 miles per hour, Maria devastated the Caribbean island's energy infrastructure and left almost all its four million people in the dark.

The Puerto Rico Electric Power Authority (PREPA) reported that all 1,570,000 of its electricity customers were without power after the storm, while much of the island's transmission infrastructure was also destroyed. With almost two-thirds of Puerto Rico's electricity generation capacity located in the south of the island and most of the population concentrated in the north, even where generation capacity was still functional, the damage meant power could not be supplied to consumers. Electricity generation reportedly dropped by some 60% in the fourth quarter of 2017, compared with the same period of 2016. Months later, some consumers were still without power.

According to the latest available figures from the U.S. Energy Information Administration, prior to Maria, Puerto Rico's electricity generation was mostly fueled by petroleum and natural gas. In 2017, these fuels made up 47% and 34% of the territory's net generation, respectively. Roughly 17% of the island's power was derived from coal while renewables provided the remaining 2% from 120 MW of solar power and 22 MW of installed wind.

With no indigenous fossil fuel resources, all these fuels were imported. Indeed, imported petroleum products fuel transportation, electricity generation, and industry in Puerto Rico, typically supplying some three quarters of the energy consumed in the commonwealth. In or-

der to support this requirement, Puerto Rico has several LPG import terminals, the largest of which is the ProCaribe installation. A vital link in the island's energy system, resiliency in the face of extreme events like Maria is key to the island's future energy supply.

LPG Is Vital for the Island

Within Puerto Rico, industrial and commercial users consume about 34 million gallons (129 million liters) of LPG annually, while the residential and domestic market is responsible for about 60% of the market volume or some 51 million gallons (193 million liters). Alongside commercial power generation, more than half a million homes use gas for cooking, for example.

After some 50 years in business, Empire Gas is the leading company operating in Puerto Rico's LPG market, and it owns and operates the ProCaribe LPG terminal. Able to receive large, fully refrigerated LPG tankers up to a maximum vessel length of 800 feet (260 meters) and a displacement of 69,000 tons, the ProCaribe LPG terminal features a storage capacity of 23,400 tons. It started operations in September 1986. Algeria is a primary source of supply to ProCaribe, while Venezuela, West Africa, and the North Sea also provide LPG to the terminal.

Today, Empire Gas serves about 80% of the propane market in Puerto Rico, delivering more than 70 million gallons a year to retail and industrial customers both in Puerto Rico as well as to some of the neighboring islands such as the Virgin Islands. With 52 plants on Puerto Rico, the company has built extensive pipeline infrastructure, in particular to the city of San Juan, where natural gas is not reliably available.

ProCaribe represents some 85% of Puerto Rico's LPG terminal capacity and



1. Siemens supplied a containerized combined heat and power solution for the ProCaribe liquefied petroleum gas terminal in Puerto Rico. Courtesy: Siemens

is capable of supplying all of Puerto Rico's LPG market. For example, ProCaribe signed a 22-year LPG Storage and Service Agreement with the 507-MW EcoElectrica power plant, which began commercial operations on LPG in March 2000.

A source of stable energy supply for the island, the installation's large storage capacity is the biggest in the Caribbean region and results in significant operational flexibility. The terminal also raises the potential for market growth through delivery to local export markets elsewhere in the Caribbean.

Given the critical nature of the asset, Empire Gas adopted a strategy that would minimize impact of potential grid outages to keep the facilities operating without interruption by adopting captive combined heat and power (CHP) plants for its own energy requirements (Figure 1).

The Empire strategy is designed to ensure a rapid response in the event of natural disaster or other emergency whilst reducing energy costs. Ultimately, the goal is to deliver business continuity whilst ensuring commercial success by supporting growth, keeping existing clients, and increasing revenue.

ProCaribe's Resiliency Solution

As part of this strategy, in 2017, Empire Gas placed an order with Siemens for a containerized CHP installation capable of powering the LPG terminal, and supplying heating and cooling to maintain the regasification process that makes the delivered LPG suitable for pipeline distribution.

With a focus on low lifecycle costs, ease of installation, and operation in compliance with the strictest environmental requirements, Siemens, jointly with local Puerto Rico business partner and solution provider Tek-Sol, offers a range of robust and high-performance engines. Suitable for all sorts of different fuel gases, including propane/LPG, natural gas, landfill gas, or sewage gas, Siemens' S-Series engines are lean burn and electronically carbureted.

This Miller cycle series of engines is turbocharged and includes two-stage charge-air cooling. A double cooling circuit system allows different output temperatures to be achieved, while an oil cooler is an additional option for the main cooling circuit to improve total efficiency or maximize heat recovery for certain suitable applications. Among the key characteristics of this series of engines are standard interchangeable parts and very high operational availability.

With a dry or wet exhaust manifold configuration, an emissions control option means this series is compliant with even the latest U.S. emissions standards—being U.S. Environmental Protection Agency certified for natural gas power generation, for example—and has reduced oil consumption too. Delivering the highest electrical efficiency and the biggest displacement within the smallest footprint, Siemens engines are available with delivery lead times that are among the shortest for spark-ignition engines.

When fueled with propane/LPG, S-Series engines offer outputs ranging from 275 kWb to 906 kWb at both 50 Hz and 60 Hz. Recognizing that the SM series of gas engines are propane-specific and thus provide an excellent solution for power generation, cogeneration, and trigeneration applications, Empire Gas ordered a containerized SGE-36SM for the ProCaribe terminal. The quality of the containerized "plug-and-play" solution, as well as locally available round-the-clock service capability and multiple

LPG (C3H8) as designated by the M nomenclature. Running at 1,800 rpm and fueled with 95% propane gives a rated performance of 676 kW_e and 700 kW_b. The unit installed at the ProCaribe hub operates at 480 V and 60 Hz, delivering 676 kW_e and 1,035 kW_{th} as standard (Figure 2).

This unit operates in trigeneration mode, providing power, heat, and cooling simultaneously. A mixed recovery boiler extracts energy from engine exhaust gases and is supplemented with a propane burner to produce hot water at 90C, both for direct plant processes and to feed an absorption vapor chiller. Producing chilled water at 5C, this absorption chiller is also used in the plant process. Recovered energy from the engine water jacket is further used to feed the absorption chiller and generate cold water for the plant.

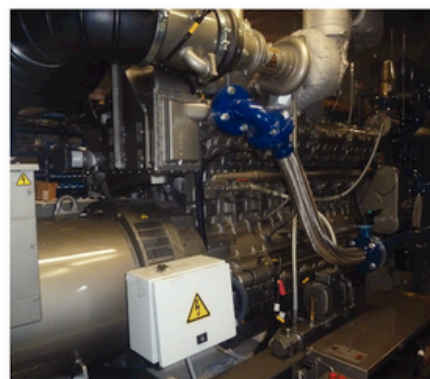
Alongside the supply of the core containerized cogeneration unit, which is fully compliant with Puerto Rican energy regulations and legislative demands, Siemens' scope of supply also included commissioning of the unit and training of service and operational staff. Commissioning of the unit was followed by a performance test in compliance with the contractual conditions.

Exceeding Performance Expectations

Following commissioning and customer acceptance in 2018, the unit has been delivering heating, cooling, and power to the ProCaribe terminal. The performance of the engine in this installation has exceeded the expectations of Empire Gas, going beyond the guaranteed performance ratios, for example.

As a ProCaribe spokesperson observed: "The benefits are significant in terms of guaranteed power to ensure continued operations, even in the event of a major natural disaster, as seen in September 2017. This contrasts sharply with smaller transmission and distribution networks seen on island states like Puerto Rico and previous operational experience at the ProCaribe terminal. In addition, there has been a significant improvement in the overall efficiency of the plant based on the new trigeneration unit."

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2. Siemens' SM series of gas engines can be fueled by natural gas, landfill and sewage gas, or propane/liquefied petroleum gas. The SGE-36SM installed at the ProCaribe terminal is designed to deliver 676 kW_e and 1,035 kW_{th}. Courtesy: Siemens

Rico. Most significantly, it did not collapse after the hurricane."

Post-Maria, building out a resiliency strategy is a growing trend in Puerto Rico. For instance, more recently Siemens has supplied four trigeneration modules for a pharmaceutical company operating on the island. This project features four 874-kW SGE-48SM units operating at 1,800 rpm and 60 Hz. A combined power output of 3.5 MWe at 480 V is coupled with process steam from an exhaust gas heat recovery steam generator, as well as chilled water from an absorption chiller.

LPG and a Robust Caribbean Energy System

With an area of just 3,515 square miles, Puerto Rico nonetheless has among the most favorable economic conditions in the Caribbean and is potentially positioned as a major energy hub for the entire region. Certainly, demand for LPG is rising in both developed and developing nations as the need for cleaner, more-flexible fuels grows. Simultaneously, population and energy usage are increasing, driving demand for LPG still further.

For Puerto Rico to maximize the potential benefit of this growth market, reliability and resiliency are key. With extreme weather events becoming more frequent, energy system resiliency is a key factor in the Caribbean and elsewhere. Siemens' comprehensive range of gas engines specifically tailored to LPG offers a reliable and high-efficiency, low-emission solution able to ensure power systems continue to

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With a dry or wet exhaust manifold configuration, an emissions control option means this series is compliant with even the latest U.S. emissions standards—being U.S. Environmental Protection Agency certified for natural gas power generation, for example—and has reduced oil consumption too. Delivering the highest electrical efficiency and the biggest displacement within the smallest footprint, Siemens engines are available with delivery lead times that are among the shortest for spark-ignition engines.

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SGE-36SM is a 36-litre displacement, V12 engine running on propane/

LPG (C3H8) as designated by the M nomenclature. Running at 1,800 rpm and fueled with 95% propane gives a rated performance of 676 kW_e and 700 kW_b. The unit installed at the ProCaribe hub operates at 480 V and 60 Hz, delivering 676 kW_e and 1,035 kW_{th} as standard (Figure 2).

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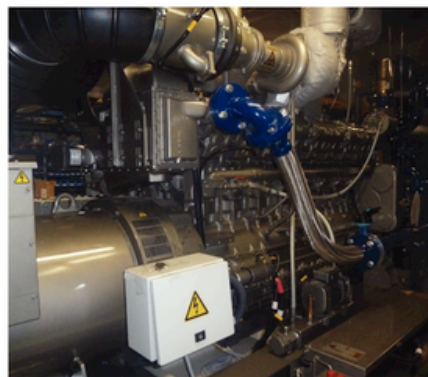
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"The SGE-36SM is part of the Siemens gas engine family that can run on propane without power capacity derating, loss of efficiency, or damage to the equipment," added the spokesperson. "This is very important because propane is the gas fuel most available in Puerto



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—**Gabriel Craig** is regional director for Latin America with Siemens Gas Engines.

