In the Matter of

Reliability and Continuity of Communications Networks, Including Broadband Technologies  PS Docket No. 11-60

Effects on Broadband Communications Networks of Damage or Failure of Network Equipment or Severe Overload  PS Docket No. 10-92

Independent Panel Reviewing the Impact of Hurricane Katrina on Communications Networks  EB Docket No. 06-119

**COMMENTS OF GENERAC POWER SYSTEMS**

Generac Power Systems, Inc. (“Generac”) hereby submits these comments in response to the *Notice of Inquiry* issued in the above-captioned proceeding.¹ These comments address specifically questions raised in the *Notice of Inquiry* regarding the optimal means of ensuring a sufficient amount of backup power in support of critical communications in emergencies.

Founded in 1959, Generac is the industry leader in standby power generation. Generac manufacturers the widest range of power products in the marketplace, including portable, RV, residential, commercial and industrial generators. Its line of industrial generators includes natural gas, bi-fuel, and diesel systems. It also offers portable backup power systems that can be deployed on a temporary basis where power is needed. In addition, Generac is a leading provider of reliable backup power for communications applications. Its industrial generators are used throughout the communications industry to provide standby power at cellular network tower sites,

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along cable and telecommunications providers’ trunk and feeder lines for signal amplification, at switch offices, and at other communications facilities.

Generac appreciates the opportunity to comment on issues affecting the reliability, resiliency, and continuity of the nation’s communications networks and infrastructure. It applauds the Commission’s efforts to ensure that critical communications networks survive and continue to operate when needed most: during emergencies stemming from natural or man-made disasters. As the Commission notes, the National Broadband Plan (“NBP”) “identified the inadequacy of backup power . . . as [a] key factor[]. . . . contribut[ing] to the congestion or failure of commercial wireless data networks, particularly during emergencies such as large-scale natural and man-made disasters.”\(^2\) Similarly, the report of its Independent Panel Reviewing the Impact of Hurricane Katrina on Communications Networks (“Katrina Report”) cited the “lack of power or fuel to maintain operation of portions of the telecommunications system as a significant concern.”\(^3\)

Generac recognizes that the Commission seeks input on a variety of issues, including “issues related to broadband network reliability and resiliency” and “the sources of legal authority that could provide the basis for Commission action.”\(^4\) Generac will, however, limit its comments to issues related to providing emergency backup power. Given its extensive experience providing reliable backup power for communications facilities, Generac is uniquely positioned to address the Commission’s inquiries regarding this issue.

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\(^2\) Id. ¶¶ 1, 9 (citing Omnibus Broadband Initiative, Federal Communications Commission, *Connecting America: The National Broadband Plan*, § 12.1 (Mar. 2010)).


\(^4\) Id. ¶ 2.
I. BACKUP POWER SYSTEMS ARE ESSENTIAL FOR CONTINUITY OF SERVICE OVER THE NATION’S COMMUNICATIONS NETWORKS

Generac supports the Commission’s goal of ensuring that the nation has access to reliable communications networks and continuous service, especially during emergencies. While the Commission describes inadequate backup power and insufficient communications backhaul redundancy as “twin issues” that “impair the reliability of commercial networks for mission-critical control applications,” the backup power issue is best characterized as an elemental requirement for continuity of service. No amount of backhaul redundancy could save the communications network if a widespread lack of power existed for an extended period of time. Indeed, powerful hurricanes such as Hurricane Katrina, severe ice storms, massive earthquakes, tsunamis, terrorist attacks, and other natural or man-made disasters are all capable of causing widespread power losses, often with little or no advance notice. That lack of power, in turn, cripples communications networks and hinders emergency communications at times when they are needed most.

Inadequate backup power also threatens the viability of the nation’s most important emergency communications systems. Not only does it disrupt the operations of first responders and other mission-critical communications, but it also limits the ability of government officials to communicate with the people directly affected by the disaster. For example, the Emergency Alert System ("EAS") is designed to disseminate alert information through multiple communications sources, including television and radio broadcasters, cable television systems, wireless cable systems, satellite service providers, and wireline video service providers.\(^5\) Similarly, the Commission’s recently announced Personal Localized Alerting Network ("PLAN") keeps pace

with advancing technology by providing geographically-targeted, text-like messages directly to consumers’ mobile devices to alert them of imminent threats in their area. But without adequate backup power to support the communications infrastructure, including along cable trunk and feeder lines and at cellular network tower sites, many of these systems can be rendered totally ineffective, including powerful emergency communications tools, such as PLAN, that rely on wireless communications infrastructure.

Consequently, to ensure that communications facilities remain fully operational during emergencies and that powerful alerting systems such as EAS and PLAN can serve their intended purposes, Generac supports Commission efforts to motivate and encourage communications service providers to maintain adequate backup power. Communications service providers can ensure the reliability of their networks and continuity of service by installing a sufficient number of appropriately fueled, strategically located, dependable, on-site emergency backup power systems throughout their network infrastructure. Generac has worked with many providers to design and install such systems, and is confident that an industry-driven approach would have the greatest – and fastest – impact on ensuring the continuity of our communications networks.

II. INSIGHTS FROM AN INDUSTRY EXPERT IN BACKUP POWER SYSTEMS

The Commission invited comment on “how various backup power techniques or performance standards could or should be employed to ensure adequate levels of service continuity during major emergencies.” Generac’s extensive experience developing backup power systems and their ability to work closely with communications service providers has given them a unique perspective on the importance of maintaining adequate backup power. By working closely with providers to design and install emergency backup power systems, they have observed that a well-planned and executed approach can significantly enhance the reliability of communications networks during emergencies. Generac believes that an industry-driven approach is crucial to ensuring the continuity of our communications networks.

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7 While Generac believes that communications service providers are motivated to solve backup power issues – indeed, it has worked with many such providers to do just that – it would support a limited regulatory approach if it became clear that informal Commission efforts were not sufficient to ensure network continuity nationwide.

8 Notice of Inquiry ¶ 23.
power solutions for the telecommunications industry provides it with unique insights regarding the advantages and disadvantages of different backup power solutions. While the demands placed on a communications network may vary depending on the type of infrastructure deployed, geography, climate, other site-specific characteristics, or the type of disaster likely to strike it, Generac has learned that certain backup power systems are generally more reliable and provide more continuity than others.

A. On-Site Standby Power Systems Are More Reliable and Effective Than Fleets of Mobile Power Systems.

Some may argue that fleets of mobile standby generators provide as good or better a solution for communications providers than investing in on-site backup power. While Generac has developed and markets its own line of mobile standby generators, it has found through experience that mobile power systems cannot guarantee network continuity as effectively as on-site generators.

During man-made and natural disasters, on-site backup power systems are more reliable and efficient than fleets of mobile standby generators for several reasons. The efficacy of a mobile power system depends largely on its proximity to the site where it is needed. For example, a disaster could render useless an entire fleet of mobile generators if they are housed far from where they are needed or the communications provider cannot deploy them there in a timely manner. Moreover, as the Commission noted in its Notice of Inquiry, the Katrina Report found that “lack of access to carrier sites located within disaster areas was a major issue impacting the ability of carriers to restore communications.” Major hurricanes, floods, and other disasters can block or submerge roads and other transportation infrastructure, rendering access to

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9 See id. ¶ 22 (seeking comment on “measures industry presently uses to maintain or restore communications during emergencies, including their advantages and disadvantages”).

10 Id. ¶ 18 (citing Katrina Report at 15-17); see also Katrina Report at 14, 17-18.
communications sites – and therefore either the delivery of additional fuel or the deployment of mobile power systems to those sites – impossible.\textsuperscript{11}

The efficacy of a mobile power system-based regime, therefore, is a function of the communications provider’s ability to:

- adequately anticipate the location of the next disaster;
- accurately estimate the appropriate number of standby systems it will need;
- appropriately domicile the units in advance of the disaster to provide for their safe and timely deployment after the disaster takes place; and
- dispatch and provide site access for appropriately skilled personnel to install and commission the equipment during the disaster.

Most communications providers will likely be unable to predict accurately each of these factors, and will have to rely on educated guesses or luck to position their mobile generating resources where they are needed. By contrast, a sufficient number of appropriately fueled, strategically located, reliable, on-site emergency backup power systems would eliminate the guesswork and risks inherent in a mobile solution and ensure that the backup power systems are present and operating where they are needed, when they are needed. For these reasons, a mobile fleet is best considered a supplement to, not a substitute for, a robust system of on-site standby power systems.

B. Natural Gas Fueled Standby Systems Are More Reliable and Effective Than Diesel Fuel Systems.

Generac’s experience further indicates that certain fuel systems are more reliable and effective than others. Even though many industrial standby systems run on diesel fuel, including some manufactured by Generac, diesel-fueled standby power systems are not the most reliable

\textsuperscript{11} \emph{Id.} ¶ 19 (stating that flooding is another major factor that impedes the ability of providers to restore communications).
options during emergencies, and do not ensure continuous service. Like mobile power systems, the efficacy of any diesel-fueled system is hindered when access to carriers’ sites within disaster areas is limited, particularly during long-term power outages. Where the on-site standby power system is diesel-fueled and the carrier cannot transport additional diesel fuel to the site due to flooding or other breakdowns in transportation infrastructure, then the standby power system will serve merely as a temporary stopgap until its on-site fuel supply is depleted.

For this reason, Generac advocates that communications providers install gaseous-fueled backup power systems wherever gas is available to the site. All of the major U.S. manufacturers of standby power units, including Generac, offer gaseous-fueled systems. These natural gas systems are fueled by a dependable and robust delivery infrastructure for natural gas, which is rarely impacted or disrupted by natural disasters.12 Moreover, Generac’s natural gas systems can also be configured to operate on propane. Thus, in the unlikely event that a disaster did interrupt the supply of natural gas to a standby power unit, a carrier could utilize an on-site propane fuel tank to provide a redundant fuel source. Propane is an ideal option for a redundant, on-site fuel source because it is extremely stable and less costly to maintain than diesel. Unlike diesel, propane will remain fresh and viable if left unused over an extended period of time and it does not require the same degree of maintenance as diesel fuel.13 Finally, bi-fuel systems offer another valuable option at central switch offices for reliable on-site backup power, where larger backup power systems are typically needed. Bi-fuel units are designed to run on a mix of diesel fuel

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(25%) and natural gas (75%) and can extend the hours of run time otherwise available from a
given diesel fuel supply by a factor of four or more.14

The Commission also seeks comment on developments in backup power technology,
such as systems based on solar, hybrid, and other renewable energy sources, and whether those
systems can be expected to overtake traditional battery or generator solutions.15 Alternative
energy-based backup power systems are not adequate replacements for existing technologies due
to both high system acquisition costs and the variable and unpredictable availability of the
renewable energy sources on which they depend. For example, during a natural disaster such as a
hurricane or similar weather event, in the cases of solar and wind energy, there may be either too
little sun (causing a power shortage) or too much wind (causing the turbine to shut down
entirely), thus rendering these resources useless. As a result, these renewable backup power
resources may be unavailable precisely when and where they are most needed. Fuel cell
solutions are similarly hampered by high system acquisition costs and the potential
complications surrounding fuel delivery during a natural disaster. For all of these reasons,
Generac believes that a clean burning natural gas engine generator is the superior on-site standby
power solution.

C. Industry Best Practices.

The Commission seeks input regarding “any standards and best practices that presently
exist in the industry regarding the provision of service during major emergencies.”16 The fact is,
however, that different stakeholders employ different “best practices” depending on the nature of

15 Notice of Inquiry ¶ 24
16 Id. ¶ 21
the communications service they offer, the infrastructure required to deliver and receive their services, and the amount and type of backup power needed to secure the continuity of their networks. Therefore, each type of industry stakeholder should engage in a dialogue with other similarly situated stakeholders to develop tailored, industry-driven best practices for its own segment.

D. Industry Trends.

Aside from the obvious benefits of a stable national communications infrastructure for public safety considerations, as the Commission notes in its introductory comments, businesses of all sorts within the healthcare, financial services, utility, and other industries are becoming increasingly reliant on a stable and secure communications infrastructure. As previously stated, Generac believes the best way to assure the uptime of this national communications infrastructure is to stimulate the installation of a sufficient number of appropriately fueled, strategically located, dependable, on-site, emergency power systems throughout the network.
III. CONCLUSION

Generac commends the Commission for seeking comment on these important reliability and continuity issues, particularly as they relate to backup power for communications infrastructure, and welcomes the opportunity to work with the Commission and industry stakeholders to ensure continuity of communications services during major emergencies.

Respectfully Submitted,

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Date: July 7, 2011
ATTACHMENT A
INTRODUCTION
Traditionally, the choice between diesel-fueled and gaseous-fueled generators has been relatively straightforward. Power density as well as capital cost advantages in large-kilowatt applications typically favored diesel for standby power of 150 kilowatts of electricity (kW) or more—large commercial and industrial standby applications.

However, technological innovations are making gaseous-fueled generators both more powerful and more cost effective. Additionally, issues of fuel storage and reliability in diesel-fueled generators are becoming a bigger challenge. Finally, as more and more companies seek to reduce their carbon footprints, they are more open to options that are more environmentally friendly.

As a result, standby generator system designers, electrical contractors and electrical engineers have significantly more gaseous-fueled choices than they had before.
DIESEL VS. GASEOUS-FUELED GENSETS: A TRADITIONAL PERSPECTIVE

Diesel and gaseous-fueled generators each offer advantages to consider when designing a standby power solution. The most noticeable advantage of a gaseous-fueled generator is the extended run time provided by a continuous supply of natural gas. The natural gas infrastructure has shown itself to be extremely reliable in situations that cause power outages; through four Florida hurricanes in 2004 and the Northeast grid failure of 2003, the natural gas supply was unaffected.

By comparison, diesel-fueled generators provide access to backup power in remote areas that do not have a gaseous-fuel infrastructure. When applied to standby power applications of 150 kW or more, a diesel-fueled generator delivers a lower capital cost per kilowatt of electricity than a gaseous-fueled generator. Attempts to lessen this disparity, such as converting industrial diesel engines to gaseous fuel, only add engineering costs to the project. As a result, diesel-fueled generators have a capital cost advantage over their spark-ignited counterparts in larger standby applications, making them the traditional market norm.

Additionally, a significant part of the market—especially those segments with mission-critical applications like hospitals and 911 call centers—uses diesel-fueled generators because of code requirements for on-site fuel. While gaseous-fueled generators using on-site LP fuel can often meet such code requirements, as can systems designed to run in a dual-fuel configuration with natural gas as a primary fuel and LP as the secondary fuel, the capital cost advantage of diesel-fueled generators typically makes them the preferred solution when on-site fuel is a must.

Both diesel and gaseous-fueled units share applications below 150 kW. Gaseous-fueled generators are often chosen for residential and small commercial standby applications. The automotive-style engines used in these units are readily available in high volumes, making them extremely cost effective. The ready supply of LP and natural gas in these applications also makes them ideal.

DIESEL CHALLENGES

In spite of their widespread use for standby power in large-kilowatt applications, diesel-fueled generators can have some significant drawbacks that are often overlooked. Fuel storage and reliability considerations are foremost, as are environmental issues.

Fuel Storage

There is no question that the ability to store diesel fuel on site fills a critical need for backup power in remote areas without a gaseous-fuel infrastructure. However, because it is typically stored for long periods of time, contamination and breakdown are real concerns.

According to Exxon Mobil, diesel fuel can be stored for up to one year without a reduction in quality if it is kept clean, cool, and dry. Longer storage periods require periodic filtrations and the addition of fuel stabilizers and biocides. In the case of a diesel generator set, however, it could easily take a diesel-fueled generator with a tank sized for 72 hours of full-load operation about 20 years to turn a single tank of fuel. Without proper maintenance, the fuel will become contaminated with water and biomass.

Water enters the tank as humidity through the normal vent and condenses. Moisture binders in the fuel capture and contain the moisture, but as these binders become overloaded, water will drop to the bottom of the tank and begin accumulating. If pulled into the engine, it could result in loss of power, loss of lubrication, and corrosion. Water also creates an environment that will support biomass at the water/fuel interface. When these microbes are pulled into the engine, they clog the fuel filter, resulting in power loss and shutdown. To minimize these effects, fuel tanks require a well-defined low point where the water can collect, and monthly maintenance to drain the water. Periodic fuel polishing (filtering and water removal) may be required, as well.

In addition to contamination, fuel breakdown seems to be more prevalent with today’s low sulfur fuels. The additional refining processes necessary to remove the sulfur may also be removing some of the fuel’s stability elements. As diesel fuel gets older, a fine sediment and gum forms in it, brought about by the reaction of diesel components with oxygen from the air. Additives are helpful in treating common fuel breakdown issues when integrated into a fuel filtering preventive maintenance program. However, at some point the fuel may simply need to be replaced.

2 Assuming a 60% typical load level, weekly no-load exercising, and average power outages of only four hours per year.
GASEOUS VS. DIESEL FUEL GENSETS

By contrast, natural gas is continuously supplied via the local municipal infrastructure, so storage is not an issue. As for LP, it can be stored on site for several years—more affordably and more safely than diesel fuel—providing an additional redundant backup to the already stable gaseous-fueled pipeline infrastructure.

Reliability of Fuel Delivery
According to the Edison Electric Institute, severe weather events account for 62% of unexpected power outages in the United States. These events can close roads and cripple municipal infrastructures, making it difficult or impossible to refuel the diesel generators used in so many standby applications. Designers who size fuel tanks more modestly to address the aforementioned issues of fuel contamination or breakdown run the risk of implementing a solution that will run out of fuel in an emergency.

Environmental Concerns
More and more companies are considering how their overall environmental footprint affects the world. This trend holds true in virtually all areas of business, and automatic standby generators are no exception. In this regard, diesel-fueled generators face significant challenges. Not only do diesel engines emit more nitrogen oxides and particulate matter than comparable spark-ignited units, but diesel engines are also being ever more scrutinized to minimize their environmental impact.

For example, diesel engines have been subject to intense emission level regulations, and have seen aggressive Environmental Protection Agency (EPA) tier changes. This additional oversight has increased the total cost of both diesel engines and fuel. Future governmental cap and trade regulations for emissions trading may cause diesel engines to be taxed at a higher rate due to higher CO₂ emissions.

Fuel containment and the environmental concerns surrounding large quantities of fuel stored on site are considerable issues, as well. Because quantities of fuel are typically kept in a main storage tank and then transferred to a smaller day tank at the generator for usage, fail-safe controls must be designed into the system to avoid spillage. Additionally, no single point of failure in the fuel delivery system should result in fuel spillage. Many localities have their own code requirements covering fuel containment and delivery—some of which include concrete-walled secondary containment, double-walled piping, fire-rated tanks, special fill and spill requirements, special permitting, etc. In fact, permitting costs for diesel storage also continue to rise as local governments attempt to control the environmental impact of accidental spills, odors and other factors.

Thus, while diesel-fueled generators above 150 kWₑ do offer significant capital cost advantages when compared to similar gaseous-fueled units, managing the fuel storage, reliability, and environmental concerns tends to flatten this cost differential.

TECHNOLOGY SHIFTS IN GASEOUS-FUELED GENERATORS
Thanks to advances in technology, gaseous-fueled generators are growing in popularity for larger applications. Key advancements include the optimization of engine speed (RPM), integrated approaches to generator paralleling, and bi-fuel (combined diesel and gaseous-fuel) operation. These technologies are reducing the historical cost advantage of diesel-fueled generators.

Optimizing Engine RPM
The AC frequency of the generator electrical output is a function of engine speed and alternator design. To achieve 60 Hz, the alternator rotor must revolve at a specific speed for a given alternator pole configuration. Fifty years ago, most generator engines operated at speeds below 900 RPM. Within the last 30 years, however, engine outputs have increased. As such, the diesel standby generator market has moved from 1200 to 1800 RPM.

This trend has affected gaseous-fueled generators in applications up to 150 kWₑ, as well. Historically operating at 1800 RPM, current technology is optimizing these automotive-style engines for operation at 2300, 3000, and 3600 RPM. Some manufacturers utilize a simple gear reduction device between the engine and a four-pole alternator to achieve the optimal amount of mechanical power at a 60 Hz electrical output.

Increasing the operating speed of spark-ignited automotive-style engines offers many advantages, including improved transient performance, less stress on engine bearings, and increased power densities. The graph below illustrates the transient performance increase associated with optimizing the RPM of these engines.

![Graph: 125 kW Block Load, Transient Performance Data](image-url)
GASEOUS VS. DIESEL FUEL GENSETS

Most importantly, though, this trend means more powerful engines and reduced capital costs.

Integrated Generator Paralleling
Using these speed-optimized, spark-ignited engines as building blocks, manufacturers are connecting smaller gaseous-fueled generators together and combining their output in an integrated approach to generator paralleling. In this way, they are able to provide a cost-effective alternative to single, large diesel-fueled units.

Parallel power solutions have always offered significant advantages, including application flexibility, scalability, and redundancy. However, the implementation of such solutions had been limited to mission-critical applications and large kilowatt projects largely because of panel board constraints including cost, space, and issues of single source responsibility. Traditional parallel power solutions were also extremely complex. Each generator in the system normally required four to six analog and digital micro-controllers from various manufacturers, all hardwired together. A typical two-generator system would have between nine and fourteen controllers (including the master control section) to manage the speed governor, load-share controller, synchronizer, voltage regulator, generator controller, and protective relay.

Today, manufacturers have mitigated cost and complexity by using one digital controller per generator to control all functions, significantly enhancing system performance and reliability. Some have also integrated the paralleling switch into the generator connection box, eliminating the cost and space requirements of external panel boards. Today, three 300 kW gaseous-fueled generators operating in parallel could replace a single large 1000 kW diesel-fueled generator at a more feasible cost—but with the added advantage of built-in redundancy. With a single 1000 kW unit, generator failure means the facility will be without backup power. In a parallel solution, however, if one of the 300 kW units doesn’t run, the most critical loads will be distributed among the remaining two generators.

Bi-fuel Generators
Bi-fuel generators combine the power density and capital cost benefits of diesel engines with the extended run time of natural gas. Using mass-produced diesel engines as prime movers, bi-fuel generators start up on diesel fuel in a normal manner. As loads are added, natural gas is introduced to the combustion air while diesel fuel is reduced. Under typical load conditions, bi-fuel generators will operate on a ratio of 25% diesel and 75% natural gas, with no reduction in power. An example fuel mix for a 600 kW generator is illustrated below.

Bi-fuel Generators

Only slightly more expensive than diesel-only designs, bi-fuel generators offer several important advantages. For one, the lower capital cost of a compression-ignited engine is retained while capitalizing on many of the advantages of gaseous fuel, such as an improved emissions profile.

Run times are significantly extended, as well, due to the reduced consumption of diesel fuel. This can be very important, since refueling may be difficult during emergencies that cripple municipal infrastructure. It can also allow for smaller diesel tanks, because natural gas is the predominant fuel. With smaller fuel tanks, the risk of fuel contamination and the cost of fuel maintenance is significantly reduced.

Finally, fuel redundancy is built into the system. If the natural gas supply is interrupted for any reason, or if there is a fault in the bi-fuel delivery system, the controls automatically revert to 100% diesel without interruption.
EFFICIENCY AND CO₂ EMISSIONS

To evaluate the bigger environmental picture, it is important to compare the source-to-site cost of the fuel used in diesel and gaseous-fueled generators. This is the total cost associated with using the fuel. It includes such items as extraction and transportation costs, the current market price of the fuel, and the cost per kilowatt hour. Consideration of total CO₂ emissions is critical, as well, in determining environmental impact. It is possible to quantify all of these items and bring them into the cost-benefit analysis regarding generator fuel choice.

The following chart shows efficiency and CO₂ comparisons of gaseous-fueled and diesel generating sets.

### Diesel vs. Gaseous-fueled Generators: Total Cost and Total CO₂ Emissions

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit kWₑ</td>
<td>Fuel Type</td>
<td>Engine Volume (liters)</td>
<td>Engine RPM</td>
<td>Power (kWₑ)</td>
<td>Nat Gas Fuel Flow (H₂/hr)</td>
<td>Diesel Fuel Flow (gal/hr)</td>
<td>Cost/kWₑ</td>
<td>Cost/kWₑ²</td>
<td>Btu/kWₑ</td>
<td>CO₂ Emissions From Engine Exhaust Only (lbs/hr)</td>
<td>Energy use (mBtu/hr)</td>
<td>Total CO₂ Emissions from Engine and Processing (lbs/hr)²</td>
<td>% CO₂ Increase vs Natural Gas</td>
<td></td>
</tr>
<tr>
<td>100 Gas</td>
<td>6.8</td>
<td>2300</td>
<td>100</td>
<td>1380</td>
<td>—</td>
<td>$13.11</td>
<td>$0.131</td>
<td>13,800</td>
<td>$205</td>
<td>168.4</td>
<td>1.380</td>
<td>328</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>100 Diesel</td>
<td>6.7</td>
<td>1800</td>
<td>100</td>
<td>7.9</td>
<td>$20.15</td>
<td>$0.201</td>
<td>10,490</td>
<td>$220</td>
<td>175.4</td>
<td>1.116</td>
<td>383</td>
<td>16.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 Gas</td>
<td>13.3</td>
<td>1800</td>
<td>200</td>
<td>2750</td>
<td>—</td>
<td>$26.13</td>
<td>$0.131</td>
<td>13,750</td>
<td>$270</td>
<td>335.5</td>
<td>2.750</td>
<td>654</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>200 Diesel</td>
<td>8.7</td>
<td>1800</td>
<td>200</td>
<td>15.5</td>
<td>$39.53</td>
<td>$0.198</td>
<td>10,291</td>
<td>$180</td>
<td>344.1</td>
<td>2.189</td>
<td>751</td>
<td>14.9%</td>
<td></td>
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</tr>
</tbody>
</table>

1 Based upon fuel usage and overall current price of fuel, 100% rated load. Natural gas: $0.95/therm. Diesel: $2.55/gal.
2 GREET Transportation Fuel Cycle Analysis Model, developed by Argonne National Laboratory; September 5, 2008.

Combining fuel cost with environmental impact provides companies with a broader view to the true bottom line, and overall environmental impact, of their generator choice. For example, while a 100 kWₑ diesel engine burns fuel 23% more efficiently than a similar-sized gaseous-fueled engine (column J), its fuel cost per kilowatt hour is almost double (column I) and its total CO₂ emissions are more than 16% greater (column O). Additionally, gaseous-fueled generators have historically cost less per installed kilowatt than their diesel counterparts in the smaller sizes (column K).

Given the new technologies associated with gaseous-fueled generators, and their advantages in terms of fuel reliability and cost, customers might be more willing to consider a gaseous-fueled solution where historically they would have purchased a diesel-fueled unit.

**SUMMARY**

Gaseous-fueled generators are becoming more attractive for standby applications above 150 kWₑ. The capital cost and thermal efficiency advantages of diesel over gaseous fuels have been moderated by the maintenance and reliability challenges of storing diesel fuel over long periods of time. Additionally, a number of recent technological innovations in implementing high-kWₑ gaseous-fueled solutions are allowing such generators to compete with their diesel-fueled counterparts on cost and power.

Additionally, the fact that spark-ignited engines offer improved emission profiles over compression-ignited engines—and that gaseous fuels do not pose the kinds of environmental risks inherent in diesel fuel storage—is making gaseous-fueled generators more attractive to the ever-growing number of companies looking to reduce their overall carbon footprint.

Diesel-fueled generators will most assuredly continue to serve the standby power market; no single solution is ideal for every application. Gaseous-fueled generators, however, are becoming more cost-effective and environmentally-friendly options for applications above 150 kWₑ.
Generac Industrial Power offers diesel and gaseous-fueled generators for every standby power solution.

- Diesel up to 600 kW<sub>e</sub> (1 MW<sub>e</sub> with Gemini®)
- Gaseous up to 300 kW<sub>e</sub>
- Bi-Fuel™ 600 kW<sub>e</sub>
- Parallel power solutions up to 9000 kW<sub>e</sub> using Generac’s Modular Power Systems (MPS)

**Modular Power Systems (MPS)**

Generac’s Modular Power System (MPS) is a combination of the industry’s most reliable generators and state-of-the-art integrated paralleling technology. Powered by either diesel or gaseous fuel, MPS is appropriate for numerous types of businesses, including hospitals, airports, office buildings, manufacturing plants, data centers, and retail superstores. Not only does MPS boast a reliability rate of up to 99.9999%, it is more cost effective and flexible than single generator sets with the same load capacity, making expensive stand-alone switchgear obsolete.

**Gemini®**

Generac’s Gemini Twin Pack houses two generators within a single enclosure, providing the same amount of power in a footprint that is 20% smaller than many single engine units. Gemini provides built-in redundancy for superior system reliability and scalability along with load shedding capabilities. Parallel up to seven diesel or gaseous-fueled Gemini systems without additional switchgear.

**Bi-Fuel™**

Perhaps the solution that most effectively combines the power of diesel with the environmental friendliness of natural gas, Generac’s Bi-Fuel system generators start on diesel fuel and add natural gas as load is applied. During an outage, each Bi-Fuel unit can optimize at a fuel mixture of 75% natural gas and 25% diesel. If the natural gas supply is interrupted, the generator automatically switches to 100% diesel without any power drop during the transition. At varying loads, the advanced fuel system maximizes the use of natural gas while closely monitoring the system for safe operation.

For more information about the information contained in this white paper, or to learn more about the full line of Generac Industrial Power generators, contact Generac at 1-888-GENERAC (1-888-436-3722) or visit us at www.generac.com to find your local dealer.
INTRODUCTION

Within the context of power generation and automotive engines, the terms Bi-Fuel™ and dual-fuel are being used inconsistently by manufacturers, after-market installers, industry organizations and government agencies. Depending on the source, either term may be used to describe one of two different schemes for internal combustion:

1) Simultaneous combustion of two fuels
2) Redundant fuel supply systems, where a second fuel type can be used if the primary fuel supply is interrupted, depleted or intentionally switched off, but only one fuel is burned at a given time.

In any discussion, understanding the difference and clarifying terminology can help avoid confusion. Attention to the scheme used should identify the design, regardless of it being referred to as Bi-Fuel or dual-fuel.

**Generac uses the term Bi-Fuel for the simultaneous combustion of two fuels in an engine.** With the products we offer, Bi-Fuel can be further defined as the simultaneous combustion of diesel fuel and natural gas (methane) in a compression ignition (diesel) engine. Note that this concept has also been referred to at times as fumigation, meaning natural gas is fumigated into the combustion air supply for a diesel engine.
HISTORY

The concept of using Bi-Fuel on diesel engines is not new. Rudolf Diesel, who invented the engine bearing his name, experimented with enriched combustion air mixtures in the early 1900’s. Before long, natural gas became popular as an enriching fuel for two main reasons:

1) Its combustion characteristics are reasonably compatible with typical diesel engine designs
2) Extensive distribution infrastructure has been developed to make it an economical, commonly available, utility supplied fuel

Throughout the Twentieth Century, various methods were developed to properly deliver natural gas into a diesel engine. Extreme care is required during this process, as an excess concentration of natural gas can cause engine damage due to pre-ignition, or “knock” (this will be discussed in further detail later in this paper). Early Bi-Fuel designs used conventional mechanical control systems of the day to control the process. Due to limited capabilities of these controls, performance was compromised and commercial success was restricted to niche applications. More recently, microprocessor controls along with advanced automotive sensor and actuator technologies have provided new opportunities to meet the challenges.

WHY BI-FUEL?

The desire for Bi-Fuel engines is driven by several environmental and economic factors. Combining diesel fuel with natural gas in Bi-Fuel operation provides several benefits compared to engines fueled only by diesel or natural gas. Major benefits include:

- Extended run time capabilities
- Reduced diesel fuel storage requirements
- Lower capital cost per kilowatt (kW) compared to spark-ignited engines
- Improved reliability with redundant fuel supply
- Reduced maintenance costs
- Potential for less fuel costs
- Lower exhaust emissions than diesel engines

Each of these points will be discussed further in the “Generac Bi-Fuel Benefits” section, found later in this paper.

OVERVIEW OF BI-FUEL METHODS AND OPERATION

Since Bi-Fuel operation utilizes compression ignition, some traits of the basic diesel engine will first be reviewed. Several characteristics distinguish the diesel engine from four-cycle spark ignited (also referred to as Otto cycle) engines commonly used today to burn gasoline or vaporized fuels such as natural gas:

- A diesel engine uses compression ignition rather than spark ignition. The heat generated by compressing air to high pressures provides the source of ignition for the diesel fuel.
- A diesel engine compresses only air and then injects fuel directly into the cylinder for combustion. Most Otto cycle engines mix the fuel with air before it enters the cylinder(s), using either a carburetor or “indirect” fuel injector(s), often referred to as throttle body or port fuel injection. After the mixture is compressed in the cylinder, an electrical spark (delivered through a spark plug) provides the energy to ignite the fuel.
- Since diesel engines compress only air, they can safely operate at higher compression ratios (typically 13:1 ~ 23:1 compared to 8:1 ~ 12:1 for spark-ignited engines) without concern for pre-ignition. A major benefit of the higher compression ratio is that diesel engines are inherently more energy efficient than lower compression spark-ignited engines. In other words, more of the fuel energy gets converted to mechanical energy rather than being rejected as heat (this was the primary motivation for Diesel’s invention in the first place.)

Natural gas ignites at a much higher temperature (1150° - 1200° F) compared to diesel fuel (500° - 750° F). A diesel engine cannot operate on 100% natural gas, because the heat generated during compression is not sufficient to ignite this fuel. To create ignition in Bi-Fuel engines, a small amount of diesel fuel must be injected. Cylinder temperatures are high enough to ignite the diesel fuel, and the flame created reaches a temperature sufficient to ignite the natural gas.
A Bi-Fuel engine uses a conventional diesel engine as its basis. With most designs, the diesel fuel is delivered using the injectors that already exist on the engine. Additional components are installed to deliver natural gas into the combustion chamber. There are three proven methods that have been employed to do this:

- **Low pressure injected natural gas (LPiNG)** introduces the natural gas using port injection, so it mixes with combustion air just before it enters the cylinder. This is done under moderate pressure, usually less than 50 pounds per square inch (psi). As many diesel engines use turbochargers to feed air into the cylinders, injection pressures must be greater than the boost pressure developed. This approach has been used in large stationary installations, but is more recently finding use in trucking applications. Requirements for injectors at each cylinder, a gas compressor and a multiple line fuel delivery add substantial cost to this type of engine.

- **High pressure injected natural gas (HPiNG)** delivers natural gas directly into the combustion chamber under extremely high pressures of approximately 3000 psi. This is necessary since the natural gas is injected when the cylinder pressure is very high – at the end of the compression stroke and after diesel fuel has been injected to initiate combustion. This approach has found application in very large Bi-Fuel engines that typically operate for extended periods, producing prime or continuous power. This is due to the economics involved, as separate high pressure natural gas injectors (or sophisticated combination diesel/natural gas injectors), pumps and fuel delivery lines drive a large price premium for these engine systems.

- **Combustion air gas integration** introduces the natural gas with intake combustion air just prior to the turbocharger. Since a single, low pressure delivery system is used, additional engine component costs are minimized. Advanced microprocessor, sensor and actuator technologies can now economically provide the precision and response necessary to control the system. This approach was selected by Generac because it offers the broadest range of operation at the lowest cost, and is best suited for the standby generator market.

**GENERAC’S SOLUTION**

Figure 1 shows a diagram of the system used in Generac Bi-Fuel generators. A base turbocharged and after-cooled diesel engine generator is equipped with a natural gas delivery system, additional engine sensors and a microprocessor to monitor and control Bi-Fuel operation. The required pressure for natural gas supply to the Bi-Fuel unit is 3 to 5 psi.
During initial startup, the engine operates on 100% diesel fuel. After certain permissive criteria are satisfied (for instance, the engine coolant temperature reaching 160° F, or acceptance of the electrical load), the microprocessor commences Bi-Fuel operation. The system meters in an increasing amount of natural gas with the intake air. A dynamic gas control valve with positive supply pressure is used to provide precise metering. As more fuel energy is provided by the natural gas, the engine governing system automatically cuts back on the amount of diesel fuel injected.

Throughout the process, the controller continuously monitors a variety of engine and generator parameters, including intake air temperature, engine coolant temperature, intake manifold temperature and pressure, kW load, engine speed, and engine vibration at each cylinder. Through extensive mapping of these variables and their effect upon engine performance, the microprocessor automatically adjusts the Bi-Fuel ratio and fine tunes the mixture for optimum engine operation.

Figure 2 shows fuel percentage versus load for a given intake air temperature. Similar curves have been developed across the range of temperatures to develop a 3-dimensional curve used by the microprocessor to determine fuel ratios. With the Generac system, the optimum Bi-Fuel ratio under typical operation is approximately 90% natural gas and 10% diesel.

Note that our Bi-Fuel generators can operate on 100% diesel fuel in the event natural gas supply is interrupted. The control system automatically switches between Bi-Fuel and straight diesel modes as conditions dictate. Transition is seamless and transparent to the end user. In addition, there is no power derate for Bi-Fuel operation versus straight diesel mode, or during mode transitions. Generator load response and stability remain the same while operating in either mode.

ADVANTAGES OF GENERAC’S BI-FUEL SOLUTION

Generac’s Bi-Fuel engine generators offer a distinct cost advantage over more complex LPING or HPING engines, both in terms of initial capital investment and replacement part costs. When compared to other after-market systems using combustion air gas integration, Generac provides several distinct advantages:

- Designs are optimized for specific engines in our diesel generator product line
  - Engine characteristics have been carefully and comprehensively mapped
  - Gas deliveries have been established for all combinations of load and temperature
  - The result is maximum Bi-Fuel performance with safe, reliable operation
- Pre-ignition sensors immediately detect condition transients for corrective action, prior to knock ever occurring
• Dynamic gas control provides instantaneous adjustments for engine protection
• No performance compromises are required
• Generac’s PowerManager® Digital Control Platform integrates control of Bi-Fuel operation with all other generator control functions into a single microprocessor. Benefits include fast system response, minimized interconnect wiring, easy system monitoring and advanced diagnostic capabilities
• The entire system has been factory prototype tested
• All systems are factory installed and the complete Bi-Fuel generator is factory load tested to verify performance and reliability
• Factory warranty and service support cover the entire generator

ACTIVE KNOCK PREVENTION — A KEY TO SUCCESS

With its comprehensive fuel ratio mapping, the Generac Bi-Fuel control system safely operates the engine at all conditions of load and temperature. However, unexpected transients, such as temporary variations in fuel content, can result in pre-ignition, or “knock”, if proper safeguards are not in place. A key to the success of Generac’s Bi-Fuel solution is to detect when engine conditions are approaching pre-ignition and take corrective action prior to its occurrence. This safeguard system is not required during normal operation, but is available when needed to ensure reliable engine operation under all conditions.

As stated earlier, pre-ignition can be very harmful to an engine. It is an inherent problem in Otto cycle and Bi-Fuel engines, since they compress a mixture of air and fuel in the cylinder prior to ignition. Pre-ignition occurs when a portion of the air / fuel mixture spontaneously ignites during the compression stroke but prior to the desired moment of ignition. This results in a “collision” of three pressure waves:

1) The flame front from the spontaneously ignited fuel
2) The flame front created by the normal ignition source
3) The piston compressing the air / fuel mixture

This collision causes a violent shock within the cylinder. When strong enough, the shock wave creates a knocking sound that can be heard outside the engine (thus the common term “knock”). Worse, however, is that the shock wave can actually erode the materials comprising combustion chamber components, including the pistons, valves and valve seats. Component damage may occur even prior to “knock” being audible. Another effect is higher cylinder temperatures, which further aggravate conditions. If left unchecked, the repeated pounding can quickly destroy an engine.

In a Bi-Fuel engine, pre-ignition results from an air / fuel mixture that is too rich for given conditions of load, temperature and fuel quality. One approach used by others to avoid problems is running lower percentages of natural gas, but the consequence is that less of the Bi-Fuel benefits are realized. Generac uses advanced automotive sensor and control technologies to achieve the best combination of performance and reliability.

Generac Bi-Fuel engines are equipped with piezoelectric accelerometers adjacent to each cylinder. These sensors electrically send vibration signals back to the Bi-Fuel controller. Knowing engine position and speed, the controller “pays attention” to this signal during the compression stroke of each cylinder. Through extensive testing, Generac has determined the signature vibration signal created by conditions approaching, but prior to, pre-ignition. Sensing such conditions, the Bi-Fuel controller immediately initiates a reduction of natural gas supply to lean out the air / fuel ratio. This is accomplished via a motorized gas control valve located in the natural gas supply line.

A closed loop control system between the accelerometers, Bi-Fuel controller and gas control valve ensure that proper adjustments are made. System response is fast enough that corrective action can be taken prior to knock ever occurring. Diesel fuel injection is immediately increased as needed to maintain power requirements during safeguard adjustments.

GENERAC BI-FUEL BENEFITS

• Extended run times. The reduced consumption of diesel fuel by the engine under Bi-Fuel operation means that run times per tank of fuel are significantly extended. This provides longer backup coverage during extended electrical power outages. Figure 3 shows a typical comparison of run times on a single tank of fuel for Bi-Fuel versus straight diesel operation. As illustrated, run times with Bi-Fuel operation can be measured in days rather than hours. This can be very important, since replenishment supplies may be difficult to obtain during widespread extended power outages associated with blackouts or major weather events.
• **Reduced diesel fuel storage.** Because natural gas is the predominant fuel, smaller diesel tanks are a viable option, with added benefits:
  – less fuel is stored on site; permits may be easier to obtain
  – indoor installations with capacity limits per NFPA or local codes may become feasible
  – fuel heating in cold climates is more manageable
  – fuel treatment or replacement to prevent spoilage is less costly

• **Lower capital cost.** The cost of a midrange to large diesel engine generator is approximately two-thirds that of a spark-ignited gaseous engine generator of equivalent output. With Generac’s Bi-Fuel design, we can offer primarily natural gas fueled gensets at nearly the cost of a diesel-powered unit. In addition, with higher thermal efficiency, less heat is rejected, so indoor applications can use smaller, less costly air handling systems.

• **Built-in fuel redundancy.** If the natural gas supply is interrupted for any reason, or if there is a fault in the Bi-Fuel system, the controls will automatically direct the unit back to 100% diesel without interruption of operation. Obviously, this is not possible with a spark-ignited natural gas engine.

• **Reduced maintenance costs.** Maintenance costs are reduced due to the clean burning characteristics of natural gas. Testing has shown that Bi-Fuel engine oil remains cleaner compared to engines running straight diesel. This presents opportunities for enhanced engine life and extended maintenance cycles. In addition, there are no ignition system maintenance items (spark plugs, wires, distributor, etc.) as with natural gas engines.

• **Less fuel costs.** On an equivalent energy basis, natural gas fuel costs have traditionally been lower than diesel fuel. Bi-Fuel systems allow lower fuel costs, yet provide the flexibility to resort to diesel fuel if price conditions dictate.

• **Lower exhaust emissions than diesel engines.** The introduction of natural gas in Bi-Fuel operation significantly reduces oxides of nitrogen (NOx) and particulate matter (PM) emissions compared to straight diesel combustion. Generac testing has demonstrated a 30% reduction in NOx and a more than 50% reduction in PM when operating in Bi-Fuel compared to straight diesel mode.

In California, Bi-Fuel engines used for standby generators are classified as compression ignition engines. Generac Bi-Fuel engines meet emissions requirements established by the South Coast Air Quality Management District (SCAQMD), the regulatory agency for a large portion of southern California, including Los Angeles. Certified Equipment Permit (CEP) numbers have been issued to Generac by SCAQMD in recognition of emissions compliance (CEP #407661 for the 300 kW engine and CEP #414037 for the 375 kW engine — see below for more product details).

Air quality management districts in other portions of California have similar emissions requirements as SCAQMD. However, many of these districts have tightened permissible levels of PM emissions. Generac Bi-Fuel engines also comply with these low-PM requirements (0.1 gram/HP-hour limit).

While California has long been a forerunner in regulating engine exhaust emissions, other metropolitan areas in the United States are also adopting or considering emissions regulations for standby generators. Also, more companies are adopting environmentally conscious or “green” operating philosophies in response to increased awareness of the need to protect our environment. Both consumers and businesses are providing influence in this movement. One example is the increased adoption of ISO 14000, Standards for Environmental Management. The automotive manufacturing industry is a leading proponent of this standard, and is extending requirements for its suppliers to incorporate an ISO 14000 Environmental Management System. The reduced emissions output of Generac Bi-Fuel generators may prove to be a solution when such requirements are encountered.

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**Comparison of Diesel vs. Bi-fuel Run Times per Tank Fill**

**300 kW Genset at 80% Load, 240 kW Output**

<table>
<thead>
<tr>
<th>Diesel Tank Size</th>
<th>Diesel Run Time</th>
<th>Bi-fuel Run Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>12&quot;/183 gallons</td>
<td>8.9 hours</td>
<td>76.2 hours (3.2 days)</td>
</tr>
<tr>
<td>24&quot;/438 gallons</td>
<td>21.4 hours</td>
<td>182.5 hours (7.6 days)</td>
</tr>
<tr>
<td>36&quot;/693 gallons</td>
<td>33.8 hours</td>
<td>288.8 hours (12.0 days)</td>
</tr>
</tbody>
</table>

Note: Fuel consumption rates and run times are approximate. Actual results may vary depending on fuel and operating conditions.

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Figure 3
Generac produces Bi-Fuel engine powered generators with electrical outputs of 300 kW and 375 kW. For both units, the base prime mover is a turbocharged and after-cooled 12.0 liter diesel truck engine that has provided many years of reliable service in diesel generator use. This engine is factory equipped with our Bi-Fuel system that has been fully developed and tested by Generac. The 300 kW unit has a direct drive 1800 RPM engine while a Generac gear reduction system allows engine operation at 2300 RPM (within the engine’s peak power band) to produce the higher power output for the 375 kW unit.

These units are available in various configurations for standby power applications:

- Single stand-alone gensets – SB300 and SB375
- Modular Power Systems units – MB300 and MB375
- Gemini® Twin Pack gensets – MB600-GEM and MB750-GEM

The latter two versions utilize Generac’s Modular Power System technology to cost-effectively parallel multiple gensets for larger power requirements up to 3750 kW.

All Bi-Fuel system components are fully covered under the prevailing generator warranty. Our generators carry a standard two-year warranty, with optional two-year comprehensive, five-year basic and five-year comprehensive warranties available.

All Generac Bi-Fuel units also use our PowerManager® Digital Control Platform, which incorporates digital control of Bi-Fuel operation along with the balance of generator control functions into a single, powerful, microprocessor-based module. The result is a very reliable system that is also easy to service. For more information on any of these products, contact your Generac representative or visit www.generac.com.


