the Energy to Lead

GTI TOPICAL REPORT

Assessment of Natural Gas and Electric Distribution Service Reliability

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Executive Summary

Natural gas delivery systems are seen as cost-effective, safe, and reliable methods of bringing energy to customers. These attributes, however, are sometimes more qualitatively perceived, rather than reduced to quantified metrics. How safe? How reliable? Fusing together quantitative safety and reliability methodologies (Figure 1) – viewing them as symbiotic and mutually reinforcing – can be a framework for traditional gas infrastructure activities (e.g., investment planning and operations), while also supporting public relations, marketing, and sales objectives (e.g., natural gas use for distributed generation, including onsite emergency generators).

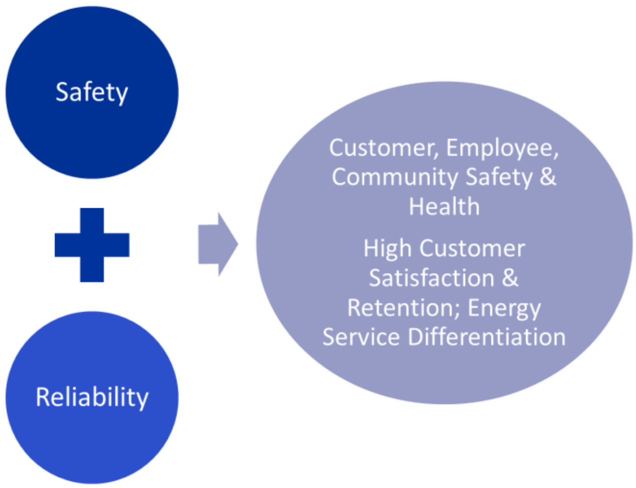


Figure 1: Natural Gas System Safety and Reliability

This report highlights that natural gas and electric distribution service are both reliable in an absolute sense, with superior attributes for natural gas distribution systems. Table 1 and Figure 2 provide a summary of the results related to: 1) reliability and availability of these energy services to homes and businesses and (2) the frequency or likelihood of outages per year. Natural gas distribution systems operate at very high levels of service reliability. These data indicate natural gas distribution systems operate at a service availability on par with six-sigma performance – a top-tier service designation.

Table 1: Summary Energy Distribution Reliability and Outage Rate Results

Metric	Natural Gas Distribution	Electric Distribution
Average Reliability/Availability (Planned and Unplanned)	0.9999957	0.999703
Average Reliability/Availability (Unplanned)	0.9999991	--
Average Outage Rate – Planned and Unplanned (Event Per Customer Per Year)	0.00895	1.017
Estimated Unplanned Outage Rate (Event Per Customer Per Year)	0.00125	--

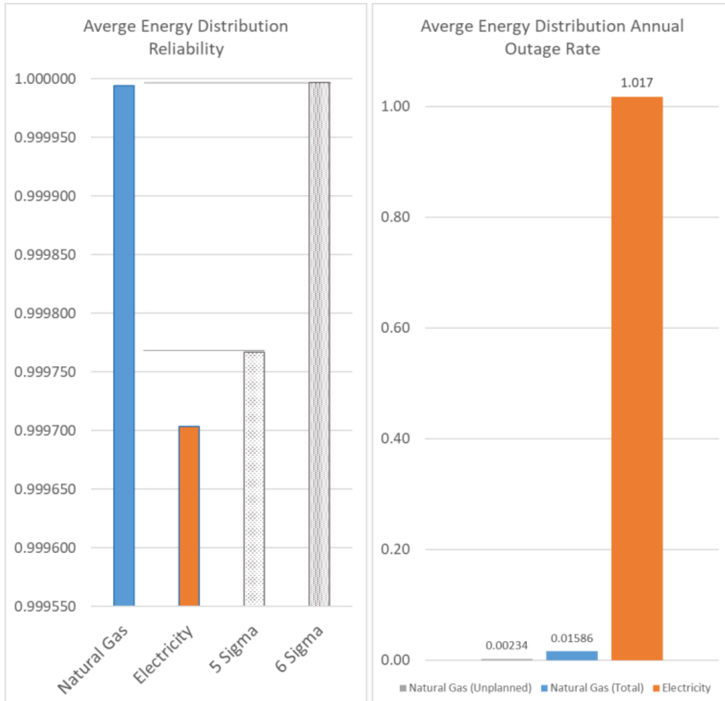


Figure 2: Energy Distribution Reliability and Outage Rate Comparison

Natural gas service disruptions are rare. On average, only 1 in 112 customers are expected to experience an outage (planned or unplanned) in any given year. Most natural gas outages are for planned equipment replacement. Unplanned outages affect about 1 in 800 natural gas customers per year. By comparison, electric distribution systems have between four and five sigma reliability performance, with an average of one outage per year per customer.

While not specifically quantified in this report, anecdotal experience indicates most electric distribution outages occur due to unplanned impacts such as severe weather; in contrast, most natural gas outages are due to planned maintenance and gas systems often remain operational during extreme weather events. In most regions, North American natural gas distribution systems should have intrinsic reliability levels equal to, or better than, onsite liquid fuel storage – a key consideration for emergency and standby generators. In earthquake prone regions, further assessment may be needed, while noting there are pipeline construction methods that minimize pipeline damage during earthquakes.

Natural gas industry improvement efforts should seek to fuse together safety and reliability as mutually reinforcing concepts. While natural gas distribution service is reliable and exhibits very low outage rates, there are pathways for continuous improvement to raise service reliability and lower outage rates. Examples include methods and techniques to replace residential meters or underground pipeline and assets by using onsite supplemental natural gas supply (e.g., compressed gas cylinders or trailers) to homes or businesses. Improved methods for identification of the location of underground natural gas systems and enhanced effectiveness of 811 one-call centers can also result in avoidance of excavation damage – a leading contributor to unplanned natural gas outages.

Future efforts should look to revisit and update this natural gas distribution reliability assessment. Gas distribution operators are encouraged to enhance their information systems to include tracking of planned and unplanned outage events and, to the extent possible, customer outage time per event.

Introduction and Background

Natural gas delivery systems are generally viewed as cost-effective, safe, and reliable methods of bringing energy to customers. These attributes, however, are sometimes more qualitatively perceived, rather than reduced to quantified metrics. How safe? How reliable? Where can improvements be made? Do customers and other stakeholders understand and place appropriate value on natural gas system reliability?

On process improvement, W. Edwards Deming stated: if you can't measure it, you can't manage it. There is a growing trend toward employing approaches such as quantitative risk analysis (QRA) for natural gas system safety. Process reliability and quality control principles (e.g., "six sigma") are congruent with quantitative safety and risk management methodologies – albeit viewed from a slightly different perspective.

The term six sigma (6σ, or 6 standard deviations) is used in manufacturing, process improvement, and quality management to denote top-tier quality and reliability. Technically, Six Sigma is a Motorola trademark that pertains to a set of tools and techniques for process improvement, but the term is widely used in industry. Broadly, six sigma is the ability of a "process" to produce output within specifications and with less than 3.4 defects per million units produced. Processes that operate with six sigma quality are statistically expected to be 99.9997% reliable, free of defects, etc. For manufacturing, it is often tied to the number of defective parts per million made. The six sigma concept can be applied to service quality as well – for example, the annual reliability or availability of natural gas or electric energy delivery service to customers.

Fusing together quantitative safety and reliability methodologies (Figure 3) – viewing them as symbiotic and mutually reinforcing – can be a framework for traditional gas infrastructure activities such as investment planning, system engineering, and operations, while also supporting public relations, marketing, and sales objectives. For example, quantified energy delivery service metrics can inform and improve gas operations while also enhancing customer and community-facing business outcomes such as elevating customer satisfaction, improving brand perception, and ensuring differentiation against potential substitute energy options (e.g., electricity).

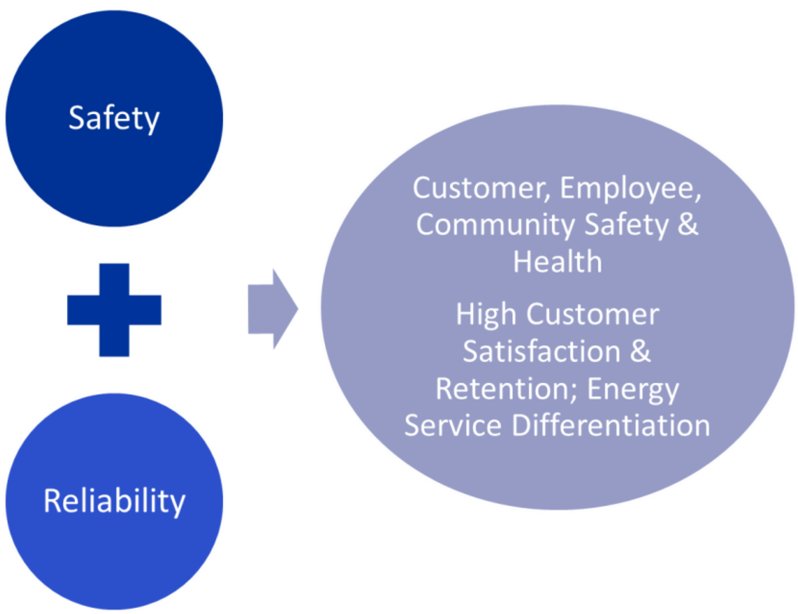


Figure 3: Natural Gas System Safety and Reliability

Energy delivery system reliability and resilience is gaining attention. One reason is the growing focus on natural gas and electricity interdependence in the United States (U.S.). Since 2000, U.S. natural gas power generation (Figure 4) has grown from 15% to approximately 32% of the overall U.S. power generation mix. Importantly, natural gas serves as the primary resource for meeting critical peak electric demand.

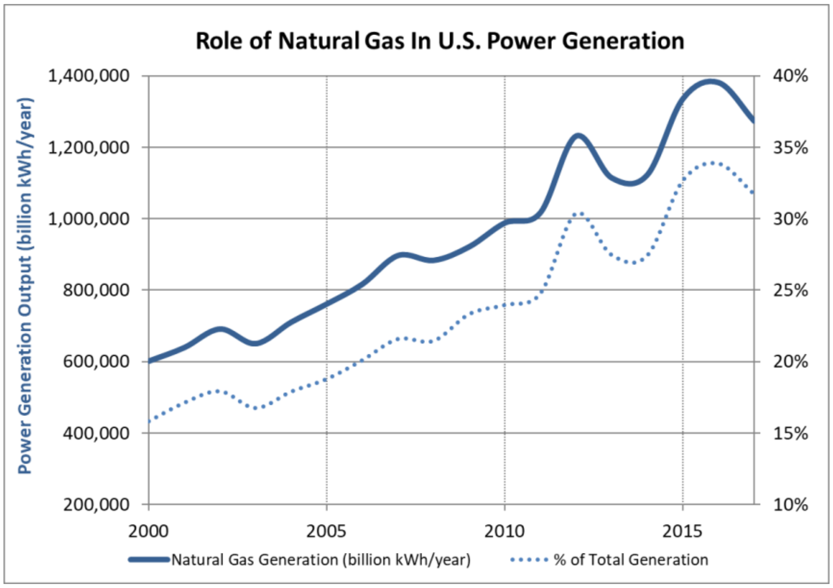


Figure 4: Growing Role of Natural Gas Power Generation

In this context, it is feasible natural gas delivery system reliability may receive greater attention and possibly foster tracking metrics similar to those incorporated into the Institute of Electrical and Electronic Engineers (IEEE) 1366 Guide for Electric Power Distribution Reliability Indices.

A wide range of factors – including natural phenomena (e.g., weather or earthquakes), material failure, and human activity – can cause energy delivery system service interruptions. In the U.S., there are two primary public sources of incidents affecting natural gas pipelines: U.S. Department of Transportation (USDOT) and the Common Ground Alliance (CGA). Figure 5 shows USDOT data, in Pareto chart form, on the primary factors that contributed to U.S. gas distribution and transmission serious incidents since 2005; there are specific USDOT criteria for what constitutes a serious incident.

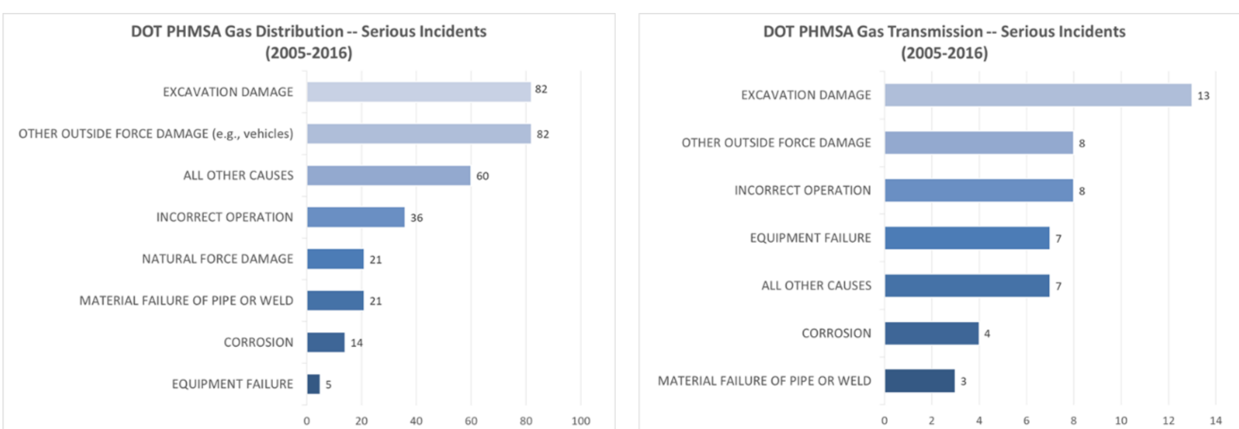
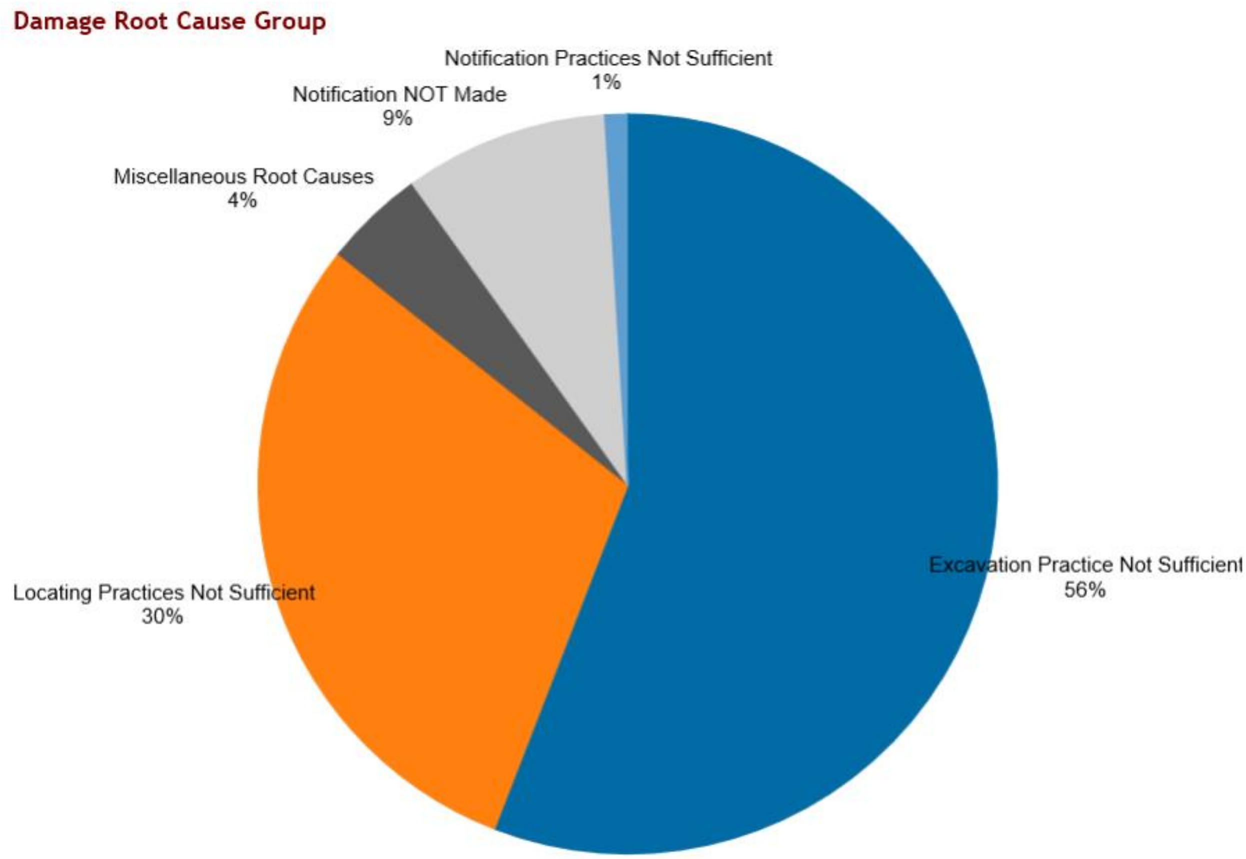


Figure 5: U.S. Department of Transportation Data on Serious Pipeline Incidents (2005-2016)

The CGA maintains a database of reported incidents leading to damage across a wide range of underground services such as natural gas, electrical, telecommunications, cable, etc. Figure 6 shows example 2016 CGA data on causes of damage and the types of utility service impacted. In 2016, natural gas assets experienced the second largest amount of economic damage, involving over 86,000 different incidents. Most incidents are due to excavation activity (e.g., when equipment operators or property owners dig into underground assets).



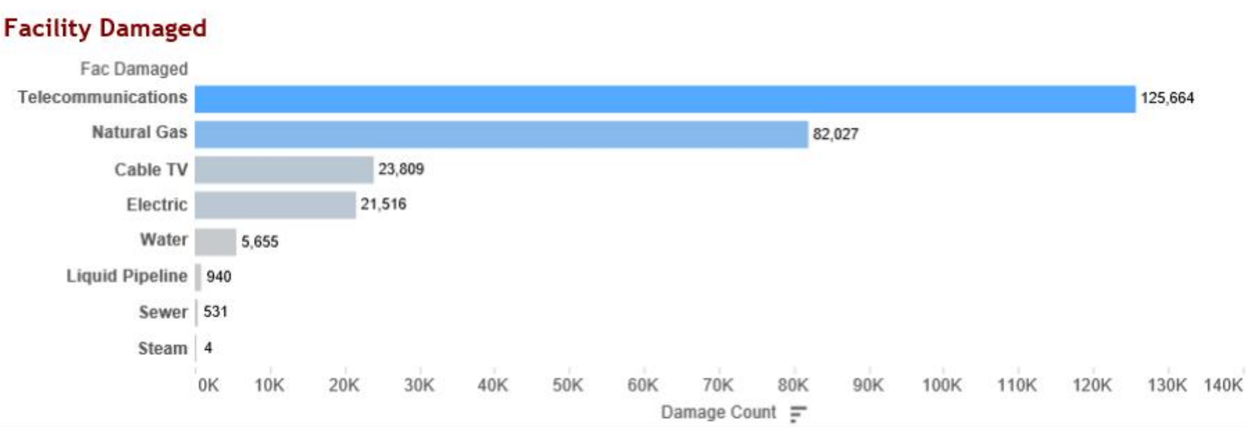


Figure 6: Common Ground Alliance Damage Incident Data

Note that the number of natural gas incidents reported by CGA in 2016 is appreciably larger (over 86,000 incidents) than the number of serious incidents in the USDOT database. For example, USDOT reports include about 1,500 serious natural gas distribution incidents from 2005-2016, averaging about 125 per year. This is about 0.15% of the number of CGA-reported incidents in 2016. This indicates most natural gas incidents are relatively limited in terms of impact to people or economic damage – nominally one serious incident per 700 overall incidents. The goal from a safety and reliability viewpoint is to drive both of these numbers downward.

Figure 7 shows state-level CGA natural gas incident data, normalized by the number of residential natural gas customers in the state, within a +/- 3 standard deviation range. This view of the data has limitations. There may be commercial and industrial customers impacted by an incident within the CGA database or there may be incidents not captured by CGA. With these caveats, the data provide a proximate incident rate metric that should correspond with natural gas customer unplanned outage rates.

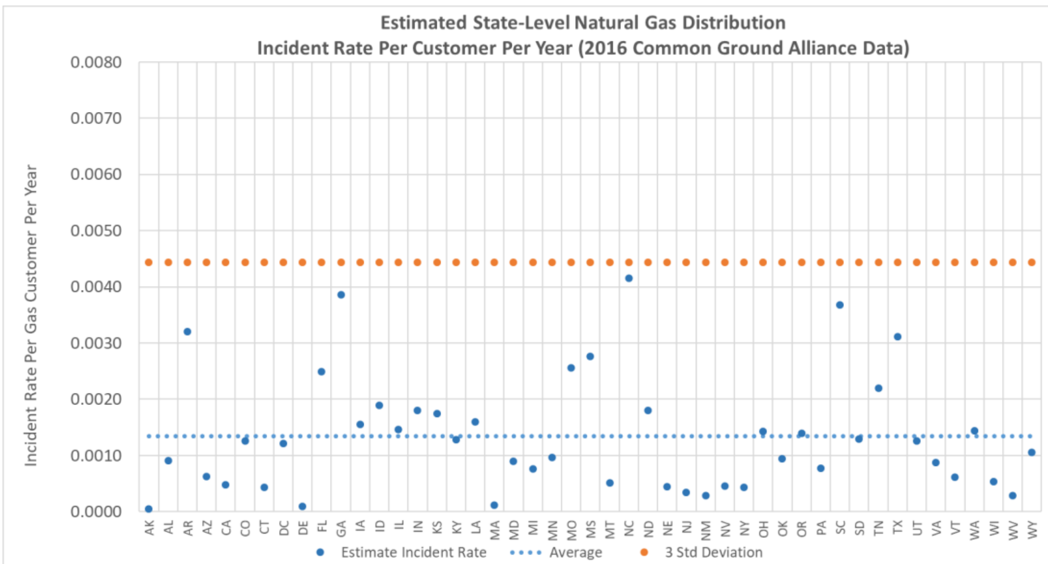


Figure 7: State-Level Natural Gas Incident Rate (CGA Data; 2016)

In statistical process control theory, 99.7% of measurements should randomly distribute within +/- three standard deviations of the mean. One way of visually displaying this is a Process Control Chart; Figure 7 is an example of this type of chart. State-level gas incident data are consistent with this concept, indicating no states falling outside a +/- 3-standard deviation range. There are generally less than 0.004 incidents per residential customer per year based on this CGA incident database, with an average around 0.00135 incidents per residential customer per year. The inverse of this unplanned incident rate implies:

- An individual customer might experience an unplanned natural gas service disruption once every 740 years or
- About 1 in 740 customers could experience an unplanned natural gas service incident in any given year.

Reliability and associated concepts are quantitative metrics; they can be measured and monitored. The IEEE 1366 Guide for Electric Power Distribution Reliability Indices provides a methodology for ascertaining electric distribution system reliability indices. Several IEEE 1366 metrics are illustrated in Table 2.

Table 2: IEEE 1366 Electric Distribution Reliability Indices

Reliability Metric	Determination
System Average Interruption Duration Index (SAIDI)	Total time all customers were without service / total number of customers
System Average Interruption Frequency Index (SAIFI)	Number of sustained customer service outages / total number customers
Customer Average Interruption Duration Index (CAIDI)	SAIDI / SAIFI
Average Service Availability Index (ASAI)	Customer Hours Service Availability / Customer Hours Service Demand

Within this report, we use the terms Reliability or Availability as synonyms for ASAI. That is, what fraction or percentage of the year might customers have their energy delivery service available for use (or how many 9's of reliability, for example 99.9991%)? The phrase Annual Outage Rate is used in this report as a synonym for SAIFI. That is, what is the typical frequency (or likelihood) of an individual customer experiencing service outages during a year?

The USDOT and CGA data are public sources providing insights into safety incidents affecting natural gas pipeline systems; these are unplanned (or forced) outage events. However, in terms of customer service reliability, we also need to include planned outages to obtain comprehensive annual outage rate statistics. Planned natural gas distribution outage information is not publicly available. Further, there is a need to quantify the number of hours customers lost natural gas service to determine service reliability or availability (similar to the ASAI metric within IEEE 1366). In the following sections, we discuss a survey GTI conducted to gather natural gas service distribution outage information.

Natural Gas Distribution Service Survey

In an effort to quantify natural gas distribution service reliability and outage rate, GTI undertook a survey of several North American natural gas distribution operators. The intent was to gather information on:

- Number of annual service outages (planned and unplanned, in separate categories if available)
- Number of lost service hours due to outages (actual or best engineering estimates)

Figure 8 shows the survey questionnaire.

				If available	If available	If available	If applicable, place an X	If available	If available	If applicable, place an X
	1. Calendar Year for Data Reporting	2. Total Number of Customers Served	3. Total Number of Calendar Year Outages	3a. Number of Single Customer Outages	3b. Number of Multiple Customer Outages	4. Total Number of Customers Impacted	4a. Based on Engineering Estimate	4b. Total Number of Planned Customer Outages	5. Actual or Estimated Total Calendar Year Customer Outage Hours	5a. Based on Engineering Estimate
Residential										
Commercial										

Figure 8: Natural Gas Distribution Service Reliability Survey

With these survey results, the goal is to:

- Provide statistical data to quantify the outage rates and service availability for natural gas distribution operations
- Use these data to enable a comparison of natural gas and electric distribution service reliability
- Make quantitative data available to inform codes and standards making processes, specifying engineers, end users, and other stakeholders with respect to the reliability of using natural gas as a fuel source for emergency generators in lieu of diesel or other onsite stored fuels

In prior discussions with natural gas distribution operators, it appeared evident that outage information was available, but that tracking outage hours was less probable. For this reason, the survey included the option for providing an engineering estimate of outage hours.

In advance of the survey, a gas distribution company provided GTI an example reliability tracking report. This used an engineering estimate of 8 hours to approximate outage duration per event. From this, the total number of outages was multiplied by 8 hours to obtain the total number of customer outage hours. In the context of planned outages, a value of 8 hours is likely a reasonable and, perhaps, conservative estimate. For example, during a common process of replacing a residential customer meter and regulator set, the actual outage time may only last one or two hours (though more time may be needed in preparing equipment for replacement). If not included in the survey response, an 8-hour outage time per event engineering estimate was used by GTI.

Unlike planned outages, unplanned outages would undoubtedly vary in length depending on the extent and nature of the infrastructure impacted. In rare instances, such as extreme events like an earthquake, the extent and duration of outage time may be extensive and fall into a major event –a category defined within IEEE 1366. Due to the fundamental differences between unplanned and planned outages, the survey aimed to quantify these two outage categories. From a customer perspective, an unplanned outage is likely more significant than a planned outage. For example, planned outages are scheduled in advance and provide customers the opportunity to make contingency plans to minimize disruption to their home or businesses. Further, planned outages would not likely take place during more cold weather periods when natural gas service is critically important. The CGA incident data, discussed previously, provides a secondary source for estimating unplanned outage rates.

Survey respondents were informed to exclude interruptible customer events. That is, during extreme demand periods a select number of larger customers may have natural gas service interrupted. These interruptible customers – as compared to firm-rate customers – make an economic decision to allow natural gas service suspension during times of high demand. Interruptible service outages are categorically different from service outages due to an unplanned or planned event. In addition, the primary focus of this survey is on core residential and commercial customers who would not likely be on interruptible natural gas service.

A question was raised by one company about outages related to safety concerns. For example, outages that occur when service is shutoff due to reports of natural gas within a building. Guidance was provided to include this type of outage if the cause was due to natural gas assets within the jurisdiction of the natural gas pipeline operator. Safety-related outages due to downstream piping or equipment in the building could be excluded (which would be similar to excluding an electrical breaker outage within a building). This would be technically outside the natural gas distribution service responsibility. Companies could also include these events regardless of the cause of the incident. In either case, this is expected to be a small number of incidents and would not materially affect the results.

Natural Gas Distribution Service Reliability
GTI received survey responses from twelve North American natural gas distribution companies. Table 3 provides a summary of the survey input. This encompassed about 10.5 million natural gas customers – mainly residential and commercial, with some industrial customers. Four of the companies had one million or greater customers and six had less than one million customers. Some respondents provided data for multiple years.

Table 3: Natural Gas Distribution System Reliability Data Summary

Number of Companies	12
Number of Companies-Years	22
Approximate Number of Customers	10,462,000
Average Reliability/Availability (Planned and Unplanned Outages)	0.9999942
Average Reliability/Availability (Unplanned Outages)	0.9999978
Average Outage Rate – Planned and Unplanned (Event Per Customer Per Year)	0.0159
Estimated Unplanned Outage Rate (Event Per Customer Per Year)	0.00234 (survey) (0.00135, CGA data)

Figure 9 and Figure 10 summarize the natural gas service reliability and annual outage rate data, respectively. Outage rates include planned and unplanned outage events – shown separately when both were available. Figure 10 also includes the 2016 CGA data finding of a 0.00135 incident rate per residential customer per year. Based on this limited sample, the unplanned outage rate information from the survey is consistent with the 2016 CGA incident rate.

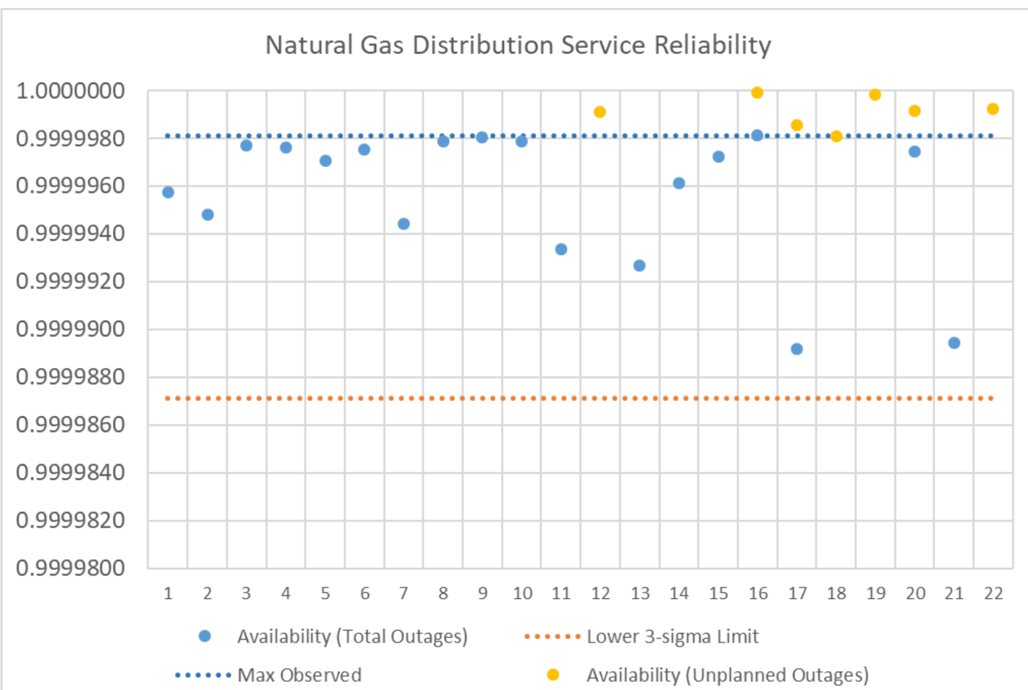


Figure 9: Natural Gas Distribution Service Reliability

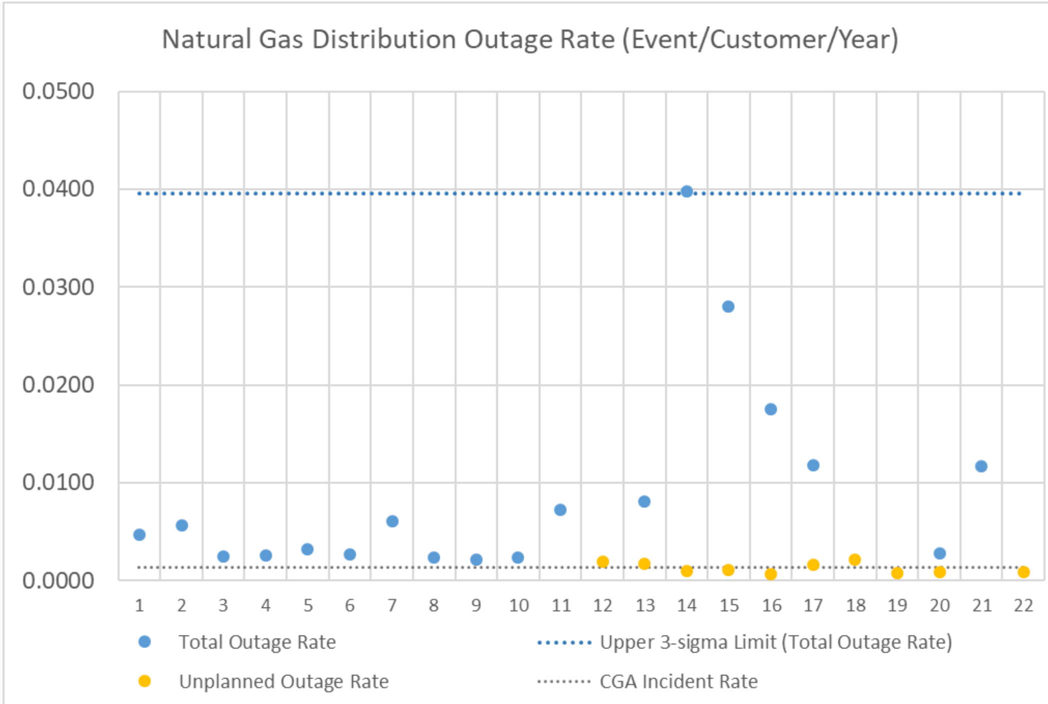


Figure 10: Natural Gas Distribution Service Annual Outage Rate

Some companies had notably higher annual outage rates (planned and unplanned). In these instances, their unplanned outage rate is consistent with expectations, but the planned activity outage rate is higher. This likely indicates companies that are replacing equipment (e.g., main and services or replacing residential meter sets) at an appreciable rate as part of system modernization and accelerated replacement programs.

As noted previously, the reliability data includes in most cases an estimate of outage hours per event (e.g., 8 hours). Currently, most natural gas distribution operators do not track outage event duration. In most cases, an 8-hour outage assumption is used to estimate outage time. Table 4 shows the impact on calculated reliability using an 8-hour and 24-hour outage assumption; the difference is small due to the low outage rates for natural gas distribution service.

Table 4: Natural Gas Distribution System Reliability Data Comparison

Average Reliability/Availability (8 hour assumption)	0.9999942
Average Reliability/Availability (24 hour assumption)	0.9999902

Table 5 provides a summary of the natural gas distribution company data.

Table 5: Summary of Natural Gas Distribution Reliability by Company

Company	Customer Range	Reliability/ Availability (Planned & Unplanned)	Reliability/ Availability (Unplanned Only)	Annual Total Outage Rate	Annual Unplanned Outage Rate	Year
1	1 MM +		0.9999957		0.0047	2006
1	1 MM +		0.9999948		0.0057	2007
1	1 MM +		0.9999977		0.0025	2008
1	1 MM +		0.9999976		0.0026	2009
1	1 MM +		0.9999971		0.0032	2010
1	1 MM +		0.9999975		0.0027	2011
1	1 MM +		0.9999944		0.0061	2013
1	1 MM +		0.9999979		0.0023	2014
1	1 MM +		0.9999981		0.0021	2015
1	1 MM +		0.9999979		0.0023	2016
2	100K-1 MM	0.9999933		0.0073		2017
3	100K-1 MM		0.9999991		0.00193	2017
4	1 MM +	0.9999927		0.0080	0.00171	2017
5	100K-1 MM	0.9999961		0.0398	0.00097	2017
5	100K-1 MM	0.9999972		0.0280	0.00106	2016
6	100K-1 MM	0.9999981	0.9999999	0.0175	0.00061	2017
7	100K-1 MM	0.9999892	0.9999985	0.0118	0.00160	2017
8	1 MM +		0.9999981		0.00211	2017
9	1 MM +		0.9999998		0.00076	2017
10	100K-1 MM	0.9999974	0.9999992	0.0028	0.00091	2017
11	100K-1 MM	0.9999894		0.0117		2017
12	100K-1 MM		0.9999992		0.00084	2017

Pathways for Increasing Natural Gas Service Reliability and Reducing Outage Rates

There are opportunities for further increasing natural gas service reliability and reducing outage rates, including:

- Using supplemental natural gas supplies (e.g., compressed natural gas cylinders and trailers, vaporized LNG, etc) to provide temporary gas supply during repair and replacement of natural gas distribution piping and related assets
- Using techniques resulting in interruption-free natural gas meter maintenance and replacement (e.g., similar to the Mueller DBS System or alternatives)
- Improved methods for underground asset identification – advancements in plastic pipe locating, expanded geographical information systems with high resolution accuracy, and other techniques that help to avoid excavation damage
- Enhancement in utility notification and 811 call center education and effectiveness
- Using new technologies such as the GTI-developed excavation encroachment notification system to enable real-time awareness during operation of heavy equipment such as excavators and agricultural tillers/cultivators

Electric Distribution Service Reliability

For comparison, GTI assembled a representative set of electric distribution service reliability statistics. Several state public utility organizations require annual reporting of these data, typically using the IEEE 1366 methodology; these data are available online. Summary GTI-collated electric distribution statistics are shown in Table 6. This encompasses nine electric distribution service operators and sixty company-years (for example, includes data from 11 years from some companies). These data are from electric distribution operators in California, New York, Massachusetts, Illinois, and Oregon.

Table 6: Electric Distribution System Reliability Data Summary

Number of Companies	9
Number of Companies-Years	60
Average Reliability/Availability	0.999703
Average Outage Rate (Event Per Customer Per Year)	1.017

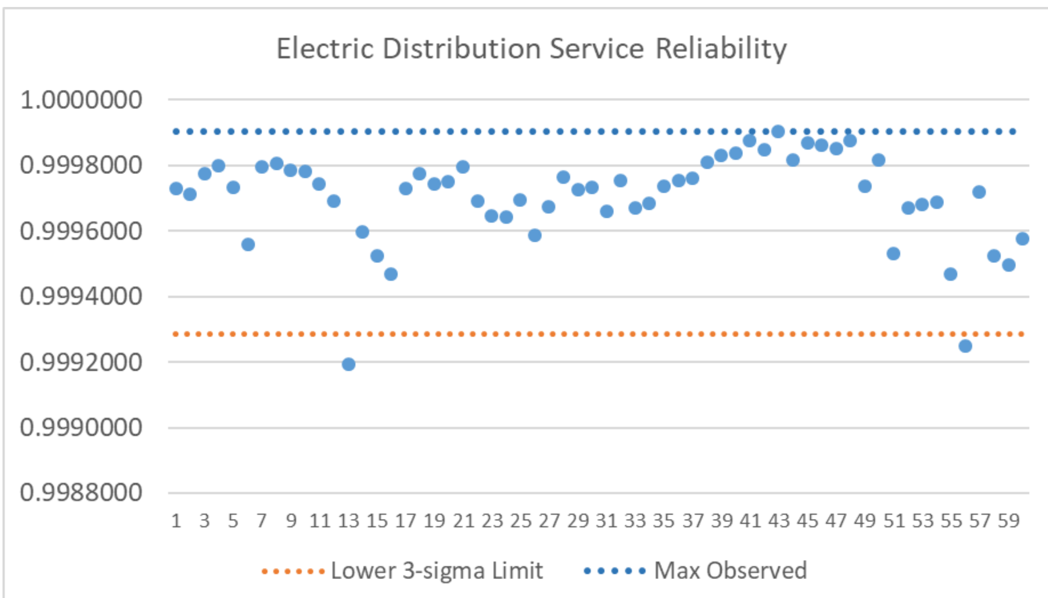


Figure 11: Electric Distribution Service Reliability

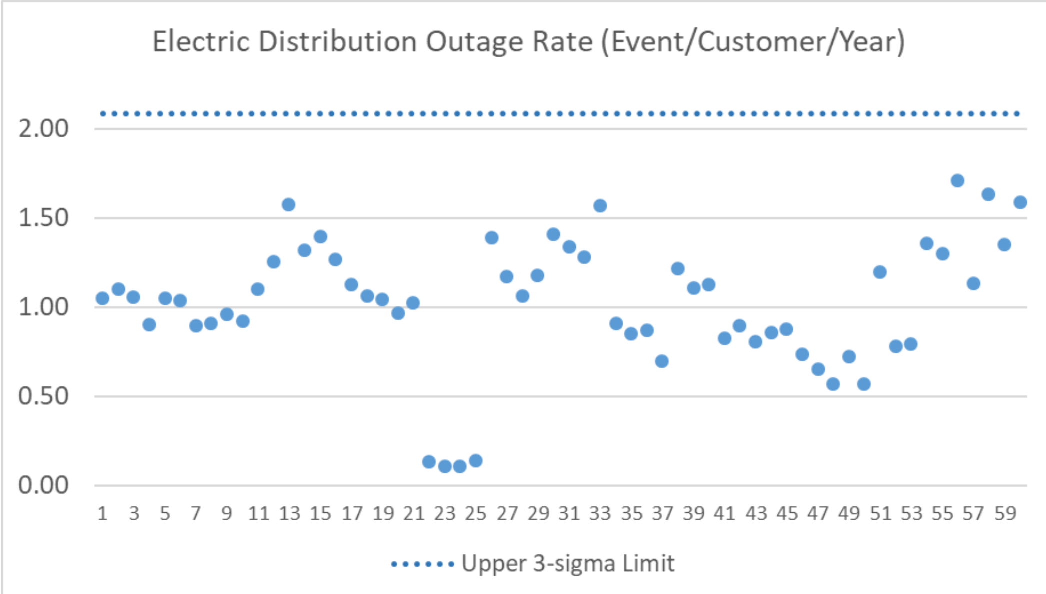


Figure 12: Electric Distribution Service Annual Outage Rate

Table 7 provides a summary of the electric distribution company-level reliability data.

Table 7: Summary of Electric Distribution Reliability by Company

Company	Reliability/ Availability	Annual Outage Rate	Year
Southern California Edison	0.9997296	1.0471	2006
Southern California Edison	0.9997121	1.1028	2007
Southern California Edison	0.9997738	1.0586	2008
Southern California Edison	0.9997987	0.8998	2009
Southern California Edison	0.9997319	1.0472	2010
Southern California Edison	0.9995579	1.0386	2011
Southern California Edison	0.9997943	0.8930	2012
Southern California Edison	0.9998048	0.9100	2013
Southern California Edison	0.9997869	0.9622	2014
Southern California Edison	0.9997815	0.9200	2015
Southern California Edison	0.9997441	1.1000	2016
PG&E	0.9996910	1.2540	2007
PG&E	0.9991933	1.5750	2008
PG&E	0.9995970	1.3160	2009
PG&E	0.9995253	1.3940	2010
PG&E	0.9994696	1.2670	2011
PG&E	0.9997310	1.1250	2012
PG&E	0.9997759	1.0650	2013
PG&E	0.9997454	1.0440	2014
PG&E	0.9997492	0.9670	2015
PG&E	0.9997972	1.0210	2016

Table 7: Summary of Electric Distribution Reliability by Company (cont'd)

Company	Reliability/ Availability	Annual Outage Rate	Year
Consolidated Edison	0.9996906	0.1300	2013
Consolidated Edison	0.9996473	0.1100	2014
Consolidated Edison	0.9996416	0.1100	2015
Consolidated Edison	0.9996952	0.1400	2016
National Grid	0.9995879	1.3900	2013
National Grid	0.9996724	1.1700	2014
National Grid	0.9997637	1.0600	2015
National Grid	0.9997249	1.1800	2016
NYSEG	0.9997329	1.4100	2013
NYSEG	0.9996610	1.3400	2014
NYSEG	0.9997557	1.2800	2015
NYSEG	0.9996701	1.5700	2016
RG&E	0.9996861	0.9100	2013
RG&E	0.9997352	0.8500	2014
RG&E	0.9997557	0.8700	2015
RG&E	0.9997614	0.7000	2016
NStar	0.9998086	1.213	2006
NStar	0.9998305	1.11	2007
NStar	0.9998373	1.127	2008
NStar	0.9998763	0.826	2009
NStar	0.9998468	0.893	2010
NStar	0.9999026	0.807	2011
NStar	0.9998161	0.854	2012
NStar	0.9998700	0.877	2013
NStar	0.9998611	0.734	2014
Portland General Electric	0.9998516	0.650	2010
Portland General Electric	0.9998744	0.570	2011
Portland General Electric	0.9997374	0.720	2012
Portland General Electric	0.9998174	0.570	2013
Portland General Electric	0.9995320	1.200	2014
Portland General Electric	0.9996689	0.780	2015
Portland General Electric	0.9996804	0.790	2016
PacifiCorp	0.9996895	1.360	2010
PacifiCorp	0.9994692	1.300	2011
PacifiCorp	0.9992489	1.710	2012
PacifiCorp	0.9997203	1.130	2013
PacifiCorp	0.9995243	1.630	2014
PacifiCorp	0.9994958	1.350	2015
PacifiCorp	0.9995753	1.590	2016

Natural Gas and Electric Distribution Service Reliability Comparison

In an absolute sense, natural gas and electric distribution service are both reliable. Figure 13 shows a comparison of natural gas and electric distribution service reliability. The bars labeled 5-sigma and 6-sigma are statistical measures; 5-sigma reliability is 233 events per million and 6-sigma is 3.4 events per million.

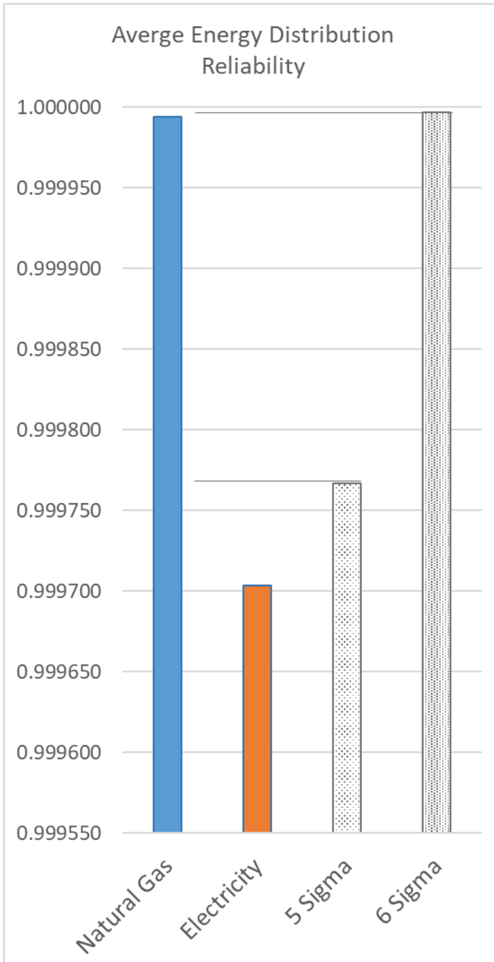


Figure 13: Comparison of Natural Gas and Electric Service Reliability (ASAI)

In this comparison, natural gas distribution service exhibits six-sigma-level availability performance, while electric distribution service has availability performance near the five-sigma level. If this is translated into nominal outage time per year, on average natural gas customers could expect to be without service for 3 minutes (and 1.2 minutes based on unplanned outages) and electric customers could expect to be without service for 156 minutes.

There is a materially different likelihood of an outage event occurring between natural gas and electricity distribution service (Figure 14). Annually, it is likely an electric distribution customer would experience one outage per year (1.017). For natural gas, the number is about 0.0159 outage per customer per year. Taking the ratio of these two values, an electric customer is 64 times more likely to experience an outage than a natural gas customer. For natural gas customers, the likelihood of an annual outage is 1 in 63; unplanned outage events have a likelihood of 1 in 428.

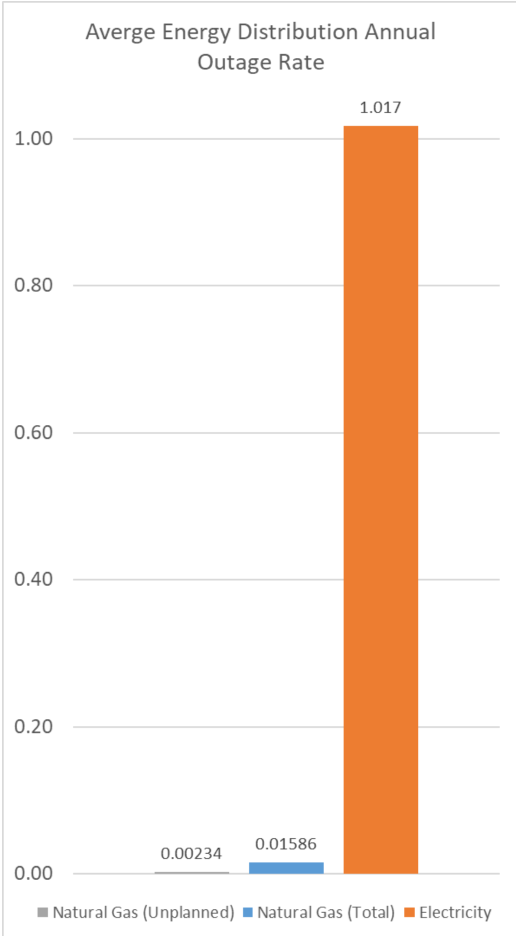


Figure 14: Comparison of Natural Gas and Electric Annual Outage Rates

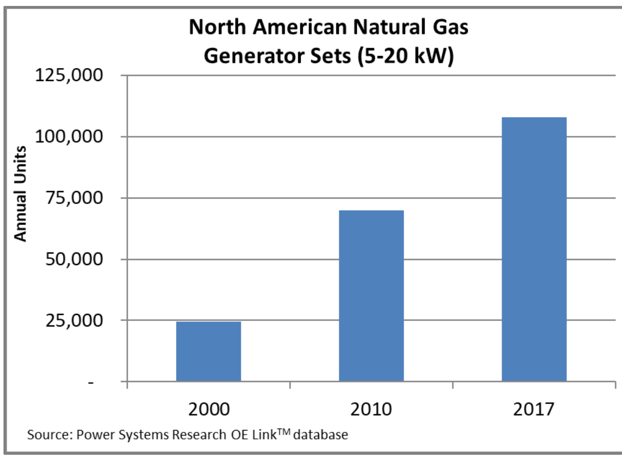
Recent extreme weather events such as hurricanes in Texas, Florida, and elsewhere empirically demonstrate the differences in the ability of electric and natural gas distribution service to remain intact and operational. The electric infrastructure is considerably more vulnerable to weather conditions such as high winds (e.g., hurricanes, tornadoes), ice storms, and other weather events. In contrast, underground natural gas pipelines have proven reliable and resilient throughout many major weather events.

Role for Natural Gas as a Cost-Effective and Clean Reliability and Resilience Solution

While electric distribution service reliability is high in an absolute sense, for some end users the impact of electric outages at their homes or businesses can be highly disruptive and pose an economic hardship. For these applications, end users may employ onsite generators for emergency or standby service. In some instances, end users strive for 100% power reliability by coupling onsite generation with uninterruptible power supply (UPS) systems. This includes critical life safety applications such as hospitals and 911 call centers as well as instances where the costs of power outages are extremely high (e.g., financial institutions, pharmaceutical manufacturing, and others).

Earlier estimates placed the installed capacity of standby and emergency generators near 170 GW; this number has likely increased over the past decade. These distributed generation units serve a vital role during electric power outages. Historically, many of these have been diesel-fueled standby or emergency engine generators – especially for commercial and industrial facilities – while gasoline or gaseous (i.e., natural gas or propane) generator units may be used at homes and light-commercial businesses.

A number of factors are opening up greater market opportunity for onsite natural gas power systems to supplement grid electricity. This is evidenced by the increasing sale of natural gas engines and generator sets. As shown in Figure 15, according to data from Power Systems Research, the North American market for 5-20 kW natural gas and liquefied petroleum gas (LPG, or propane) generator sets has grown by over a factor of four since 2000 – totaling about 110,000 units in 2017. Internationally, sales of larger 1-5 MW natural gas engines is also growing. In 2016, natural gas commanded over 15% market share in the 1-5 MW range (the balance being diesel engines); in 1990, gas engine market share was below 4%.



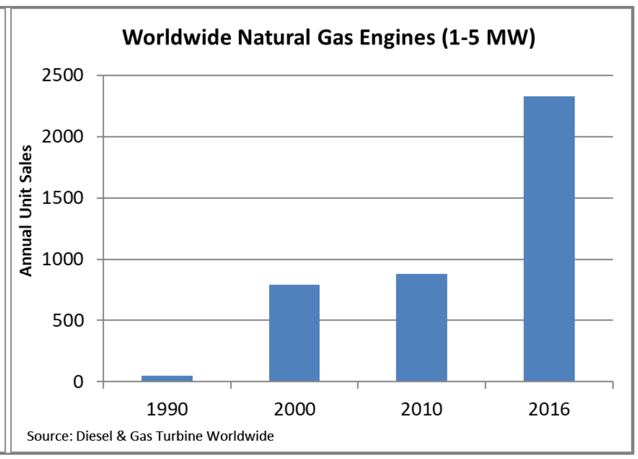


Figure 15: North American Production of Natural Gas and LPG Generator Sets

Figure 16 shows typical natural gas-fueled generators for standby and emergency power at residential (left) and commercial or industrial facilities (right). These units connect to the natural gas distribution pipeline system and can provide nearly instantaneous power (e.g., in about ten seconds) after a power outage. End users benefit from using natural gas due to avoided need to replenish onsite liquid fuel tanks (e.g., diesel or LPG) as well as the lower fuel costs. Onsite liquid fuels are consumed during periodic (e.g., weekly) running of generator sets ("exercising") or, more significantly, when called upon for extended run times during long power outages. The continued supply of pipeline natural gas is a substantial resilience benefit for end users compared to managing the logistics of liquid fuel resupply during extreme disruptions in building power supply.

Figure 16: Example Residential and Commercial/Industrial Natural Gas Generator Sets

There is market pull for using natural gas in place of diesel engines. To help end users, GTI worked with a major generator set manufacturer (Generac) to develop a total cost of ownership calculator to assist in comparing the business case for natural gas and diesel for standby and emergency generator sets (calculator available at [www.generatorTCO.com)](http://www.generatorTCO.com). Figure 17 shows an example screenshot of a portion of this online calculator. There is also a white paper available on this topic (see References). From an economic perspective, an onsite natural gas generator can open the possibility for customers to participate in an electric demand response program to capture additional savings.

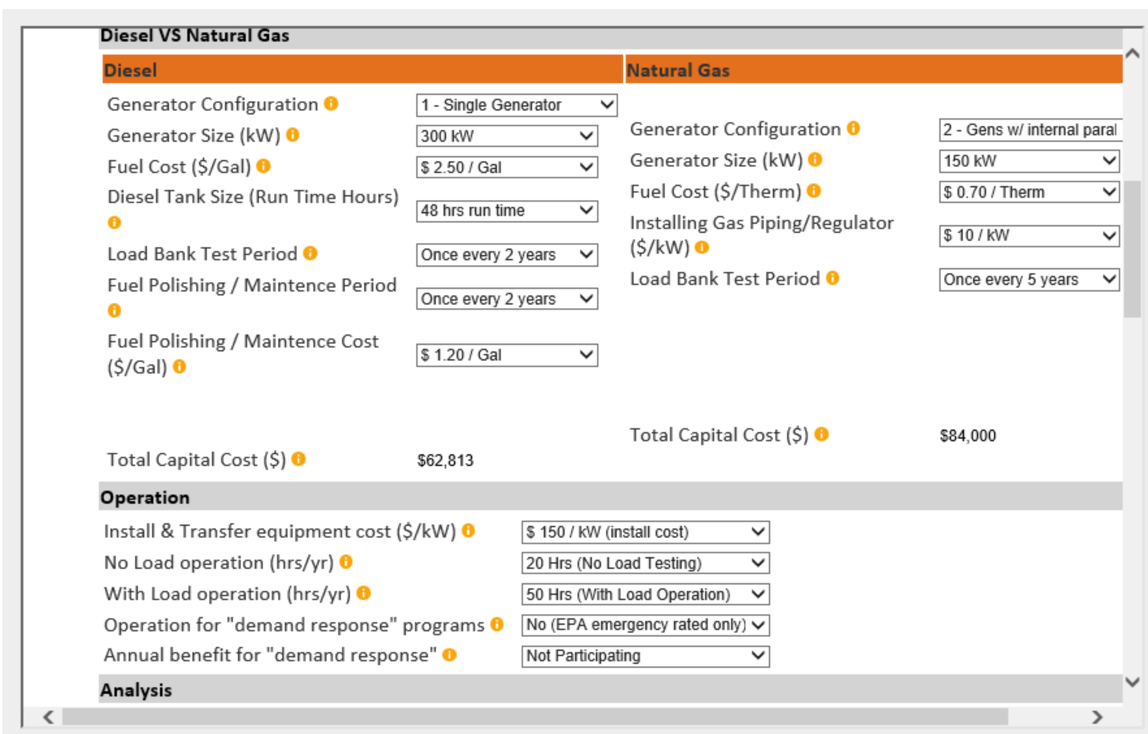


Figure 17: Natural Gas vs Diesel Generator Set Lifecycle Cost Calculator

Against this backdrop of growing end user interest in using onsite natural gas power generation to improve site electric reliability, traditional practices and historical code and standards language have typically favored diesel-fueled engines for standby and emergency power. This stems in part from the view that onsite fuel storage was either preferable or required (e.g., in life safety applications).

As noted by Generac in a whitepaper publication, reliability of fuel supply is of great concern for code officials – that is, authorities having jurisdiction (AHJs), such as fire marshals or others, involved in permitting emergency generators. Per National Fire Protection Association (NFPA) National Electrical Code (NEC), onsite fuel is required for facilities with Level 1 loads "where failure of the equipment to perform could result in loss of human life or serious injuries." Mission-critical applications, including hospitals and 911 call centers, often rely on diesel-fueled generators because on-site fuel storage is viewed as more reliable.

While NEC requires on-site fuel supply for mission-critical standby systems, it grants AHJs the flexibility to permit the use of alternative fuels in other standby power applications where there is a low probability of a simultaneous failure of both the off-site fuel delivery system (e.g., natural gas) and the power from the outside electrical utility company. As the natural gas distribution service data highlighted in this report indicates, the probability of a customer losing natural gas service during an unplanned event is quite low – particularly in the absence of major catastrophic event such as an earthquake. Even during several recent major U.S. weather events, anecdotal information indicates natural gas service to customers remained largely unaffected.

Traditional perception within the market is that diesel engines are the most reliable prime movers for standby generators; however, despite their widespread use, diesel generators have demonstrated multiple reliability issues. Outages associated with major weather events have highlighted diesel-fueled generator vulnerability, including improper or inadequate fuel maintenance practices, and the difficulty or impossibility of fuel replenishment in the midst of prolonged and wide-scale outage events. The introduction of ultra-low sulfur diesel (ULSD) successfully reduced engine emissions, but ULSD has a shorter shelf life and requires more rigorous maintenance and periodic fuel polishing. In addition, newer diesel engines require higher quality fuel, and so are less tolerant of fuel issues. During extended power grid outages following extreme weather events, the ability for over-the-road diesel resupply can be disrupted for days to weeks, limiting the generator operation to the 2 to 4 days provided by on-site fuel storage. In this context, reliable natural gas fuel supply – free from issues such as water in diesel fuel storage tanks -- could serve as a more reliable emergency generator fuel supply option than diesel.

Regions with potential seismic activity comprise a higher risk category for natural gas pipelines. However, earthquake-resistant design practices may help minimize theses impacts by ensuring pipelines have flexibility to move (e.g., pipelines embedded in pea gravel or geofoam, or the use of expansion loops that avoid long, fixed pipeline segments). For applications where traditional onsite fuel storage may be preferred or required, onsite LPG could serve as a supplemental energy supply for natural gas generator sets for some equipment.

The growing role of natural gas emergency and standby generator sets that use natural gas distribution pipelines underscores the societal value of natural gas as:

- A reliable energy supply option for homes and businesses
- Part of an integrated solution that enhances onsite electric supply reliability and improves end user and local community resilience during extreme events that can disable electric distribution (as well as liquid fuel supply) service for an extended duration.

Conclusions

Natural gas energy delivery systems are generally viewed as cost-effective, safe, and reliable – but how reliable? Quantified reliability metrics, like those outlined in this report, can help inform natural gas system engineering and operations, while also enhancing customer and community-facing business goals.

This report highlights that natural gas and electric distribution service are both reliable in an absolute sense. Table 8 and Figure 18 provide a summary of the results related to: 1) reliability and availability of these energy services to homes and businesses and (2) the frequency or likelihood of outages per year.

Table 8: Summary Energy Distribution Reliability and Outage Rate Results

Metric	Natural Gas Distribution	Electric Distribution
Average Reliability/Availability (Planned and Unplanned)	0.9999942	0.999703
Average Reliability/Availability (Unplanned)	0.9999978	--
Average Outage Rate – Planned and Unplanned (Event Per Customer Per Year)	0.0159	1.017
Estimated Unplanned Outage Rate (Event Per Customer Per Year)	0.00234 (survey) (0.00135, CGA data)	--

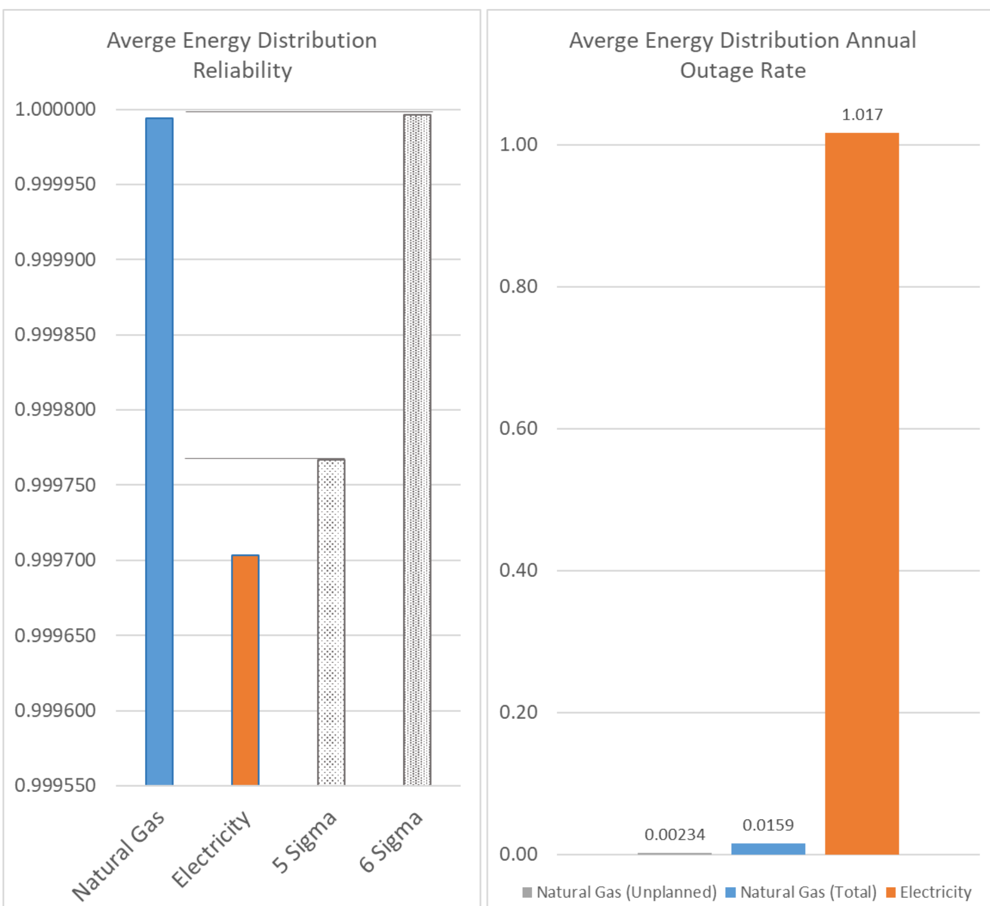


Figure 18: Energy Distribution Reliability and Outage Rate Comparison

Natural gas distribution systems operate at very high levels of service reliability. These data indicate natural gas distribution systems operate at a service availability on par with six-sigma performance – a top-tier service designation. Natural gas service disruptions are rare. On average, only 1 in 63 customers (1/0.0159) are expected to experience an outage (planned or unplanned) in any given year. Most natural gas outages are for planned equipment replacement; data in this report indicate unplanned annual natural gas service outages affect about 1 in 428 natural gas customers (1/0.00234) per year.

By comparison, electric distribution systems have between four and five sigma reliability performance, with an average annual outage time of 156 minutes per year per customer and each electric distribution customer can expect at least one outage event per year – a much higher rate than for natural gas distribution service. While not specifically quantified in this report, anecdotal experience indicates the vast majority of electric distribution outages occur due to unplanned impacts such as severe weather (whereas most natural gas outages are due to planned events).

In most regions, North American natural gas distribution systems should have intrinsic reliability levels equal to, or better than, onsite liquid fuel storage – a key consideration for emergency and standby generators. In earthquake prone regions, further assessment may be needed to evaluate this hypothesis, while noting there are pipeline construction methods that can minimize pipeline damage during earthquakes and ground movement.

Natural gas industry improvement efforts should seek to fuse together safety and reliability as mutually reinforcing concepts. While natural gas distribution service is reliable and exhibits very low outage rates, there are pathways for continuous improvement to raise service reliability and lower outage rates. Examples include methods and techniques to replace residential meters or underground pipeline and assets by using onsite supplemental natural gas supply to maintain natural gas supply (e.g., compressed gas cylinders or trailers) to homes or business. Improved methods for identification of the location of underground natural gas systems and enhanced effectiveness of 811 one-call centers can also result in avoidance of excavation damage – a leading contributor to unplanned natural gas outages.

Future efforts should look to revisit and update this natural gas distribution reliability assessment. Gas distribution operators are encouraged to enhance their information systems to include tracking of planned and unplanned outage events and, to the extent possible, customer outage time per event.

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List of Acronyms

Acronym	Description
AHJ	Authority Having Jurisdiction
ASAI	Average Service Availability Index
CAIDI	Customer Average Interruption Duration Index
CGA	Common Ground Alliance
GTI	Gas Technology Institute
IEEE	Institute of Electrical and Electronic Engineers
kW	Kilowatt
LPG	Liquefied Petroleum Gas
MW	Megawatt
NEC	National Electrical Code
NFPA	National Fire Protection Association
QRA	Quantitative Risk Analysis
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
ULSD	Ultra-Low Sulfur Diesel
UPS	Uninterruptible Power Supply
USDOT	United States Department of Transportation

END OF REPORT