EXERGY ENERGY

Natural Gas vs. Diesel

It is easy to take electricity for granted, but almost every aspect of modern life depends on a reliable supply of electricity. The same is true for businesses.

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Introduction:

It is easy to take electricity for granted, but almost every aspect of modern life depends on a reliable supply of electricity. The same is true for businesses.

For some firms, power outages can result in equipment damage or failure, resulting in significant expenses. Many companies require 24/7 power since they literally cannot shutdown.

As the grid ages and depreciates, in combination with rising ambient temperatures and more extreme weather, the frequency of major electrical disturbance events has significantly increased, especially during the past decade.

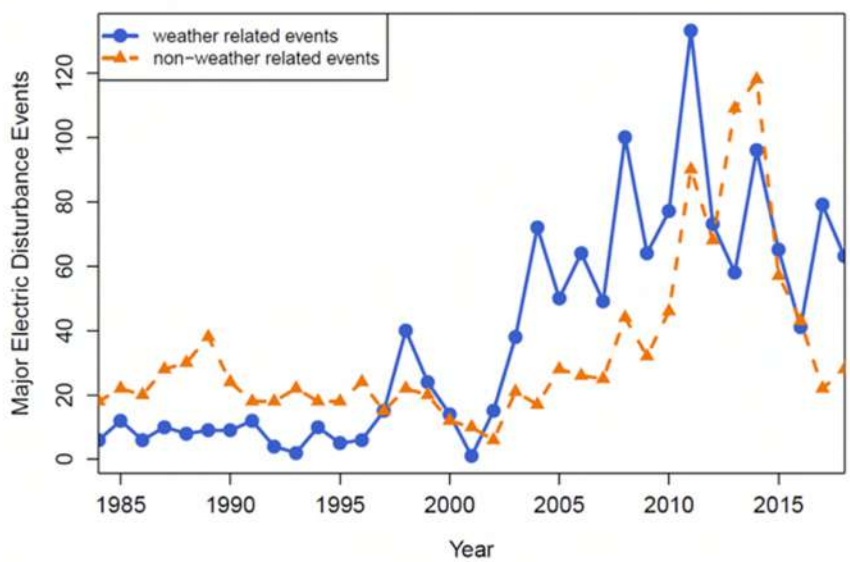


Figure 1. Major electric disturbance events between 1984 and 2018.

Figure adapted from (Laws, Anderson, DiOrio, Li , & McLaren, 2018) with additional data from DOE form OE-417.

Although it is hard to estimate the economic costs of power outages, each typically averages in the billions. For example, the 2003 Northeast blackout was estimated to cost more than $6 billion, with the total cost of outages in 2015 estimated to range from $26 billion to $75 billion.

Even shorter outages can be problematic. A loss of power, even for less than a minute, can damage machinery or require extended time to reset operations, all on top of the opportunity cost of zero output. More prolonged outages can result in even greater opportunity costs from lost revenues, food spoilage, or general disruptions to the industrial process. Furthermore, and of greater significance, outages of any duration are unacceptable for operations supporting life-saving activities.

As the incidence of power outages increases, firms without backup generators are increasingly considering resiliency measures. Backup generators are highly reliable, a great value, and available in diesel or natural gas configurations. But unfortunately, as reliable as backup generators are, they are useless without fuel.

When planning and designing your resiliency plan, it is essential to consider the fuel source and its reliability. This eBook examines the reliability and risks related to diesel and natural gas. However, our analysis would not be complete without considering non-fuel backup, specifically batteries and solar. This non-fuel alternative is also considered, but please download our eBook dedicated to this subject for a comprehensive, in-depth analysis of batteries versus backup generators.

Background:

Diesel has been the go-to fuel to power standby backup generators in commercial and industrial settings for decades. The marketplace has traditionally favored diesel because the fuel is readily available, could be safely stored for long periods of time, and it has a very high energy density. However, the reliability profile of diesel backup generation has declined considerably over the last two decades resulting in natural gas becoming increasingly competitive in terms of performance and reliability.

As the technology improved, natural gas-powered generators have progressively taken a greater share of the standby generator market, from 28 percent in 2013 to 38 percent in 2016; since then, the share has continued to increase.

The increase in market share has been influenced not only by improved technology but also by increased awareness of natural gas as a cleaner, more reliable fuel; increased concerns over diesel maintenance and refueling issues; increased revenue generating capabilities from participation in grid programs such as demand response; and fewer emissions.

Since performance differences between diesel and natural gas have largely disappeared, issues relating to fuel supply now take on much greater significance.

The different physical forms of the two fuels have a major impact on the reliability and resiliency of fuel supply. In addition, natural gas is distributed in underground pipelines, and access to these lines is widely available throughout the United States.

There is no diesel pipeline grid; therefore, diesel is delivered by truckload or tanker. The difference in the way both fuels are distributed has implications for reliability. Although both fuels are readily available, and their delivery is reliable under normal circumstances, longer outages and local physical damage can favor one fuel over the other.

The following sections examine the differences between diesel and natural gas in terms of fuel quality and security and their implications for maintenance and reliability.

Fuel Quality and Fuel Maintenance: The rise of Biodiesel and ULSD

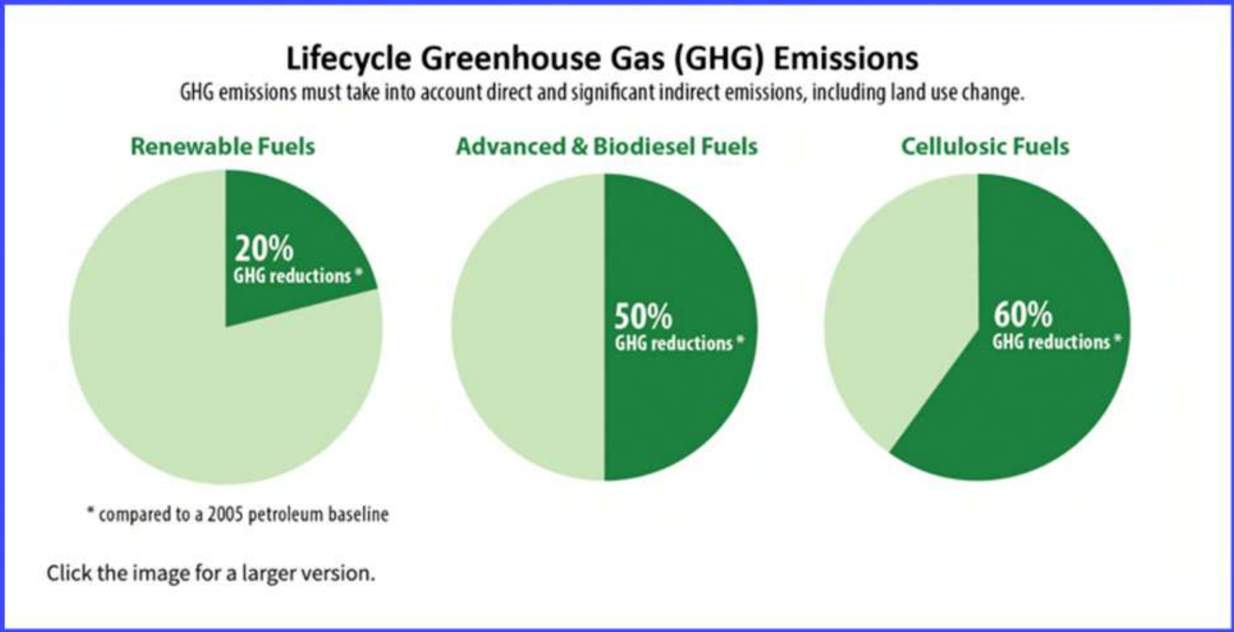
As mentioned earlier, diesel fuel has an enviable history of supplying reliable energy for emergency backup applications; however, recent changes to the composition of the fuel have affected the reliability and perceived reliability of on-site diesel. These changes include the introduction of biodiesel mixtures and the rise of ultra-low sulfur diesel (ULSD). Both biodiesel and ULSD have altered the reliability of diesel used in backup applications. The following sections examine these effects.

Biodiesel and Fuel Quality:

In 2005, Congress amended the Clean Air Act (CAA) by implementing the Renewable Fuel Standard (RFS) program under the Energy Policy Act of 2005 (EPA). In 2007, Congress further amended the CAA with the Energy Independence and Security Act of 2007 (EISA). The RFS program was implemented at the national level and requires a particular volume of renewable fuel to replace the quantity of petroleum-based transportation fuel, heating oil, or jet fuel.

Biodiesel is produced domestically in the United States and is a renewable fuel manufactured using animal fats, vegetable oils, and recycled restaurant grease. Biofuels, including biodiesel, are incredibly important to the sustainable fuel transition and in solving climate change. Biodiesel can be blended and utilized in many different concentrations, anywhere from B100 (pure biodiesel) to B4 (4% biodiesel, 96% diesel).

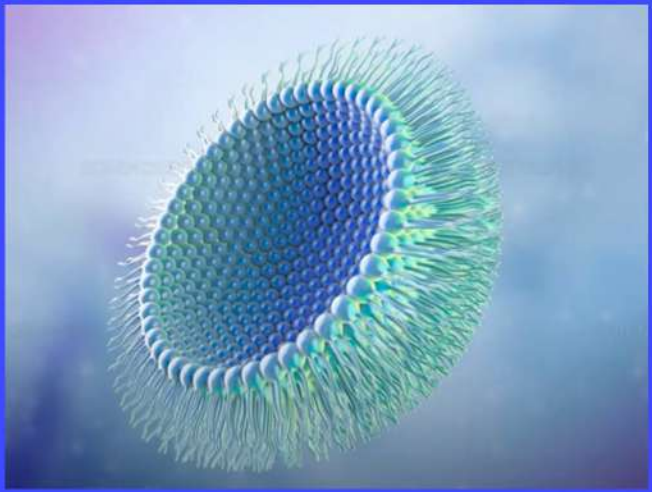
As biofuels, specifically biodiesel, have gained traction, the frequency of biodiesel mixtures has increased. Biodiesel-diesel mixtures are required in almost all jurisdictions; therefore, the likelihood of biodiesel being present in the diesel your firm consumes for backup power is close to 100 percent. As seen in the figure below, biodiesel can reduce GHG emissions by up to 50 percent. Despite the benefits, biodiesel has important implications for reliability. In 2006, following the RFS, biodiesel-diesel mixtures were first implemented, and by 2007, genset operators and experts first noticed issues relating to its introduction into the fuel supply.



In terms of physical properties, biodiesel is very similar to petroleum diesel; it just burns cleaner and significantly reduces lifecycle carbon emissions; however, it has a few key chemical differences that have specific implications for fuel quality.

Before biodiesel, the biggest concern with diesel gensets was the buildup of water due to changes in ambient temperatures resulting in condensation within the fuel tank. Water would lead to microbial growth and eventually fuel corrosion, which impacts the operational reliability of a generator. Fortunately, because the water would accumulate at the bottom of the tank, periodic draining of the water layer was a required and standard maintenance practice to keep the diesel generator operating reliably for long periods. Unfortunately, the use of biodiesel has complicated this once simple process.

Because biodiesel is polar, and diesel is not, pure biodiesel absorbs 15 to 25 times as much water as pure diesel. In addition, water absorption happens quickly, and saturation can occur in a day. Biodiesel encapsulates water molecules, creating what is known as a micelle. The figure below depicts a micelle. The polar head of the biodiesel molecule, represented by the circular head, is attracted to the water, while the nonpolar tail creates a barrier between the biodiesel and the diesel.



The water molecules and microbes would be within the structure; however, they are omitted to make the model easier to understand. Because biodiesel completely encapsulates water molecules, traditional diesel filters cannot filter out the water as they must be able to touch the water to detect and remove it. Furthermore, the micelles are denser than diesel; therefore, they sink to the bottom of the diesel tank, where they can form a layer up to 6 inches thick that is difficult to drain or remove, unlike before with traditional diesel.

In addition, the problems resulting from microbial growth, such as fuel acidification and corrosion of the injectors, are worsened as the 6-inch layer of micelles that accumulates at the bottom of the diesel tank is the perfect environment for microbial growth. The microbes consume both biodiesel and diesel, producing acidic waste that can corrode the micron-sized fuel injector, reducing the reliability and efficiency of the generator.

The emergence of micelles in the general diesel supply has increased the incidence of water in the fuel tank, making fuel corrosion a more significant threat to generator reliability.

ULSD and Fuel Quality:

In addition to the rise of biodiesel use, in 2006, the same year the RFS was implemented, the EPA phased in significantly more stringent regulations on sulfur content in diesel. The regulations require the amount of sulfur in diesel fuel to be 15ppm or less. Diesel with such sulfur content is known as ultra-low sulfur diesel (ULSD).

To decrease the sulfur content in diesel and to comply with these regulations, diesel must undergo a process called hydrotreating. Studies have shown that hydrotreating alters the lubricity and chemical composition of the fuel. As a result, ULSD has a lower energy density than diesel and has increased production costs that are passed down to the consumer.

According to the EPA, hydrotreating is estimated to decrease diesel's economy by 1 percent and increase production costs by 5 to 7 cents per gallon. Depending on the market, distribution, and other production factors, these costs can be higher. Furthermore, because hydrotreating reduces diesel's lubricity, it contributes to engine wear, increasing maintenance and repair costs.

The use of ULSD (the current norm), like that of biodiesel, has increased the risk of microbe-related failure in diesel gensets, multiplying the importance of proper maintenance. ULSD, when mixed with biodiesel, enhances the micelle effect, leading to higher levels of acid buildup than untreated diesel alone and potentially devastating corrosion in the surrounding tank and injectors. Furthermore, the sulfur that used to be present in diesel acted as a biocide in that it slowed the growth of microbes and algae, which led to fuel corrosion and engine failure.

The U.S. Air force conducted a study to examine the effects of B20 biodiesel on corrosion in storage tanks. After 9 months, some of the tanks had to be removed from the study due to "severe microbiological contamination that required mitigation."

There are currently new filters designed to combat micelle growth; however, without these filters, if the fuel is not replaced frequently, generator reliability declines tremendously. Unfortunately, many remain unaware of the new maintenance practices that are now required due to the changes in diesel fuel composition. The maintenance requirements of diesel fuel are examined in the following section.

Maintenance Requirements for Diesel:

Although the traditional perception of diesel as the most reliable fuel for emergency backup power and its widespread use, diesel and diesel generators require significant maintenance to ensure reliability; this is especially true given that the composition of diesel has changed dramatically over the past 20 years. In addition, as discussed in the previous section, the rise of biodiesel and ULSD has magnified the problems associated with water absorption, microbial growth, and corrosion. As a result, today's diesel cannot sit in a storage tank for more than a year and remain reliable. This has important implications for diesel used in emergency backup applications. In such applications, the backup fuel can sit for long periods and is simply topped up periodically.

The incidence of micelles is directly correlated to the amount of time the fuel sits. The turnover rate of diesel in backup generators is less than that used in transportation, which doesn't suffer as severely from these effects. Therefore, the public view of diesel reliability is diametrically opposed when speaking about backup generators. Because of this, maintenance is even more critical than it was in previous decades.

Filters, fuel stabilizers, and biocides are required to prevent water and biomass contamination, including regular testing and fuel maintenance. As mentioned earlier, new filters have been developed to combat micelle growth (as tested against SAE J1488, the most recent standard for particulates). When using these filters, tank cleaning is no longer needed; however, many remain unaware of the need for permanent filtration systems in long-term diesel storage tanks.

Aside from micelle growth and other fuel quality issues, diesel generators can also fail due to a phenomenon called "wet stacking." Wet stacking occurs when unburned diesel fuel builds up in the engine and typically occurs when loading the generator below 50 percent of its rating. Estimates show that wet stacking is responsible for up to 65 percent of diesel generator maintenance problems.

A process called load banking is required to prevent wet stacking for emergency power or standby power applications. Load banking is when the generator is loaded to 100 percent capacity. Typically, diesel gensets require load banking every 2 to 3 years, and the process is an additional maintenance expense. However, some applications could need load banking more frequently depending on the location.

NFPA 110 regulations require monthly testing at full load for 30 minutes for life-saving applications. The cost of load banking varies depending on location, regional variations, and physical constraints; however, Generac estimates the cost to be around $1.50/kW with an initial fixed outlay of $1000.

The process of load banking, other than being expensive, is incredibly filthy. The soot and emissions from the diesel genset can coat windows and cause health-related issues if the generator is located inside.

Even though preventative maintenance can increase diesel reliability, the maintenance is frequently not performed, either because the generator operator remains unaware of the new risks present or because it is not a priority and gets overlooked. Without modification or implementation of new filters and stringent maintenance practices, the reliability of the diesel genset is significantly hampered.

According to an NREL study and seen in the figure below, in terms of reliability, the difference between well-maintained and poorly-maintained generators is significant, likely more so than in previous decades. The difference is especially significant the longer the duration of the outage. A poorly maintained generator is unlikely to provide the needed power to remain in operation for more than a few days, with reliability falling to 80 percent over 12 hours.

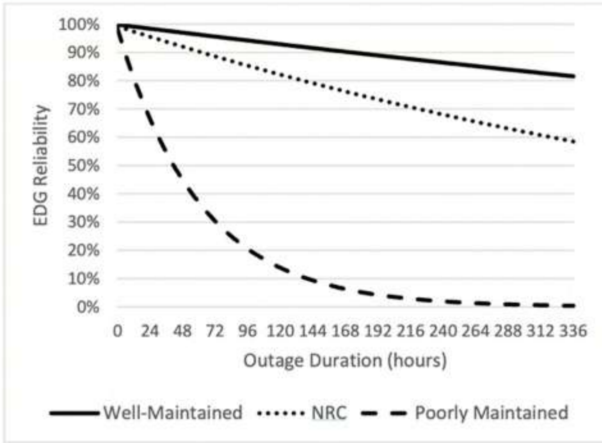


Figure 7. The reliability of a single EDG over two weeks (336 hours)

A properly maintained diesel generator adheres to the Unified Facility Criteria (UFC 3-540-07) guidelines. However, even if these guidelines are followed rigorously, well-maintained emergency diesel generators still only have 80 percent reliability after 2 weeks.

Given that some outages, especially those caused by extreme weather such as hurricanes, can last up to 31 days, as was the case during Hurricane Sandy, 80 percent probability after two weeks simply will not cut it, especially if 99 percent resiliency is critical to your firm.

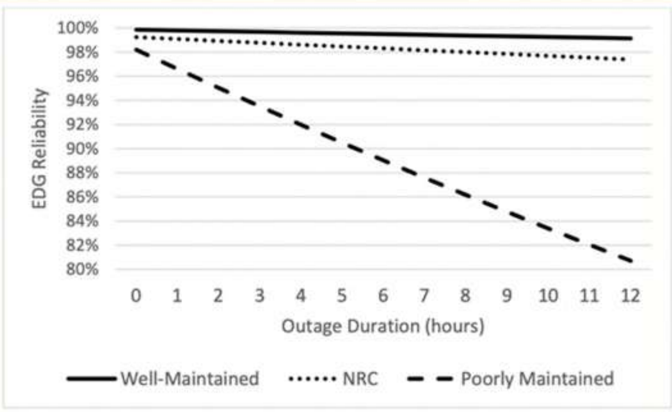


Figure 8. The reliability of a single EDG for outages less than half a day (12 hours)

The risk is severe given that many remain unaware and have yet to take action to address the threat to generator reliability due to biofuel mixes. The maintenance practices of the previous era will no longer suffice.

Standby Application
Life Cycle Total Owning Cost (x1000)

Power Rating	Diesel	Natural Gas
150kW	$140 (1 x 150)	$110 (1 x 150)
500kW	$390 (1 x 500)	$110 (1 x 500)
1200kW	$925 (2 x 600)	$110 (4 x 300)
2000kW	$1,580 (1 x 2000)	$110 (4 x 500)

As seen in the table below, natural gas is significantly more environmentally friendly than diesel; this is a crucial advantage, especially as the world frantically tries to reverse the effects of climate change while maintaining the status quo of economic growth.

Table 1: A single engine 200 kW diesel generator set compared to a 200 kW natural gas generator set using Generac Industrial Power's ROI Calculator[17]

Total Cost for 25 Years (-4% Inflation)	Diesel $148,542.00	Natural Gas $142,157.00
Total NOx Emissions	919 (lb)	25 (lb)
Total CO Emissions	596 (lb)	124 (lb)
Total PM Emissions	37 (lb)	0 (lb)

Diesel gensets can participate in peak shaving; however, to do so, they must adhere to EPA standards, meaning they must be Tier-4-compliant. Tier-4 diesel gensets are typically 40 to 50 percent more expensive. Therefore, it is significantly cheaper for natural gas generators to comply with EPA standards required to engage in non-emergency operations. As a result, because natural gas gensets can more easily be utilized for revenue-generating purposes, they can be run more frequently, increasing reliability.

The last and most significant advantage of natural gas over diesel is the theoretically unlimited supply of natural gas. Unlike diesel gensets, which require fuel to be stored on-site, natural gas gensets are connected to the national pipeline network, making it very unlikely one would run out of gas; these implications are assessed in more depth in the following section.

Fuel Security: Running on Fumes

A failure of fuel supply (FFS) occurs when the generator runs out of fuel and can no longer generate an electrical output. The causes of an FFS are different for diesel and natural gas gensets; however, as both generators converge in terms of competitiveness and engine reliability, the main factor determining overall resiliency is the security of the fuel supply. The following paragraphs assess the supply of both natural gas and diesel and the differences in reliability.

Diesel Supply:

The security of diesel first relies on the size of the on-site storage tank. Tank size varies depending on the application and the relevant regulatory requirements. For example, life-saving institutions such as hospitals are required by law, under NFPA 110, to store between 48 and 96 hours of fuel on-site. On the other hand, retail stores with backup capabilities typically only keep around 36 hours of diesel on-site.

Normally, one can easily replenish the diesel supply before the generator runs out of fuel. However, problems arise if diesel delivery is delayed or prohibited under adverse conditions. For example, long outages are correlated to extreme weather events, which have the potential to destroy or close roads, impeding delivery. In the case of hospitals or retail stores, if diesel distributors cannot deliver fuel before the 36 hours or the 48 to 96 hours of diesel supply on-site, then the operation will cease to have power.

Hurricanes Irene and Sandy severely impacted diesel supplies for an extended period. During Irene, there was limited but widespread damage to diesel distribution infrastructure in contrast to no impact on natural gas supply.

The story is the same during Sandy, just more pronounced. Sandy destroyed many fuel terminals and ports throughout the region, making it very difficult to deliver. Although delivery trucks could travel to fuel terminals, in many cases, there just was not any fuel available for them to pick up.

Furthermore, many trucks that could load diesel were redirected to hospitals and other emergency response facilities. For example, diesel was redirected during Hurricane Katrina to aid rescue operations, and during Hurricane Sandy, fourteen percent of hospitals experienced generator fuel shortages. When an outage affects an entire region, diesel demand can increase dramatically, making fuel more expensive and harder to access.

Hurricanes Irene and Sandy present two prime examples of the issues surrounding diesel fuel reliability and its ability to provide resiliency throughout an outage. These two hurricanes directly contradicted the long-standing perception that diesel fuel delivery was reliable even during especially bad emergencies. During both storms, maintaining generation using diesel was not guaranteed, while generators running on natural gas ran continuously for anywhere from days to weeks without fuel supply interruptions.

FFS presents a significant risk during more extended outages for diesel-powered generators and is very important to understand when choosing between diesel and natural gas-powered gensets.

Natural Gas Supply:

The natural gas pipeline is a broad network of interconnecting sections similar to the internet. There are often multiple delivery routes to the same destination, the same way an internet packet can travel different routes depending on the state of the network.

Because natural gas is supplied through a network of pipelines, unlike diesel, it has unique advantages and disadvantages. Because the supply of natural gas is virtually limitless, as it is piped directly to the generator from the utility, natural gas generators do not face the same risk of losing supply as diesel gensets do if the roads are impassable.

Natural gas utilities are historically very reliable and have very infrequent outages. In addition, recent studies have concluded that gas supply reliability will continue to increase as the supply of natural gas increases as the grid replaces coal-fired generating plants with natural gas.

Because natural gas systems are underground and distribution does not rely on the electrical grid, electrical outages, which are frequently due to extreme weather events, are generally uncorrelated to gas outages. Conversely, the depletion of backup diesel supply is directly correlated to extreme weather events –outages frequently occur during extreme weather events, when diesel is needed most, and when the roads and ports are most likely to be compromised.

While earthquakes and tsunamis can damage natural gas infrastructure, these occurrences are extremely rare and so localized that they do not warrant consideration except for a few operations. There is the potential for a particularly devastating natural disaster (such as wildfire or earthquake) to damage distribution lines and cause a gas outage; however, it is unlikely that diesel delivery would be possible under these circumstances as well.

Table 1. Electrical and Natural Gas Customer Outages During Select Natural Disasters.

Event	Year	Electricity Outages (Total Customers)	Gas Outages (Total Customers)	Percent Coincident Outages
Hurricane Harvey	2017	306,058[a]	2[b]	≈ 0%
Hurricane Irma	2017	4,200,000[a]	2[b]	≈ 0%
Hurricane Irene	2011	6,690,000[c]	1704[c]	0.025%
Southwest Cold Weather Event	2011	4,400,000[e]	50,000[e]	1.140%
Hurricane Sandy	2012	2,615,291[c]	32,000[c]	1.220%
California Fires	2003	58,700[a]	1,000[a]	1.704%
Hurricane Sandy (New York)	2012	2,097,933[c]	80,000[d]	3.813%
California Fires (SDGE)	2017	85,000[b]	4,800[b]	5.647%
California Fires (PG&E)	2017	359,000[b]	42,000[b]	11.700%

Data from [a] (DOE, 2003-2018), [b] (ICF, 2018), [c] (DOE, 2013), [d] (INTERCEP, 2013), [e] (FERC/NERC, 2011).

During Hurricanes Irma and Harvey in 2017, the natural gas infrastructure remained functional and was highly resilient, with only four customers losing gas service during both storms. For Hurricane Irene in 2011, the gas system did experience outages; however, only 1 percent of customers who experienced power outages also experienced natural gas curtailments.

A 2013 report by MIT's Lincoln Laboratory found that the natural gas distribution system and its infrastructure in areas without seismic activity operate at a reliability rate that exceeds 99.999%. Moreover, it has been estimated that 40% of the natural gas pipeline could be offline before it would materially impact gas delivery.

Many of the compressors used in the natural gas transmission network are powered by natural gas itself, utilizing close to 3 percent of all the natural gas produced in the United States. Because natural gas production is distributed throughout the U.S. and because there are vast transmission networks, the probability of widespread failure is low. In addition, the continental U.S. has close to four trillion cubic feet of storage capacity. Therefore, even if natural gas production were to cease, it is estimated that it would take anywhere from 2 to 9 weeks for the underground supply to be fully depleted.

But What About Solar and Batteries?

There are numerous options when it comes to selecting a fuel to provide backup power during an outage. Advances in lithium-ion battery technology have led many to believe that battery storage is the solution to the 21st-century problem of resiliency; unfortunately, it is not quite so simple.

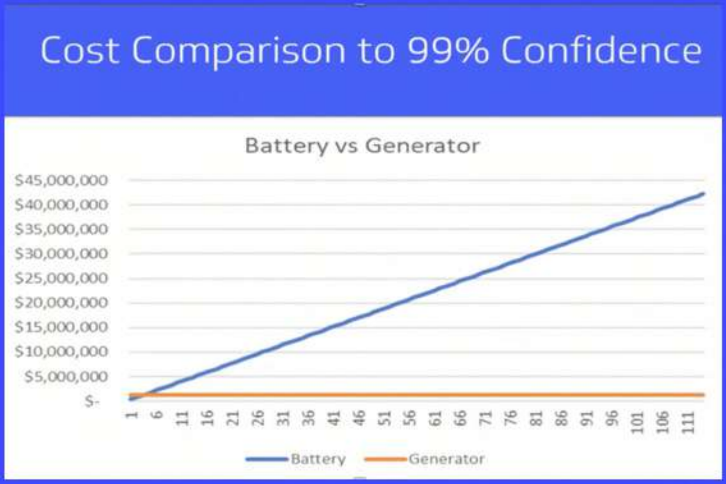
It is tremendously expensive to get your backup power from a battery. For a firm requiring 1 MW per hour for 24 hours, the batteries alone will cost over $8.8 million and that investment will only provide backup power for one day and many outages last considerably longer.

Scenario	Size of Battery Installation (hours)	Cost of Battery (millions)	Size of Solar M.W. D.C.	Cost of Solar (millions)	Total Cost of System (millions)	Multiple of Generator's CapEx
Battery Alone for 24-hour outage	24	$8.88	-	-	$8.88	7.33x
Battery Alone for 114-hour outage (99% confi-dence)	114	$42.18	-	-	$42.18	35.15x
Bigger Solar + Battery	15	$5.56	39	$52.65	$58.21	48.5x
Bigger Bat-tery + Solar	57	$21.09	7.8	$10.53	$31.62	26.35x

A battery must be able to supply power for 114 hours to be confident your firm can outlast 99 percent of outages; this would cost $42.18 million. Compared to the Capex required for a generator, the battery option is 35.15x more expensive. When solar charging is added, the Capex requirements are still significant, $31.61 million to be specific, 26.35x more than the generator.

	Outage Time	Number of Buckets Needed
Unadjusted Statistics	4.2 hours	4.2 buckets
Adjusted Statistics	84 hours	84 buckets
To be 99% Confident	114 hours	114 buckets

Because investing in battery storage, or battery plus solar, is likely an inefficient use of capital, diesel and natural gas generators are a better solution for providing backup power and resiliency.



Exergy Energy's eBook Battery vs. Generator examines the advantages and disadvantages of battery plus solar in more depth. The eBook can be found here.

Conclusion:

Natural gas generators are competitive in terms of performance and cost compared to diesel generators. As such fuel supply security becomes increasingly relevant to planning your resiliency strategy. Because the supply of natural gas is very reliable and its delivery more dependable than diesel during longer outages, which typically transpire during extreme weather events which can impede diesel delivery by truck or ship, natural gas is the more reliable choice for backup fuel.

The table below depicts reliability statistics from an NREL study on diesel and natural gas genset reliability for three regions. The study concluded that natural gas is more reliable across the United States.

Table ES-1. System Reliability by Region and Fuel Type.

Region	Diesel Reliability	Natural Gas Reliability	Difference
United States Average	94.7%	97.3%	2.6%
Florida	90.1%	95.5%	5.4%
New Jersey	97.2%	98.2%	1.0%
Texas	97.3%	98.3%	1.0%

Outage data are drawn from the outage distribution of each region, as discussed in Section 4. Generator reliability estimates are discussed in Section 3.

The high economic costs to commercial and industrial firms due to outages and with outages increasing in frequency, picking the most reliable form of backup power is incredibly important to achieving true resiliency. Given its distinct advantages over diesel, especially as the energy landscape evolves as the 21st century progresses, natural gas is the optimal choice for backup fuel in terms of reliability.

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