

THE RISE OF DISTRIBUTED POWER

BY BRANDON OWENS



ecomagination



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By Brandon Owens

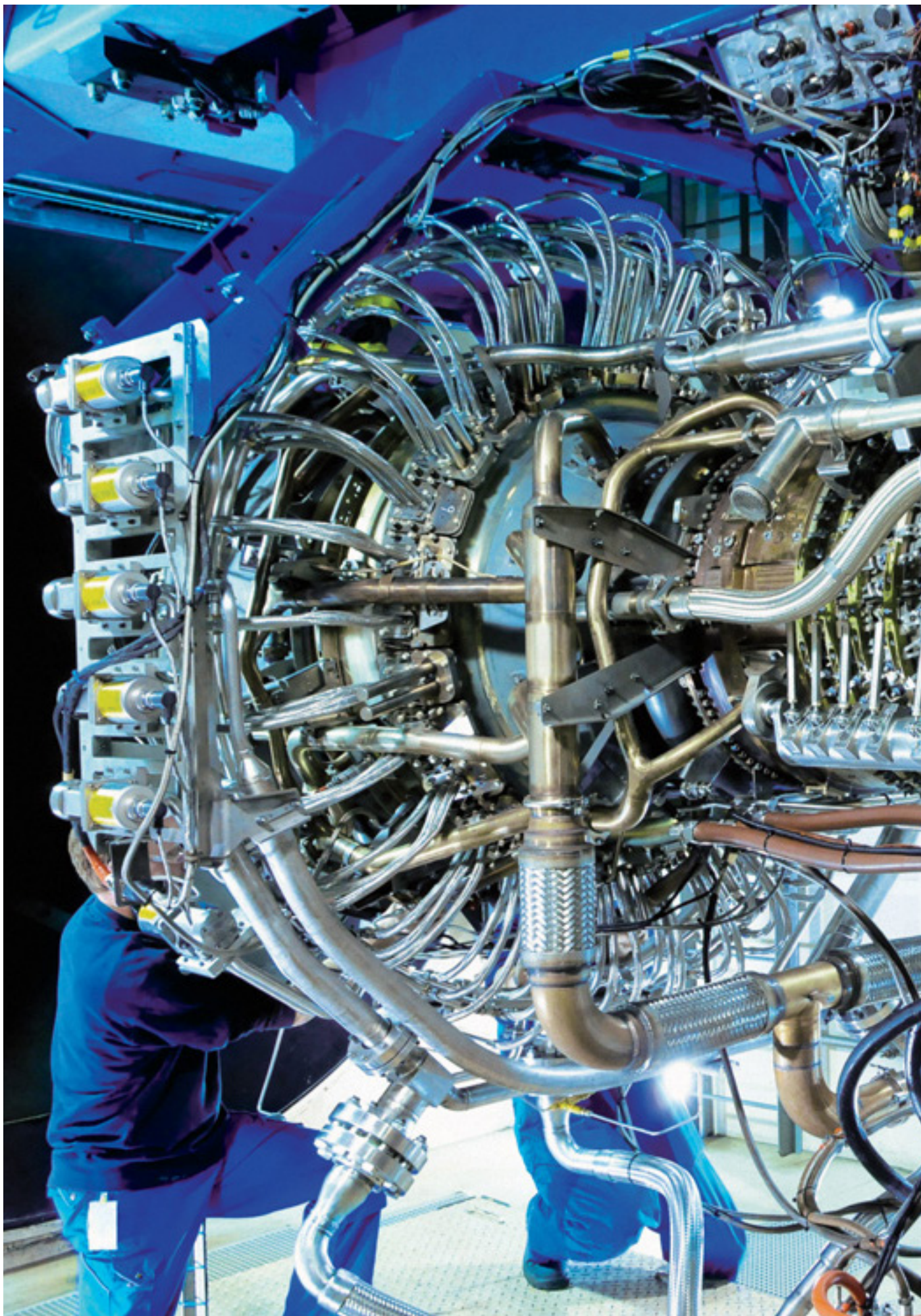
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A GE aeroderivative gas turbine, an LM2500, in assembly.



I. EXECUTIVE SUMMARY

A grand transformation is underway. A wave of decentralization is sweeping across the globe and changing the way we live, work and play. The organization of resources and people is moving away from centralized systems toward integrated networks that include both distributed and centralized elements. The trend is pervasive across society and the global economy. Telecommunications, computing, retail, and entertainment have all moved toward decentralization. Today, we are at the beginning stages of decentralization in higher education, healthcare and energy. The decentralization movement has the potential to enable unprecedented productivity gains and improve living standards for all.

Electric power systems are riding the wave of decentralization through the deployment and use of “distributed power” technologies. Distributed power technologies, which have been around since Thomas Edison built the first power plant in 1882, are used more and more today to provide electrical and mechanical power at or near the point of use. When deployed, distributed power technologies create a decentralized power system within which distributed generators meet local power demand throughout the network.

The portfolio of distributed power technologies includes diesel and gas reciprocating engines, gas turbines, fuel cells, solar panels and small wind turbines. Although there is no standard definition, distributed power technologies are less than 100 megawatts (MW) in size—and typically less than 50 MW which is the limit that distribution systems can accommodate at distribution voltages. They are highly flexible and suitable across a range of applications including electric power, mechanical power and propulsion. Distributed power technologies can stand alone, or they can work together within a network of integrated technologies to meet the needs of both large and small energy users.

The rise of distributed power is being driven by the same forces that are propelling the broader decentralization movement: distributed power technologies are more widely available, smaller, more efficient and less costly today than they were just a decade ago. But the rise of distributed power is also being driven by the ability of distributed power systems to overcome the constraints that typically inhibit the development of large capital projects and transmission and distribution (T&D) lines. Because they are small, they have lower capital requirements and can be built

“Distributed power technologies are more widely available, smaller, more efficient and less costly today than they were just a decade ago.”



and become operational faster and with less risk than large power plants. In addition, distributed power systems can be incrementally added to meet growing energy needs. Furthermore, some distributed power technologies are being propelled by the “Age of Gas,” an era of more widely available natural gas enabled by the growth of unconventional natural gas production, as well as the expansion of land and seaborne gas networks. Greater gas abundance creates opportunities for gas-fired distributed power systems. The emergence of virtual pipelines—a collection of technologies designed to move natural gas from the end of the pipeline to remote uses—have the potential to amplify the Age of Gas and make gas-fired distributed power technologies even more ubiquitous.

Taken together, the net result is an increase in distributed power investment and capacity installations that is expected to continue over the next decade. In 2012, \$150 billion was invested in distributed power technologies including gas turbines, reciprocating engines and solar PV in electric, power, mechanical drive and propulsion applications globally. Approximately 142 GW of distributed power capacity was ordered and installed. During the same year, GE estimates that 218 GW of central power capacity was ordered. This means that distributed power capacity additions accounted for about 39 percent of total global capacity additions.

By 2020 distributed power will play an even larger role. GE estimates that annual distributed power capacity additions will grow from 142 GW in 2012 to 200 GW in 2020. That’s a 58 GW increase and represents an average annual growth rate of 4.4 percent. During this period, investment in distributed power technologies will rise from \$150 billion to \$206 billion. As a point of reference, during this same period, global electricity consumption will rise from 20.8 to 26.9 terrawatt-hours (TWh). This represents an average annual growth rate of 3.3 percent. Thus, through the end of the decade, distributed power capacity additions will grow at a rate that is nearly 40 percent faster than global power demand.

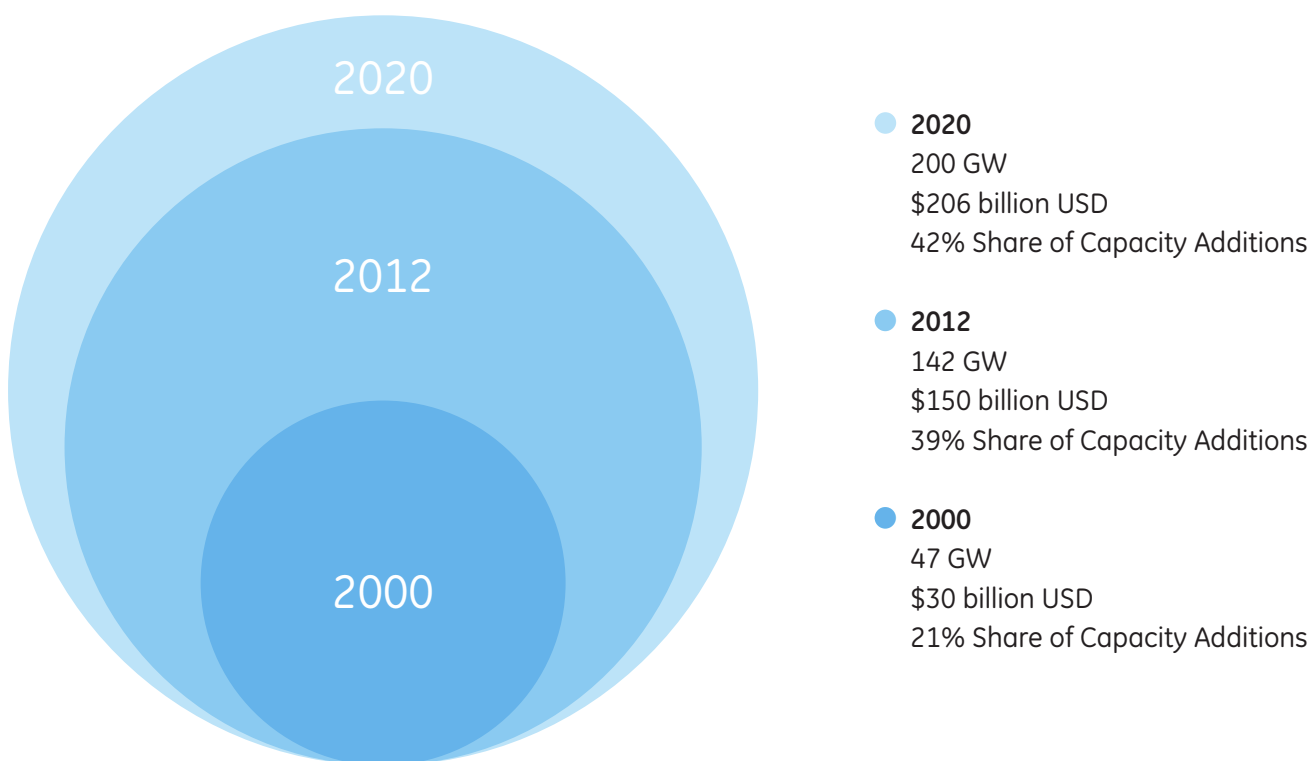
Distributed power capacity additions include gas turbines, reciprocating engines and solar photovoltaic projects less than 100 MW in size. Central power capacity additions include all power plants greater than 100 MW. Note that 60 percent of distributed power additions are used in power applications. One-third of these are back-up generators.

The proliferation of distributed power systems will benefit nations, industries and people around the world because power use is critical to human and economic development. Research has shown that increasing electricity use is positively correlated with advances in income, education and health.¹ This is particularly true in developing countries such as China, India and Brazil that have lower per capita income levels; and this is where the demand for distributed power is the greatest today.



Figure 1. Distributed power growth

Global distributed power installations and investment are on the rise. By 2020, \$206 billion will be invested annually. Distributed power applications will account for 42 percent of global capacity additions.



Source: General Electric, Diesel & Gas Turbine Worldwide, European Photovoltaic Industry Association.

These trends tell us that the re-emergence of distributed power is a transformative event that promises to positively impact the future. At GE, we are proud to play a role in realizing the potential of distributed power and humbled by the opportunity to help usher in a new energy landscape, just as we did in 1882 when Thomas Edison built the world's first power plant. The latest transformation has just begun and the best is yet to come.



The municipal utility in Rosenheim, Germany counts on a Jenbacher J920 FleXtra cogeneration plant to provide high efficiency heat and power to the citizens.



II. THE DISTRIBUTED POWER TRANSFORMATION

A grand transformation is underway. A wave of decentralization is sweeping across global industries and changing the way we live, work and play. The organization of resources and people is moving away from centralized systems toward integrated networks that include both distributed and centralized elements. The world is undergoing a process of decentralization that is impacting all facets of life.

Technology innovation is the driving force behind this megatrend. Improvements in computing power and telecommunications technologies are enabling machine intelligence and networking to shrink the geographic divide between distributed people and machines. Technology is improving equipment and making it smaller, bridging the space between connected people, places and things. The process of decentralization is creating new demand for smaller, customized and more capable and connected products and services.

A steady drumbeat of improvements in the methods, materials and devices used to develop industrial machines has resulted in more reliable, efficient and flexible machines. Today's jet engines, power plants and locomotives are all more efficient, less costly and smaller than their predecessors. Decades of cumulative learning are bearing fruit and making it possible to economically deploy a network of distributed devices in lieu of centralized machines.

People and processes are also poised for decentralization. The IT revolution and the subsequent emergence of the Internet — itself a distributed network — have enabled organizations to decentralize in order to get closer to customers and react more quickly to local conditions. This has given rise to distributed workforces within flattened organizations. The workforce is also more adept at leveraging IT and telecommunications technologies to work with colleagues and customers across the globe.

“The world is undergoing a process of decentralization that is impacting all facets of life.”



Distributed Power in a Decentralizing World

Electric power systems are riding the wave of decentralization through the deployment and use of distributed power technologies. Originally established when Thomas Edison built the first power plant in 1882, distributed power technologies are used more and more today to provide electrical and mechanical power at or near the point of use. When deployed, distributed power technologies create a decentralized power system within which distributed generators meet local power demand through the network. This stands in contrast to central power plants, which provide energy to the entire power network via transmission lines from a single centralized location.

The current suite of distributed power technologies includes natural gas and diesel-powered reciprocating engines, gas turbines, fuel cells, solar panels and wind turbines. Distributed power technologies are less than 100 megawatts (MW) in size. They are highly flexible and suitable across a range of applications including electric power, mechanical power and propulsion. These technologies are configured and customized to meet specific customer needs including the provision of electricity, heat, steam, propulsion or mechanical power.

There are a wide range of uses and configurations for distributed power technologies. For example, they can be used either as mobile devices, as they are in marine applications, or stationary devices, as they are in electric applications. Distributed power systems can generate electricity in isolation, or they can produce combined heat and power (CHP). They can be used to provide continuous, intermittent, peak or even back-up power. Distributed power systems may be connected to the grid or off-grid. Some distributed power systems send excess electricity back into the grid; others are used exclusively for on-site energy needs.

The rise of distributed power is being driven by the same forces that are propelling the broader decentralization movement: distributed power technologies are more widely available, smaller, more efficient and less costly today than they were just a decade ago. But the rise of distributed

What is Distributed Power?

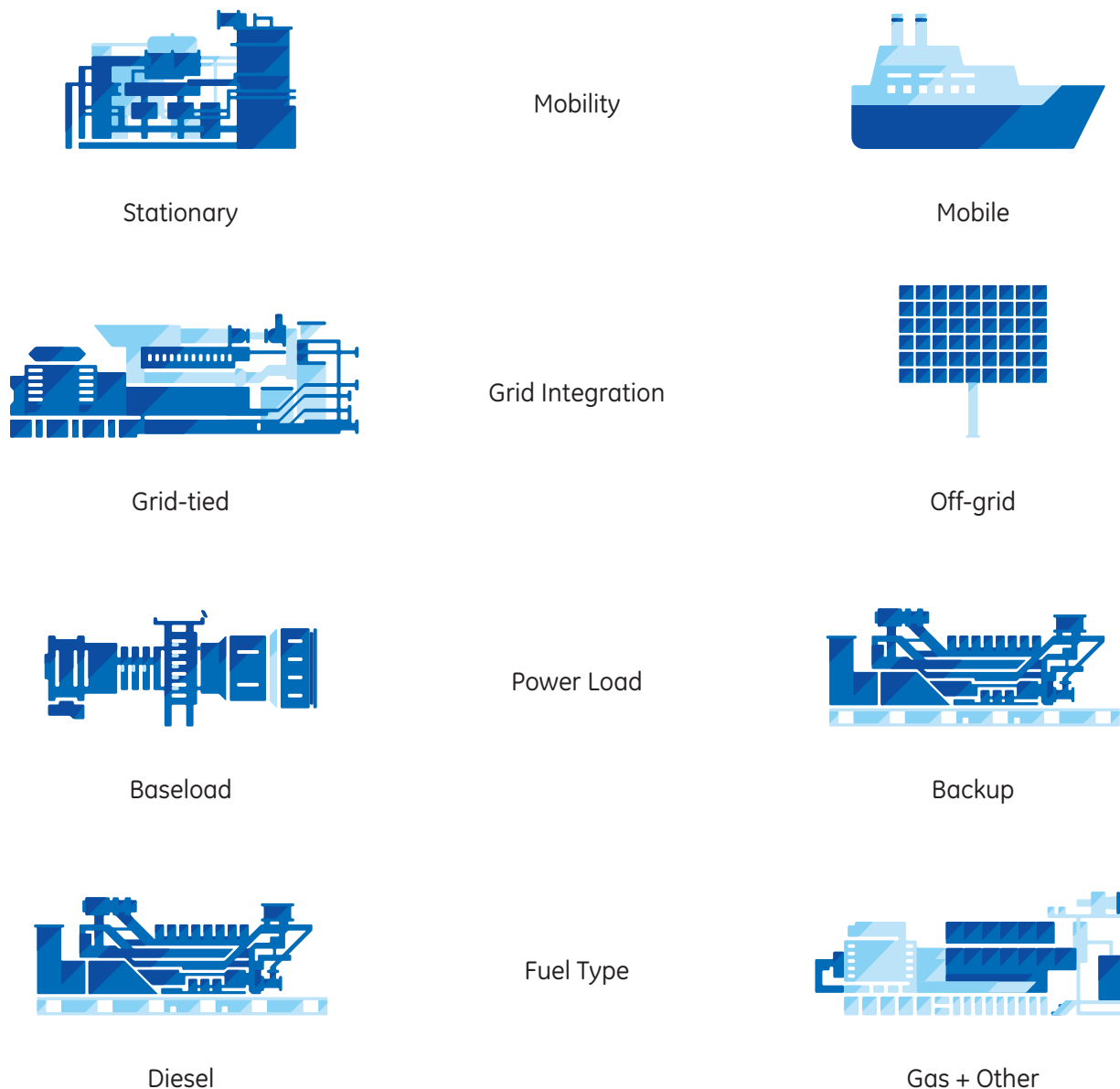
Distributed power is power generated at or near the point of use. This includes technologies that supply both electric power and mechanical power, which provide torque to move liquids (such as oil) and objects (such as boats and trains). Distributed power technologies can be stationary (typical of electrical applications) or mobile (as in marine and locomotive applications). The potential output of a distributed power system can be measured in terms of its horsepower (hp) or electrical capacity (kilowatts or megawatts). Although there is no standard definition, distributed power systems are less than 100 megawatts.

In electrical applications, distributed power systems stand in contrast to central power stations that supply electricity from a centralized location, often far from users. Electricity from central power stations is transmitted via transmission and distribution lines to end-users. Central power systems do not supply mechanical power and are always stationary and land-based.



Figure 2. Distributed power applications

There are a wide range of uses and configurations for distributed power technologies.



Source: General Electric.

power is also being driven by the ability of these systems to overcome the constraints that typically inhibit the development of large capital projects and transmission and distribution (T&D) lines. Because they are small, they have lower capital requirements and can be built faster and with less risk than large power plants. In addition, distributed power systems can be incrementally added to meet growing energy needs.



Furthermore, some distributed power technologies are being propelled by the “Age of Gas,” an era of more widely available natural gas enabled by the growth of unconventional natural gas production, as well as the expansion of land and seaborne gas networks. Greater gas abundance creates opportunities for gas-fired distributed power systems. The emergence of virtual pipelines—a collection of technologies designed to move natural gas from the end of the pipeline to remote uses—have the potential to amplify the Age of Gas and make gas-fired distributed power technologies even more ubiquitous.

To be clear, even though the drivers for distributed power are strong today, this growing trend does not spell the end of central power stations. A variety of forces, such as increasing urbanization and continued economies of scale, are creating a sustained need for central power stations in many locations. Thus, the rise of distributed power is occurring against the backdrop of a continuation of centralized power development. This is leading to a new era in which central power stations will co-exist with growing distributed power technologies. In this emerging landscape, central power stations and distributed power systems will be integrated in order to provide a range of services that couldn’t be provided by either alone.

“Central power stations and distributed power systems will be increasingly integrated in order to provide a range of services that couldn’t be provided by either alone.”

The History of Distributed Power

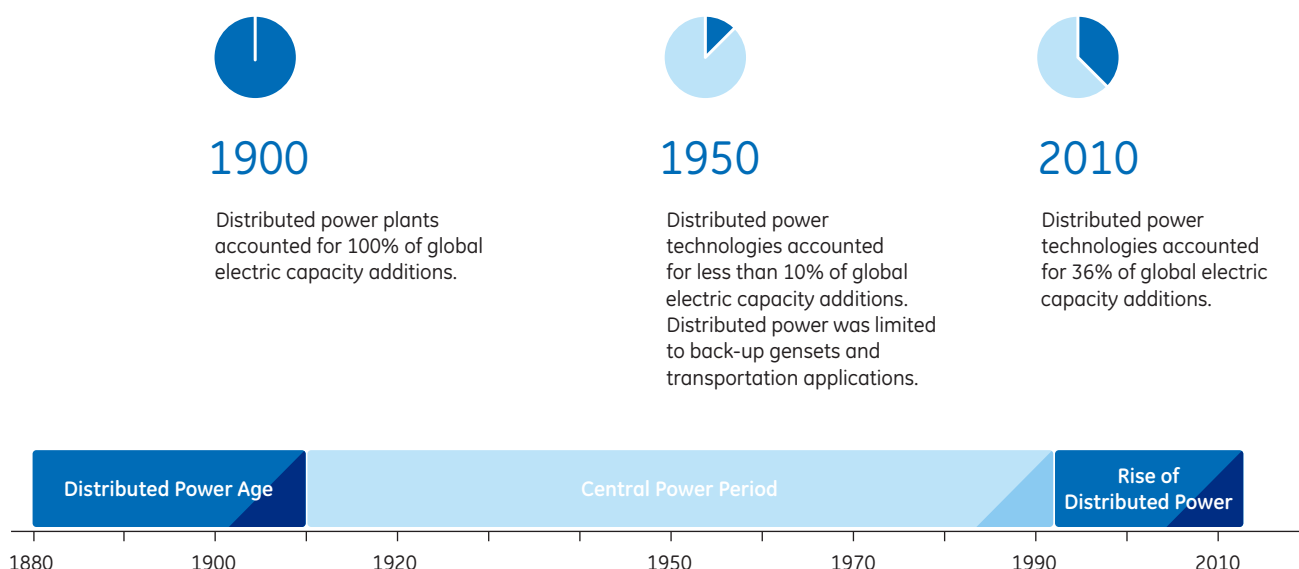
Distributed power technologies are not new. Before the development of large-scale power plants in the early twentieth century, all energy requirements—including heating, cooling, lighting, mechanical and electric power—were supplied at or near the point of use. Technology advances, economies of scale and a regulatory framework that supported central power enabled the growth of large power plants.

The first power plant, Thomas Edison’s Pearl Street Station, began supplying power in September 1882 in New York City. Edison’s reciprocating engines at Pearl Street were steam engines, a technology developed by James Watt 100 years before for mechanical drive use. The internal combustion engine wasn’t invented until after Pearl Street. Pearl Street was a direct current (DC) distributed power system that served the needs of nearby customers, like all of the early power plants built by Thomas Edison’s company, Edison General Electric. General Electric was formed through a merger of Edison General Electric and Thomson-Houston Electric Company in 1892.



Figure 3. Distributed power history

Thomas Edison's first power plant was a small reciprocating engine. Distributed power is making a comeback in the twenty-first century.



1882

Thomas Edison's Pearl Street Station distributed power plant began supplying power in New York City.

1893

Rudolf Diesel develops the Diesel engine.



1900–1950

GE placed its first steam turbine into operation in 1901. By 1902, GE offered turbines with rated capacities of 500, 1,500 and 5,000 kW. By 1913, the largest generator in the United States was 35 MW. By 1922, 175 MW power plants were being constructed.



1950–1960s

In 1957, Jenbacher began producing gas engines. In 1959, GE introduced its first aeroderivative gas turbines that were derivative of GE's J79 and C6 aircraft engines.



1994–2012

Jenbacher begins focusing on ultra-high efficiency engines. The newest gas engine delivers up to 9.5 MW with an electrical efficiency of 48.7% and a CHP efficiency of over 90%.



2010

GE's aeroderivative portfolio includes turbines with power output from 18 to 100 MW with thermal efficiencies over 40%.



Source: General Electric.



Further advances in alternating current (AC) technology would be required before larger power plants could be built and the electrical output could be distributed to far-flung customers over high-voltage transmission lines.

The Pearl Street Station was composed of six reciprocating engines, each connected to a 12 kilowatt (kW) generator to yield a total capacity of 72 kW. After the Pearl Street Station, the amount of electricity that could be produced by a single power plant grew quickly. The development of ever larger power plants was facilitated by Charles Curtis's steam turbine. Mr. Curtis presented the concept of a generator driven by a steam turbine to GE management in 1896. By 1897, he was directing steam turbine development for GE.

The movement to central station power plants started in earnest in 1891, when George Westinghouse assembled the first AC system in Telluride, Colorado. The AC system enabled the transmission of power over long distances. This resulted in the development of ever-larger power plants with increasing economies of scale. Lower power production costs were realized in the process. By 1922, 175 MW power plants were being constructed. The era of central station power was underway, and distributed power technologies were consigned to providing back-up and remote power.

Three Phases of Power System Evolution

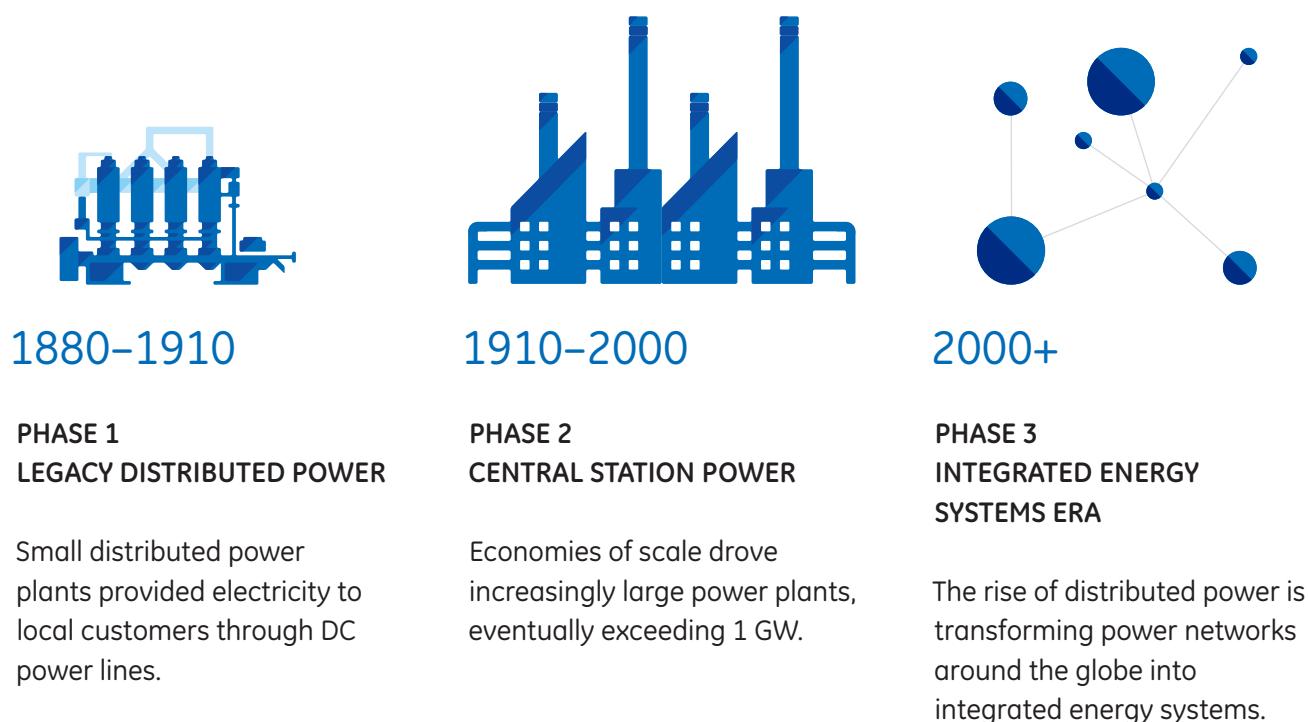
As the centerpiece of the central station model, steam turbines experienced a high degree of innovation. Between 1903 and 1907, GE alone obtained 49 steam turbine-related patents. Fourteen of these led to improvements in steam turbine performance.² These technology innovations cemented the movement to central power plants at the turn of the twentieth century.

But technology change is constant. Today, technology advances have enabled the development of a new breed of distributed power technologies that have the ability to rival the cost and performance of central station power plants, but in a much smaller package. Just as important, today's distributed power technologies now enable control and customization to occur either on-site or remotely. Thus, the operation of distributed power technologies can be synchronized within the context of a broader integrated energy system that is composed of both distributed and central power plants.



Figure 4. Three phases of power system evolution

The re-emergence of distributed power represents the third phase of power system evolution. Twenty-first century power systems will be a hybrid of central and distributed generation.



Source: General Electric.

The global power system unfolded in three eras: the Legacy Distributed Power Era (1890–1910), the Central Power Era (1910–2000) and the Integrated Energy Systems Era (2000–present). Unlike previous eras, where either distributed or central power systems dominated the landscape, today's Integrated Energy Systems era is characterized by a combination of central station and distributed power systems that can operate in isolation or together within increasingly integrated energy networks. The expansion of distributed power technologies ushers in a new energy landscape where technologies work in tandem to provide a range of services that couldn't be provided by either central station or distributed technologies in isolation.

The Incremental Revolution

The recent emergence of highly flexible, efficient, environmentally sensitive and economically attractive distributed power technologies is one of the sources behind the rise of distributed power today. It is the result of a gradual technology evolution that has played out over the last half



century. Incremental technology improvements across the range of distributed power technologies have combined to alter the economic appeal of distributed power vis-à-vis central station power plants. The cumulative effect of these incremental improvements is having a revolutionary impact on global power systems.

The emergence of aeroderivative gas turbines is emblematic of the innovations that have fueled the recent rise of distributed power systems. After having specialized in jet engines for over a decade, GE introduced its first aeroderivative gas turbine, the CF6, for hydrofoil vessels in 1959. CF6 was a derivative of GE's J79 and C6 jet engines.

Since the introduction of its aeroderivative product line in 1959, GE has progressively refined the technology to improve performance and flexibility. In 1985, GE's aeroderivative CF6 line had a maximum power output of 35 MW. Today, the CF6's descendants offer output in the 60 MW range with efficiencies higher than 40 percent and reliabilities approaching 97 percent. Today, GE aeroderivatives are the world's leading technology for industrial power use. More than 3,600 turbines have been produced, logging more than 100 million operating hours.

Reciprocating engines have followed the same path as aeroderivatives. Reciprocating engines have been commercially available since the late nineteenth century. After the emergence of large central station power plants in the first decade of the twentieth century, reciprocating engines were used primarily in automobiles and as a backup and remote power source throughout the first half of the twentieth century. However, incremental innovations over the last 50 years have resulted in the development of flexible, high performance and low emissions gas and diesel engines across a range of applications including power, marine and mechanical drive.

GE's Waukesha and Jenbacher engines provide a good example of incremental innovation in action. Jenbacher traces its roots to a smelting works founded by Jakob Fugger in 1487. This same operation installed a blast furnace in 1774. By 1842, the plant was producing blowers, cutting and drilling tools, line shafts and large mills. In 1947, diesel engines were added to the production line. Shortly after the addition of diesel engines, Jenbacher began producing gas engines. The first gas engine left the plant in Jenbach, Austria in 1957.

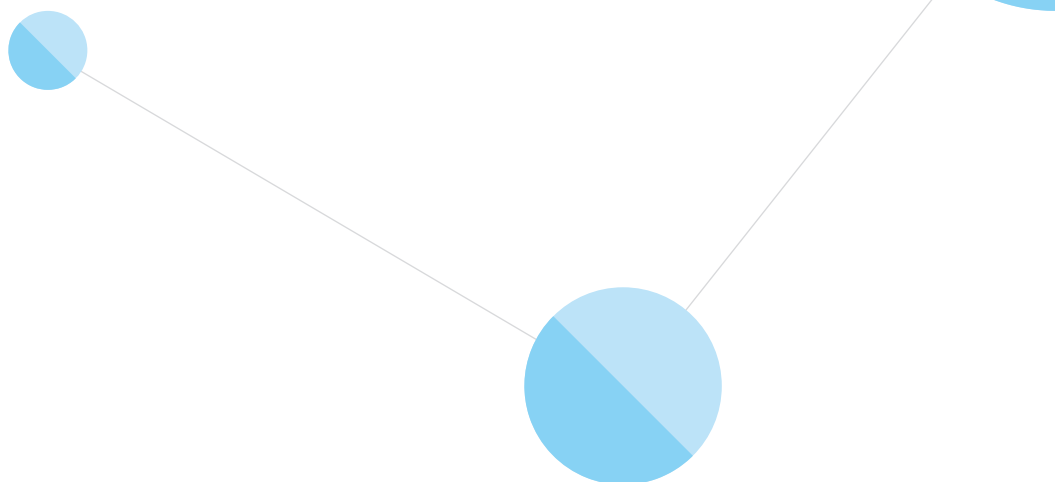
"After 50 years of continuous innovation, distributed power is now an efficient and cost-effective solution in many applications around the world."



The Type 6 gas engine was introduced in 1988 with 12-and 16-cylinder versions. Ten years later, a 20-cylinder version with an electrical output of 2.8 MW was introduced. The 20-cylinder Type 6 engine was the first high-speed gas engine and the smallest package in the 3 MW output range. Since then, this engine family has continuously evolved, including creation of the F-version, which can be used in a variety of environmental conditions.

In 2007, Jenbacher introduced the world's first 24-cylinder gas engine. In 2010, Jenbacher introduced the J920 FleXtra gas engine, GE's first gas engine in the power range of 10 MW, and the Jenbacher J624 gas engine, the world's first gas engine with two-stage turbocharging.

GE's continuous engine technology innovations have created cost efficiencies that have compounded over time. Today, these advances have accumulated to the point where GE's engines are now a cost-effective solution in both grid and off-grid applications around the world. Indeed, distributed power technologies have crossed the threshold and entered a new era of competitiveness. The new competitiveness of distributed power technologies has transformed the calculus of decision-makers who now must weigh the benefits and costs of both central power and distributed power technologies in assessing new power needs. After 50 years of continuous innovation, distributed power is now an efficient and cost-effective solution in many applications around the world.





To sustain fuel networks, pipelines move natural gas with power generated onsite by distributed power turbines and engines, including Waukesha gas engines.



III. THE DRIVING FORCES OF DISTRIBUTED POWER

In addition to technology innovations that have improved the performance and cost of distributed power technologies, a variety of other forces are driving the distributed power transformation. These forces include: 1) the growth of natural gas networks; 2) constraints that inhibit the construction of transmission networks; 3) the growth of digital technologies and the emerging Industrial Internet; and 4) the rising tide of natural disasters. Each of these forces is playing a unique and important role in advancing distributed power across the globe and accelerating the decentralization megatrend.

The Age of Gas

As discussed in a recent GE report, natural gas is poised to capture a larger share of the world's energy demand.³ The first commercialized natural gas use occurred in Britain. Around 1785, the British used natural gas produced from coal to light houses and streets. In 1816, Baltimore, Maryland used this type of manufactured natural gas to become the first city in the United States to light its streets with gas.⁴ What is new and changing today is the role of this unique resource in the global energy mix. Natural gas is shifting from a regional and often marginal fuel to becoming a focal point of the global energy landscape as it catches up and competes head-to-head with oil and coal, and complements wind and other renewable energy sources.

Gas growth is accelerating, in part, because the networks that underpin the connection between supply and demand are becoming more diverse as they expand around the world. Gas network growth, coupled with technology innovation, is contributing to creating greater network density, greater flexibility, and improved economics. As a result, the world is now entering an Age of Gas.

The role of distributed power within the energy system is inextricably linked to its place within fuel distribution and electricity transmission and distribution (T&D) networks. Distributed power technologies require fuel to operate. This means that in order to consider distributed power as an option in a particular application, fueling networks must be available to deliver the feedstock. The presence of diesel fuel supply networks around the world has long made diesel engines the technology of choice for mobile and stationary off-grid power applications. Diesel fuel



supply networks — essentially trucks and road systems — are comprised of well-established technologies and do not require large fuel-specific capital investments. These factors continue to make diesel engines the most attractive option in distributed power applications around the world.

However, natural gas-fired distributed power technologies will be one of the most prominent beneficiaries of the emerging Age of Gas. In many locations, the current availability of traditional diesel supply systems coupled with the emerging and expected availability of natural gas supply infrastructure, encourages the adoption of dual fuel distributed power technologies. Dual fuel distributed power systems have the ability to operate on diesel, natural gas, or blended combinations of these fuels. Dual fuel technologies provide owners with the ability to operate on the best available fuel today and transition to natural gas as it becomes increasingly available over time.

Furthermore, leveraging domestic natural gas sources to generate distributed power provides additional benefits. Leveraging stranded gas enables stable domestic power prices, improves current account balances, creates local jobs and brings power to remote areas. Indeed, the rise of distributed power and the Age of Gas is a powerful combination for enriching nations, industries and people around the world.

The Trouble with Transmission

In advanced economies in North America and Europe, the power system is well developed. However, further T&D growth is often inhibited by a range of barriers including long, complicated planning processes and local resistance to transmission line siting. This creates favorable conditions for distributed power as an alternative to new T&D development. Alternatively, in many emerging economies with less developed or non-existent T&D networks, distributed power provides a realistic route for meeting critical energy needs in the absence of T&D infrastructure.

In the United States, T&D networks are one part of the most capital intensive industries in the country. According to the Edison Electric Institute (EEI), in 2012, electric utilities invested \$90.5 billion in generation, transmission, and distribution systems and approximately \$20 billion on transmission alone.⁵ Compared to other assets, transmission investments are often riskier and require long lead times for the planning process and stakeholder involvement.



Transmission challenges are not limited to the United States. The European transmission system is also facing limitations and constraints. There is a need for more transmission capacity in many regions of Europe, but investment is difficult and characterized by public opposition and complicated regulation. Many transmission projects are delayed or canceled.⁶

In 2006, the association of European Transmission System Operators indicated that “in some countries not a single overhead power line exceeding five kilometers has been built in the last 10 years.” While transmission investments are developing very slowly, the need for transmission is increasing.⁷ The International Energy Agency (IEA) has estimated that \$187 billion of transmission investments are required in Europe through 2030.⁸ In this context, despite the cost advantage of central power plants, distributed power technologies become an increasingly viable option versus further expansion of the T&D network.

In developing economies such as China and India, the transmission challenge is not focused on the expansion of existing infrastructure, but the development of a whole new T&D system at a pace that meets the rapid rate of electricity demand growth. Here, distributed power can provide electricity to remote areas where there is no T&D network.

In India, there is a lack of T&D infrastructure. Distributed power, especially in rural areas, can provide reliable supply of electricity to improve delivery of basic social needs. It can play an indirect but critical role in preparing a balanced and solid 21st century workforce. Distributed power technologies provide a means to expand electricity production quickly without being constrained by T&D system limitations. For the developing world, distributed power means that electricity can be produced and delivered more quickly in order to meet critical living needs.

Another challenge associated with transmission and distribution is electricity theft. This can take the form of meter tampering or illegal connections, and is most prevalent when central station power plants transmit electricity to distant customers. Electricity theft can be avoided altogether or dramatically reduced through the use of distributed power technologies, which are located at or near end-users. Electricity theft is a serious problem in many countries around the world, which can only be estimated and not measured directly. The most straightforward estimation approach is to examine T&D losses. According to the World Bank’s Development Indicators, average global

“For the developing world, distributed power means that electricity can be produced and delivered more quickly in order to meet critical living needs.”



electricity losses in 2011 were 12.5 percent.⁹ Developing countries like India (21.1 percent) and Brazil (16.5 percent) had loss rates well above the global average. Distributed power is one strategy for reducing electricity theft and lowering these rates.

The Digital Wave

The Digital Wave is the widespread penetration of information technology hardware, software and communications technologies into the business and social fabric of our lives. From the way we shop to the way we receive our news and run our business operations, all aspects of our lives have been enhanced by the Digital Wave in the last decade. Today, the Digital Wave is acting as an accelerant to the adoption of distributed power technologies around the world. The impact of the Digital Wave on the rise of distributed power will grow over time as each of these trends gains additional momentum.

Digital control systems currently embedded in distributed power technologies enable operators to remotely optimize operations and minimize costs in ways that were not possible a decade ago. Both hardware and software have grown more sophisticated to the point where distributed power systems can be controlled from a smartphone.

But that's not the whole story. The forthcoming marriage of the Internet and industrial machines promises to transform isolated distributed power technologies into remotely operated and synchronized fleets of virtual power plants with extended capabilities.

Tomorrow's Industrial Internet-enabled distributed power control systems will have extended capability beyond today's systems. They will provide operations decision support, such as how to run, start, shut-down, and bid power. This will create better investment decisions leading to better economic returns for investments. Additional capabilities will allow distributed power operators to self-install software upgrades and eliminate the risks and costs of downtime.

Beyond enhanced control and optimization of distributed power technologies, the Industrial Internet holds the promise to coordinate distributed power systems in ways that add further value to distributed power technologies at the system level. This extended capability has the potential to further tilt the landscape in favor of distributed power systems.



A virtual power plant (VPP) is a group of distributed power technologies that are aggregated and operated in unison by a centralized control system powered by the Industrial Internet. Centralized control and operation extend the capabilities of individual distributed power units by enabling groups of grid-connected plants to deliver electricity to the transmission network in unison, during periods of peak demand. A VPP could serve as a substitute to a single large power plant. Further, individual distributed power units would be more flexible and quicker to react to fluctuations in electricity demand. VPPs also have the potential to coordinate distributed power system operation with options related to electricity demand, such as demand response and other load-shifting approaches.

Today's distributed power digital control systems have already enabled operators to remotely monitor and control all aspects of power plant operation. This capability has enhanced the distributed power value proposition, and it is part of the driving force behind the rise of distributed power. However, this is only the tip of the iceberg. Tomorrow's control systems will open the door to an extended range of capabilities that will further enhance the attractiveness of distributed power. VPPs will enable a fleet of distributed power systems to operate in a coordinated manner to facilitate fleet-wide optimization. VPPs will serve as a virtual complement to large central power plants by providing both electricity supply and coordinating demand-side options. Together, the Digital Wave and the Industrial Internet will propel distributed power to new heights.

“Tomorrow's control systems will open the door to an extended range of capabilities that will further enhance the attractiveness of distributed power.”

Resiliency¹⁰

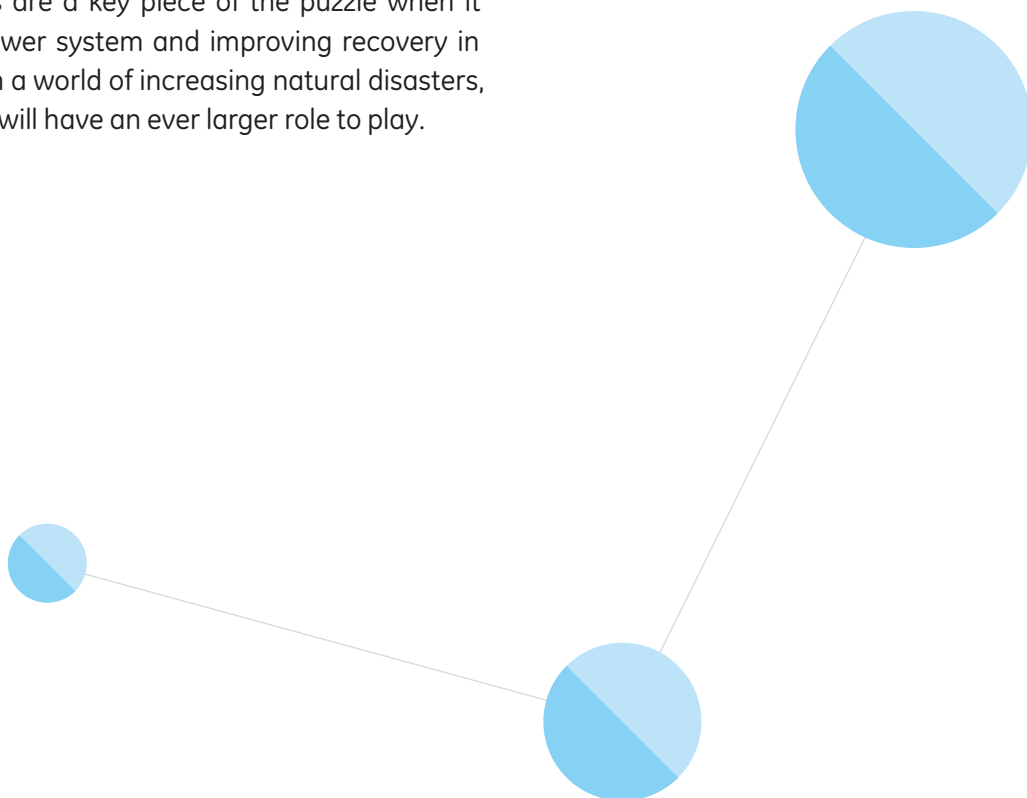
As the world grows increasingly interconnected, the infrastructure networks that deliver electricity, gas, and water to our cities have never been more important. They are also more vulnerable to a variety of natural disasters. In 2012, there were 905 natural disasters including earthquakes, severe storms, tornados, droughts, and floods, that affected 106 million people and caused economic losses estimated at \$160 billion. Hurricane Sandy formed in the Atlantic and was second only to Hurricane Katrina in destructiveness. Sandy alone is estimated to have caused \$65 billion in storm-related damages, leaving over 8.5 million customers without power, some for weeks, and disrupting fuel delivery, transportation, communications and other critical systems.¹¹



Making the power system more resilient to natural disasters is critical to protecting customers and significantly reducing the magnitude of outages, human suffering, and economic costs. Two approaches for improving power system resiliency are supporting infrastructure and providing fast recovery. Distributed power technologies are well-suited to provide both of these services, making them the right technologies to improve resiliency in the face of increasing natural disasters.

When natural disasters occur and electricity generation assets are impacted, the fastest way to achieve power recovery is to utilize a fleet of mobile, trailer-mounted distributed power technologies. This solution uses proven technologies that can readily connect to and provide power for the grid. For example, after the Fukushima earthquake damaged transmission lines and impacted several central power plants, trailer-mounted gas turbines were used to restore power and prevent black-outs. There are additional advantages to using natural gas reciprocating engines or gas turbines in these circumstances. Gas-powered mobile distributed power technologies can be connected to the existing natural gas pipeline system to avoid diesel fuel supply issues which occur in any natural disasters.

Distributed power technologies are a key piece of the puzzle when it comes to strengthening the power system and improving recovery in the wake of natural disasters. In a world of increasing natural disasters, distributed power technologies will have an ever larger role to play.





Houweling's Tomatoes is operating the first CHP greenhouse project in the U.S. with a pair of Jenbacher J624 two-stage gas engines from GE.



IV. DISTRIBUTED POWER OUTLOOK

Over the last decade, distributed power has been on the ascent. In 2000, \$30 billion was invested globally in distributed power installations, and distributed power capacity was being added at a rate of 47 GW per year. Central power capacity was being added a rate of 180 GW per year. That means that distributed power's share of global capacity additions was 21 percent. Distributed power occupied a niche role within the broader market for electric power, mechanical drive and propulsion capacity investment and additions.

Fast forward to 2012. Distributed power's share of global capacity additions nearly doubled from 21 percent to 39 percent. Investment in distributed power increased five-fold from \$30 to \$150 billion and annual distributed power capacity additions grew by 300 percent from 47 to 142 GW per year.

The distributed power growth trend is expected to continue. By 2020 distributed power will play an even larger role. GE estimates that distributed power capacity additions will grow from 142 GW per year in 2012 to 200 GW per year in 2020. That's a 58 GW per year increase and represents an average annual growth rate of 4.4 percent. Investment in distributed power technologies will jump from \$150 billion to \$205 billion.

Installations of central power capacity will also increase between 2012 and 2020. GE estimates that central power additions will grow from 218 GW in 2012 to 272 GW in 2020. That's a 54 GW per year increase and represents an average annual growth rate of 2.8 percent. During this period, distributed power's share of global capacity additions will increase from 39 percent in 2012 to 42 percent in 2020.

As a point of reference, during this same period, global electricity consumption will rise from 20.8 to 26.9 TWh. This represents an average annual growth rate of 3.3 percent. Thus, through the end of the decade, distributed power capacity additions will grow at a rate that is nearly 40 percent faster than global power demand.

It is important to note that distributed power's continued rise will probably not follow a steady path on an annual basis. Instead, distributed power will rise like a tide — ebbing and flowing as the underlying drivers strengthen and weaken over time.



Figure 5. Distributed power growth

Global distributed power installations and investment are on the rise. By 2020, \$206 billion will be invested annually in distributed power capacity, up from \$150 billion in 2012. Distributed power applications will account for 42 percent of global capacity additions by 2020, up from 39% in 2012.

	2000	2012	2020	2012–2020 Average Growth Rate (%)
Annual Central Power Additions (GW/year)	180	218	272	2.8%
Annual Distributed Power Additions (GW/year)	47	142	200	4.4%
Distributed Power Share of Annual Additions (%)	21%	39%	42%	
Distributed Power Investment (Billion USD)	\$30	\$150	\$205	4.0%

Source: General Electric.

One of the most important underlying forces will be the continued growth in global electricity consumption. Rising gross domestic product (GDP) and population levels will continue to push up electricity consumption levels over the next decade. GE estimates that global electricity consumption will grow from 20.8 terrawatt-hours (TWh) in 2012 to 26.9 TWh by 2020. This represents an average annual growth rate of 3.3 percent.

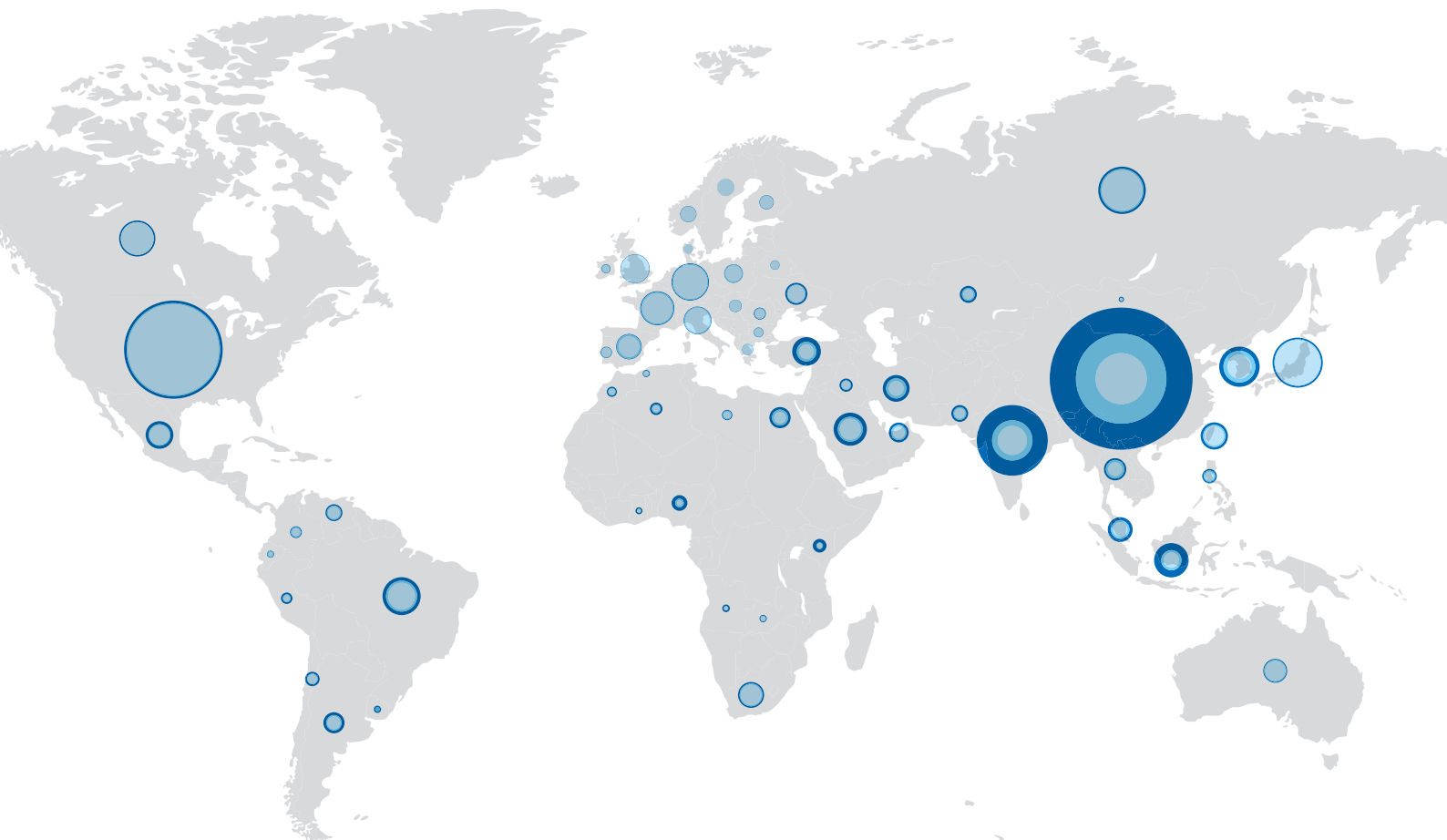
Consider the location of the growth in electricity consumption. If we examine electricity growth by country, we find that electricity consumption growth is occurring fastest in the emerging markets. The average annual growth rate for emerging markets between 2012 and 2020 is 4.7 percent, compared to 1.0 percent for developed economies. Higher rates of electricity consumption growth in developing countries are the result of increasing rates of energy intensity in these economies (i.e., energy is making a growing contribution to economic output) and more rapid electrification.

Between 2012 and 2020, nearly 90 percent of the growth in electricity consumption will occur in emerging markets. Asia is the epicenter of this growth, but large incremental growth can be found throughout the developing world. By 2020, 65 percent of global electricity consumption will be located in emerging markets, up from 57 percent today. These regions represent the greatest growth opportunity for distributed power technologies.



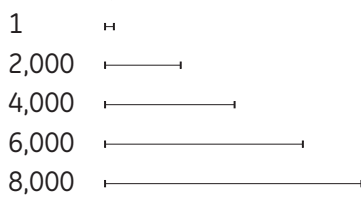
Figure 6. Electricity consumption growth

Electricity consumption is growing the fastest in Asia, Africa and the Middle East. These regions benefit from distributed power's ability to overcome barriers and deploy quickly.



- 2000
- 2010
- 2025

Electricity
Consumption (TWh)



Source: International Energy Administration (IEA), General Electric.



GE's trailer-mounted TM2500* aeroderivative gas turbines can be moved quickly and installed in days.

* Trademark of General Electric Company



V. BENEFITS OF DISTRIBUTED POWER

Small is Beautiful

The phrase “Small is Beautiful” is the title of a 1973 collection of essays from British economist E.F. Schumacher. Schumacher discussed the benefits of small, appropriate technologies, in contrast to increasingly large machines. The phrase is ideally suited to describe the core benefits of distributed power technologies today. Distributed power technologies provide a host of benefits that flow from their small size. These benefits make distributed power the appropriate technology choice in many circumstances today.

Distributed power technologies provide at least four distinct benefits due to their size:

- First, they can be installed quickly, often in a matter of days or weeks compared to years for central power stations. Rapid deployment is extremely useful in cases where there is unmet energy demand and supply must ramp up quickly. Quick build time is also useful when restoring power in the wake of natural disasters or within the context of chronically unreliable power systems.
- Second, due to their scalability, distributed power technologies require less money to buy, build and operate. In regions where capital is constrained, it is increasingly important to provide critical infrastructure such as electricity without having to raise hundreds of millions of dollars in capital to finance infrastructure projects. The capital simply isn’t available in many parts of the developing world to support large projects.
- Third, because of their small size, distributed power technologies enable energy providers to match the level of demand with the level of supply and to increase supplies incrementally as needed. Centralized power stations require large capital investment and are available in sizes that are often not appropriate for the required level of supply. Incremental distributed power development is the appropriate development path in many parts of the world today.



- Fourth, because distributed power technologies are sited at or near demand, this facilitates a local level of control, operations and maintenance that is not possible with central power stations. This enables system owners and operators to monitor and customize distributed power solutions to meet their specific needs.

The benefits of small, distributed power technologies are unmistakable and often provide both tangible and intangible reasons to support distributed power in lieu of, or in addition to, central power station development.

Electricity and Development

Energy is a fundamental element of economic development. The wealth that economic development brings stimulates demand for more and higher quality energy services. Many countries have created a virtuous circle of improvements in energy infrastructure and economic growth. However, today a large percentage of the world's growing population continues to live without energy. In the developing regions of the world, the process is just getting off the ground. Distributed power technologies have the potential to play a key role in jump-starting the virtuous cycle of energy growth and economic development.

The link between electricity and economic development has been established, and it has important implications for distributed power technologies.¹² As discussed in the previous section, significant barriers exist to the development of transmission and distribution projects. The barriers exist in both developed and developing economies. To the extent that distributed power technologies provide a means to circumvent these barriers and increase electricity production and delivery in the developing world, this will result in increased levels of electricity consumption and a rising level of economic and human development.

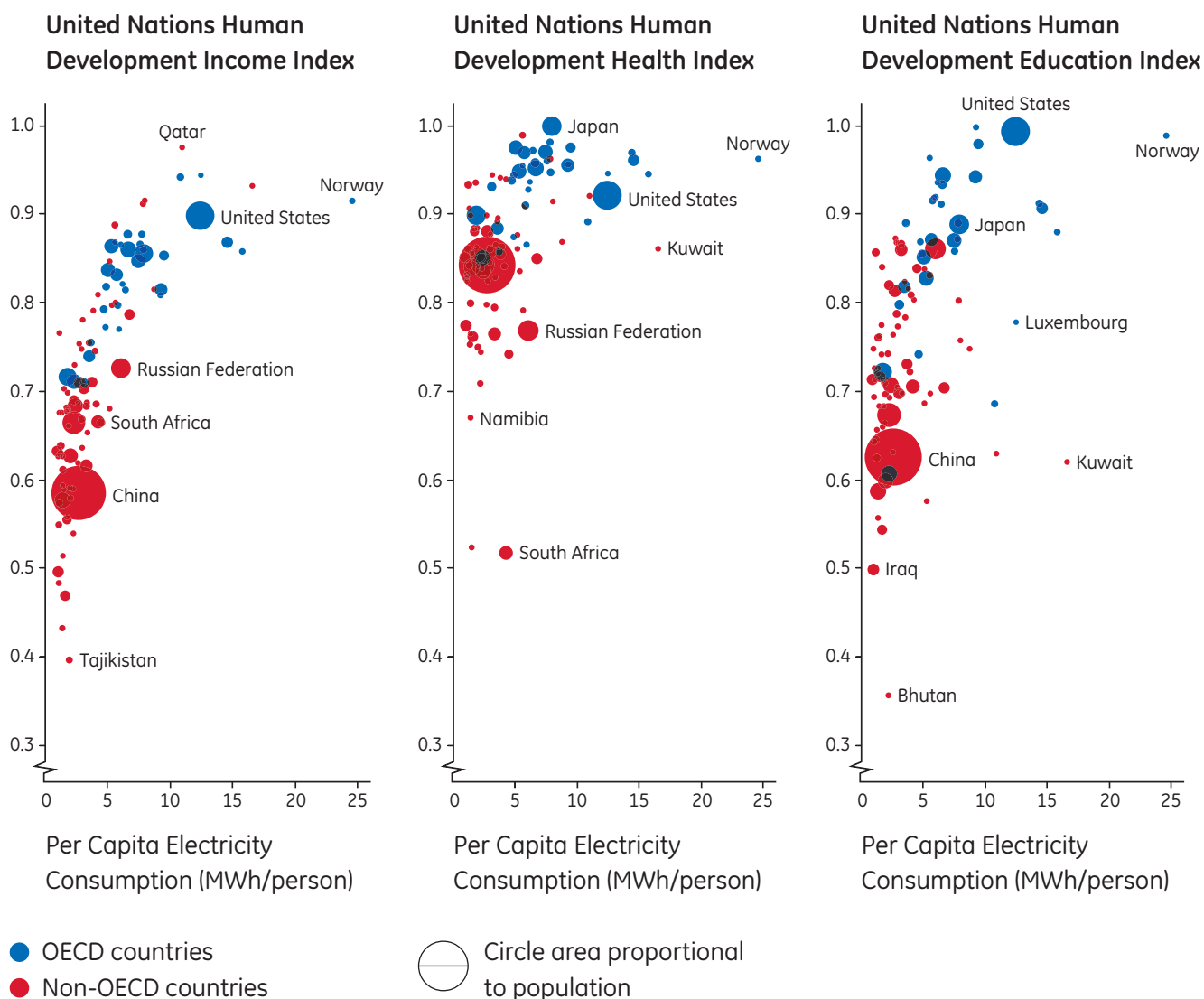
It is this role for distributed power—as a catalyst to development—that is most impactful and crucial for the lives of people and businesses around the world. In this manner, distributed power provides a critical link to emerging nations by building industries and improving lives. Distributed power's role as a catalyst to development is most impactful and critical for improving the lives of people around the world.

“Distributed power’s role as a catalyst to development is most impactful and critical for improving the lives of people around the world.”



Figure 7. Electricity and development

Income, health and education levels all rise with increasing electricity consumption. The increase is faster for developing countries.



Source: United Nations Development Programme Human Development Report 2013 and US Energy Information Administration.

Energy Efficiency and Environmental Benefits

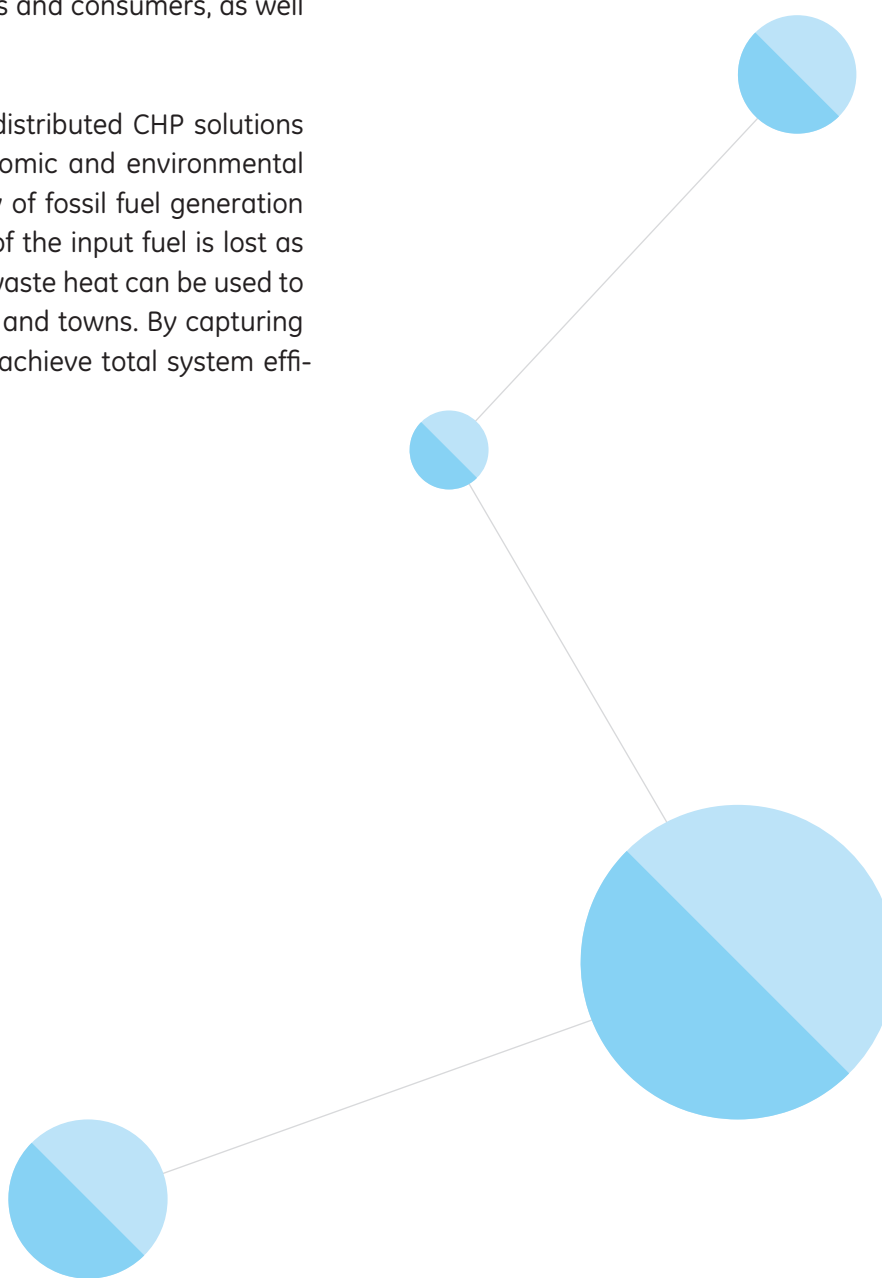
Distributed power technologies can provide a critical link between energy and human development in the rapidly growing developing world where more energy supplies are needed. However, in many developed economies, there is limited need for new energy supplies and therefore little incentive to deploy distributed power to meet growing power



needs. Here, distributed power is most useful as a method to improve efficiency and reduce the environmental footprint of the existing power system. Combined Heat and Power (CHP) and Waste Heat Recovery are two solutions for which distributed power technologies are well-suited.

CHP systems can have many different configurations and use a range of technologies, but at its core CHP is an efficient, integrated energy system that produces both electricity and heat. CHP systems capture the heat generated from electricity production and deliver it for thermal applications such as space heating and industrial processes. By converting thermal losses in electricity production to useful heat, CHP provides a variety of benefits to energy producers and consumers, as well as society as a whole.

Improving electricity supply efficiency using distributed CHP solutions has the potential to provide significant economic and environmental benefits. Consider that the average efficiency of fossil fuel generation is around 35–37 percent.¹³ About two-thirds of the input fuel is lost as waste heat in the process. Through CHP, this waste heat can be used to meet heat demand in homes, business, cities and towns. By capturing heat and putting it to use, CHP systems can achieve total system efficiencies of 90 percent.





VI. FIVE COUNTRIES THAT ILLUSTRATE THE POTENTIAL OF DISTRIBUTED POWER

China: China's distributed power push

Recent growth in distributed power in China has been strong. The Chinese government has advanced several policy initiatives designed to increase the share of distributed power in the country's energy system. By the end of 2012, the State Grid Corporation of China, the country's largest energy utility, connected 15,600 distributed power generation stations with a total installed capacity of 34 GW. According to the 12th Five-Year Plan (FYP) on Energy Development approved by the State Council in October 2012, by 2015, China aspires to have 1,000 distributed power projects fueled by natural gas, a solar power capacity of 10 GW, and 100 showcase cities that exhibit the use of distributed power.

China has traditionally used distributed heating systems with coal-fired boilers. New distributed power technologies that use natural gas and biogas can provide a more environmentally friendly alternative for heat and power generation. In the FYP, the Chinese government indicated that it will seek to increase the amount of energy generated by distributed renewable energy systems. The Chinese government wants to promote the use of gas-fired CHP.

As of March 1, 2013, the State Grid took specific steps to facilitate the use of distributed power generation by providing an incentive for households and companies to use it. Households and companies that use distributed power would be able to send excess power back into the grid and receive credit for power received by the grid. In order to qualify for the incentive, distributed power projects must be connected to the grid at 10 kV or less and the distributed power capacity cannot exceed 6 MW. The State Grid has not yet specified the price that on-site generators will receive for "net metering" their power. To further enhance the application of distributed power at the provincial level, the National Development and Reform Commission (NDRC) issued interim measures for the management of distributed power generation.



In addition to the role of distributed power in China's electric sector, distributed power technologies also have the potential to help transform China's oil and gas industry. As efforts accelerate to develop conventional and unconventional gas resources, distributed power technologies offer a ready-made solution to meet on-site power needs and provide solutions for unique oil and gas development challenges such as natural gas flaring.

Mexico: Distributed power and natural gas opportunities

Mexico provides an interesting example of how distributed power opportunities are emerging, anchored to larger natural gas projects. Mexico has the fourth largest underground shale reserves, with its geology similar to the U.S. At present, there are proposals to build 8,800 km of new gas pipelines across the country. Most of the projects are targeting low-cost US shale gas as supply sources and will often be used to displace the use of heavy fuel oil in centralized power generation. As a side benefit, these investments have the potential to expand the availability of gas-fired power. New pipelines will improve gas access to over 280 cities and towns across the country. It also has the potential to significantly reduce the cost of energy to these communities. In parallel, state-owned companies such as Pemex are investing resources and opening US subsidiaries (or operations) to tap into American shale gas resources. These investments are targeted to speed up the learning curve in complex drilling techniques for the energy giant. Currently, Mexico is a net importer of gas. These energy reforms are planned to eventually make the country a competitive producer of abundant domestic natural gas.

Today, the commercial rate of electricity is \$0.20 per kWh. Electricity for industrial consumers is \$0.12 per kWh. The Federal Electricity Commission (CFE) is the sole public power utility in the country. However, Mexico does allow CHP and renewables with various payment structures including net-metering (credits for self-generated power). The cost of electricity could fall to \$0.07–0.08 per kWh if gas can be delivered for \$8.00 per MMBtu. With gas coming into Mexico at the US border priced near \$4.00 per MMBtu, this seems possible. Leveraging the expansion of low-cost gas supply should create new opportunities for commercial and small industrial users, as well as some possibilities for remote mining or oil and gas operations.



Egypt: Solving reliability challenges

Egypt is at a critical juncture in the development of its energy system and is facing a strategic dilemma. As Egypt looks to increase its power supply and meet increasing electricity demand, its government is facing several constraints including a high budget deficit, high energy subsidies, and policy uncertainty.

The country is faced with the prospect of having to rapidly increase fuel imports. At the same time, fuel and electricity subsidies have been supporting national demand. Energy subsidies are an estimated 11.9 percent of GDP. The pace of fuel pricing reform and the availability of fuels remains a question going forward. A diversified electricity strategy is attractive as fuel risk increases and new large centralized generation projects face delays.

Given the uncertainties, distributed power could provide an appropriate option to circumvent the various infrastructure, budgetary and policy challenges facing power provision in Egypt. There are fairly mature but concentrated gas and power grids along the Nile river region. However, most of Egypt's oil and gas resources are either coastal or in the deep desert or deep water. The existing power grid into greater Cairo and points south has stressed capacity at times with reserve margins falling below 10 percent in recent years. Industries facing electricity disruptions are looking to add capacity in smaller blocks, leveraging available space in the gas system, and diversifying with gas, solar, and wind to increase electricity reliability. Recently, peaking power prices have been in the range of \$0.06 to \$0.08 per kWh and gas prices have been in the range of \$2.00 to \$4.00 per MMBtu for small industry and commercial sites. Although Egypt will need both centralized and distributed resources from a variety of sources to meet the energy needs of the country over the long-term, gas-based distributed power is the most attractive near-term option to avoid peak-period constraints even at current prices.

Myanmar: Distributed power islands

Myanmar has roughly the same population of neighboring Thailand, yet electricity consumption in Myanmar is only 10 percent of Thailand's. The prospects for demand growth are large; the electrification rate is 26 percent. Potential industries are waiting for power. Conservative expectations call for a doubling in power consumption in three to five years if supplies can emerge. The electric system in Myanmar is based on hydro-generation (70 percent), but it suffers from underinvestment



and high line losses (greater than 25 percent). Since hydro-generation is seasonal, diesel generators are a primary power source during the peak periods in Yangon. Furthermore, some of the hydro-electricity is exported. Myanmar is fortunate to have large natural gas resources. Today, most of that gas is exported to Thailand and China.

The leveraging of gas infrastructure offers potential for fast power solutions. The gas generation capacity in service today in Myanmar is reported to be inefficient. Gas pipelines serving the domestic market are in need of upgrading and repair. Estimates indicate improvements to the existing system could roughly triple gas availability into the greater Yangon area. This expansion will create opportunities for small generation and cogeneration. These high-efficiency generation “islands” can be built in less than two years.

Electricity prices in Myanmar are in the range of \$0.08 to \$0.10 per kWh. Even assuming natural gas prices near export parity of around \$10.00 per MMBtu delivered, medium-sized combined cycle (less than 100 MW) or smaller distributed power options should be economically viable. One additional challenge for the government and operators of these grids is to consider how these modular and isolated systems can be efficiently integrated into larger centralized grids over the long-term. Building small island grids with appropriate voltage and network protocols so that larger transmission systems can be linked together later will benefit the overall evolution of the integrated gas and power networks in Myanmar.

India: Meeting Basic Needs with Distributed Power

India has been an economic powerhouse in the last decade. However its growth has tapered in the last two years due to a myriad of issues. A central challenge confronting India's growth is lack of uniform social progress, especially for a large population that resides in rural villages. There is an ongoing economic debate as to whether social progress disparities between urban and rural areas are paralyzing India.

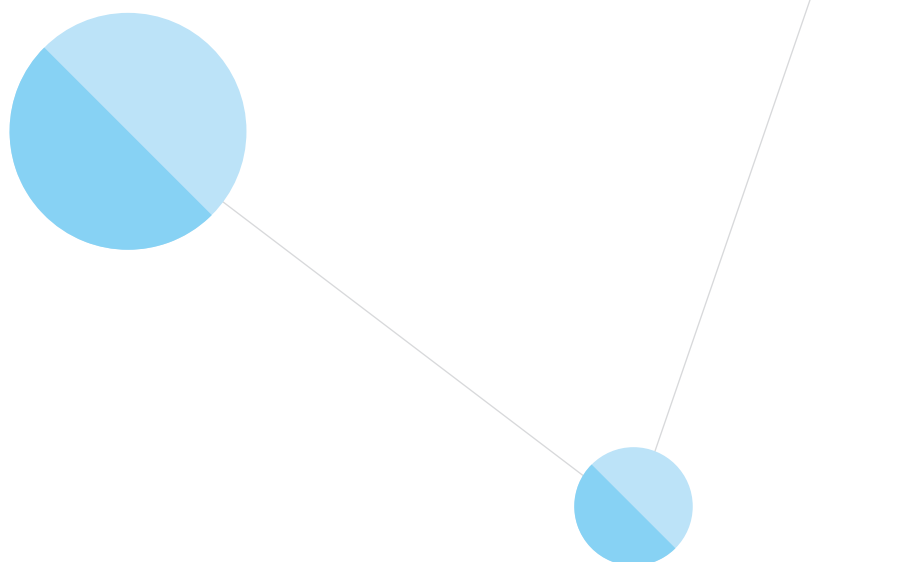
Roughly 10,000 villages are located in remote areas with hard-to-reach terrains. Supplying power through a grid system to these populous communities becomes difficult and expensive. Despite the strategic intent for capital investments in the T&D system, implementation has been slow with poor records of power quality and reliability. Rural electrification remains an open challenge continuing to weigh as an impediment to eradication of poverty.



Distributed power is an optimal solution. It can provide reliable supply of electricity to improve delivery of basic social needs: food, education and healthcare, therefore playing an indirect but critical role in preparing a balanced and solid 21st century workforce. It also enables mobile finance and agri-information exchange for farmers, therefore improving the overall health of agri-business/farming, which serves as the main occupation for rural livelihood. Availability of local power can allow women to go to school instead of gathering wood for cooking and water heating.

The western state of Gujarat exemplifies the case for distributed power. Often referred as the “Gujarat Miracle,” the state has experienced double-digit growth. Gujarat’s socioeconomic progress and industrial policy reforms have been enabled through progressive energy policy that promoted use of distributed resources for electricity generation and water irrigation. In 2011, Gujarat achieved the status of 100 percent electrification, with significant investments in solar. There is a positive correlation to social indicators including female literacy and income equality.

Development of the power sector is crucial to India’s continuous ascent. Leveraging distributed power, especially in remote regions, can alleviate suboptimal living conditions while enabling access to education and healthcare, eventually developing employable talent that can sustain India’s growth.

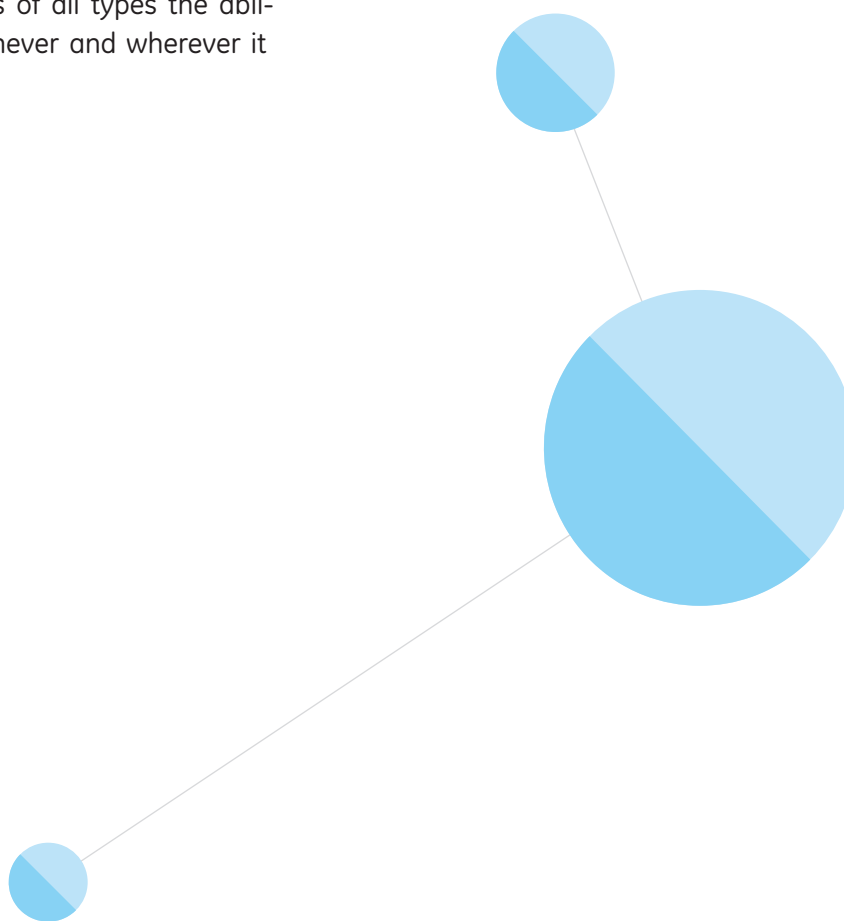




VII. CONCLUSION

After decades of both technology progress and future promise, distributed power is now poised for growth across the globe. Technology innovations have reduced the cost of distributed power technologies while increasing its flexibility and performance. The digital wave and the “Industrial Internet” promise to enhance the capability of distributed power systems. At the same time, distributed power systems are positioned to overcome barriers that are inhibiting the growth of large-scale power plants. There is a strong need for energy solutions across the globe, and by meeting this need, distributed power has become part of a virtuous cycle of human and economic development.

In this era of transformation, GE’s broad portfolio of innovative and diverse distributed power solutions gives businesses and communities around the world the ability to generate reliable and efficient power using a variety of fuels anywhere, whether on or off the grid. GE’s distributed power portfolio includes GE aeroderivative gas turbines, Jenbacher and Waukesha gas engines and GE Transportation power solutions. GE’s distributed power solutions give customers of all types the ability to generate reliable, sustainable power whenever and wherever it is needed.





VIII. APPENDIX

Distributed Power Technologies

Distributed power includes a broad range of technologies in various stages of commercial and technical maturity, including: reciprocating engines, gas turbines, solar photovoltaic, small wind turbines, microturbines and fuel cells.

Reciprocating Engines

Reciprocating engines are piston-driven internal combustion engines that use reciprocating pistons to convert pressure into a rotating motion. Their output ranges from 20 kW to 20 MW. Reciprocating engine technology was first developed in Europe during the eighteenth century. Today, the most common form of reciprocating engine is the internal combustion engine that uses gasoline to power motor vehicles. However, reciprocating engines are also used extensively to generate electricity in power applications. They also provide mechanical power for pumping and compression in oil and gas sectors, and they can also be used for propulsion in marine and locomotive applications.

Both Otto (spark ignition) and Diesel cycle (compression ignition) are widely used. They are technically and commercially mature with rapid start-up capabilities, providing flexibility to follow load and choice of fuel options. The addition of exhaust catalysts can significantly reduce pollutant emissions. Like gas turbines, reciprocating engines are particularly effective in CHP applications.

Gas Turbines

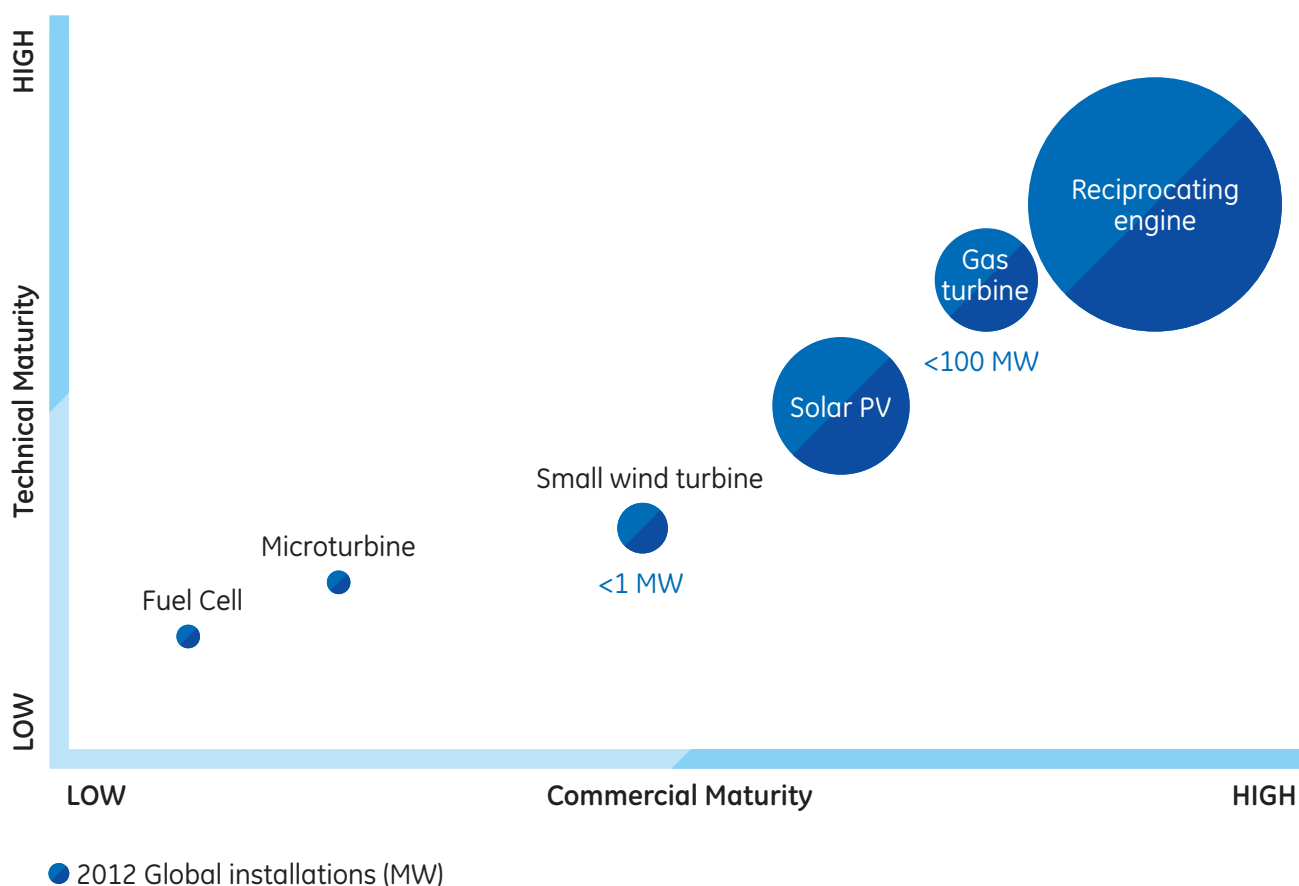
Gas turbines compress air and ignite it using a gaseous fuel, which can be natural gas, hydrogen, biologically-derived gases or gasified solids such as coal or biomass. Combusted air then expands through turbine blades in order to drive an electric generator. The compressor and turbine have multiple stages and axial blading in a gas turbine. This is what differentiates a gas turbine from microturbines that are single-stage and have radial blades.

Like reciprocating engines, gas turbines have been used in power generation since the nineteenth century. In 1899, Charles Gordon Curtis patented the first gas turbine in the United States. The following year, Sanford Alexander Moss completed a thesis on gas turbines and by 1903 Moss was applying his insights for the development of gas turbines for GE.



Figure 8. Distributed power technology continuum

Distributed power technology spans the commercial and technical maturity continuum. Reciprocating engines and gas turbines are the most technologically and commercially mature.



Source: General Electric.

Today, gas turbine system sizes range from 1 to 400 MW in combined cycle applications. Gas turbines in the size range of 100 MW or less are typically used in distributed power applications. Like reciprocating engines, these smaller distributed gas turbines can be used in stand-alone applications or in CHP applications that provide electricity and high pressure steam to commercial and industrial facilities.

Gas turbines have many of the same advantages as reciprocating engines in distributed power applications. The primary difference is that reciprocating engines are used more frequently in applications less than 20 MW. In addition, gas turbines provide higher pressure steam and can produce a greater amount of power in a given space.



Solar Photovoltaic

Solar photovoltaics (PV) are the quintessential distributed power technology. Indeed, solar power is often used interchangeably with the concept of distributed power. Given its ability to deliver electricity at the point of use anywhere around the world, this status is well deserved. Like other distributed power technologies, solar PV has a long history of development.

In 1839, physicist Edmond Becquerel noticed that some materials produced small electric currents when exposed to light. The “photovoltaic effect” discovered by Becquerel is used today in solar photovoltaic cells to convert the energy of sunlight directly into electricity. Rows of solar cells can be assembled into modules, and modules are then assembled into arrays. Solar arrays are combined with other “balance of system” components including wiring, an inverter, and batteries (in off-grid systems) to comprise a solar PV system. Solar systems can be ground mounted—as they are in utility applications—or mounted on industrial, commercial or residential rooftops. Solar PV systems are used both in remote and grid-connected applications.

Solar PV systems offer unique benefits in distributed power applications. In particular, solar PV systems do not emit pollutants during electricity generation, nor do they require a fuel source to produce power. These advantages are weighed against the intermittency of solar power, making it available only when the sun shines. However, in remote applications with limited fuel availability, solar PV systems coupled with battery storage can be the best option for meeting local power needs.

Small Wind Turbines

Wind turbines transform wind currents into electrical current through the action of rotating turbine blades that spin a shaft connected to an electric generator. As with reciprocating engines and gas turbines, the history and use of wind turbines dates back to the nineteenth century. James Blyth put the first wind turbine to use in Scotland in 1887. Blyth’s efforts were followed by those of Charles Brush in the United States in 1887 and Poul la Cour in Denmark in the 1880’s. By 1920 in Denmark, 105 small wind turbines generated electricity in combination with diesel generators, and another 145 wind turbines were in use at bigger farms and plants. In the United States, small wind power systems flourished on remote farms until federal rural electrification efforts provided transmission lines that eventually supplanted wind power as the primary electricity source in rural America.



Today, large-scale wind turbines in the range of 1 to 10 MW are clustered together in wind farms to provide bulk power that feeds into transmission networks across the globe. As with solar PV, the installed capacity of wind power has grown significantly over the last decade. Wind power has been driven by technology advances that have increased the size and reduced the cost of large wind turbines, as well as renewable energy support policies around the world. Thanks to continuous technology advances and small wind policies in key countries, wind turbines less than 50 kW have made a comeback and are now a viable option in many distributed power applications.

Microturbines

Microturbines are miniature electricity generators that burn gas and liquid fuels in a turbine to create rotation that drives a generator. They range in size from 1 kW to 250 kW. Like their larger cousins, gas turbines, microturbines work by compressing and heating air and then igniting the compressed air, which expands and rotates the turbine blades in order to drive a generator and produce power. Microturbine compressors and turbines are radial-flow designs, unlike gas turbines, which have axial designs and multiple stages of blades.

Due to their current level of commercial and technical maturity, microturbines have lower efficiencies and higher capital costs than both reciprocating engines and gas turbines. Although they hold great promise for the future, additional technology development and commercial progress will be required in order to make microturbines a more competitive option for distributed power applications.

Fuel Cells

Fuel cells convert chemical energy into electricity through a chemical reaction with oxygen or another oxidizing agent. As with other distributed power technologies, fuel cells have a lineage that dates back to the 1830's. In the twentieth century, fuel cells were first commercialized by NASA in the 1960's for use in the space program.

There are several different types of fuel cells, but all consist of a negative side, a positive side and an electrolyte that enables charges to travel between the two sides. Electrons move from the negative side to the positive side through an external current, and electricity is produced in the process. The only by-products are water, heat and carbon dioxide.



Figure 9. Distributed power technologies

Today's diverse set of technologies have different characteristics.

Characteristic	Reciprocating engines	Gas turbines	Microturbines	Fuel Cells	Solar PV	Small Wind
Typical size range	20 KW–20 MW	10–100 MW	30–250 KW	5 KW–5 MW	1 KW+	200 W+
Representative power efficiency range (%) (HHV)	28–49%	21–45%	18–20%	35–60%	-	-
Fuel options	<ul style="list-style-type: none"> • Diesel • Natural gas • Alternatives 	<ul style="list-style-type: none"> • Natural gas • Alternatives 	<ul style="list-style-type: none"> • Natural gas • Alternatives 	<ul style="list-style-type: none"> • Hydrogen • Natural gas 	Renewable resource	Renewable resource
Thermal outputs	<ul style="list-style-type: none"> • Heat • Hot water • Low pressure steam 	<ul style="list-style-type: none"> • Heat • Hot water • Low/high pressure steam 	<ul style="list-style-type: none"> • Heat • Hot water • Low/high pressure steam 	<ul style="list-style-type: none"> • Hot water • Low/high pressure steam 	None	None
Power density (KW/MW)	35–50	20–500	5–70	5–20	-	-
Min start time	10 sec	10 min	60 sec	3 hours	Immediate	Immediate
Required fuel pressure (psig)	1–45	100–500 (compressor)	50–80 (compressor)	0.5–45	NA	NA
Noise	Moderate	Moderate	Moderate	Low	None	Low
Favored applications	<ul style="list-style-type: none"> • Power • CHP • Mechanical drive 	<ul style="list-style-type: none"> • Power • CHP 	Power	Power	Power	Power

Source: General Electric and U.S. Environmental Protection Agency Combined Heat and Power Partnership. Data represents illustrative values for typically available technologies today.

Fuels cells are well-suited to provide continuous and premium power in both stationary and mobile applications. However, due to their higher cost and lower efficiencies relative to other distributed power technologies, fuels cells will require additional commercial and technical advances to become more competitive.



Notes

- 1 For example, see International Energy Agency (IEA) World Energy Outlook 2004 (WEO2004). Chapter 10 discusses energy and development and shows a positive correlation between energy development and human development. For a more recent analysis of the linkage, see Niu et al., "Electricity Consumption and Human Development Level: A Comparative Analysis Based on Panel Data for 50 Countries," *International Journal of Electrical Power & Energy Systems*, 53, December 2013, 338–347.
- 2 Zinc, John C. "Steam Turbines Power an Industry: A Condensed History of Steam Turbines," *Power Engineering*, August 1996.
- 3 Evans, Peter and Michael Farina. *The Age of Gas & the Power of Networks*. General Electric, October 2013.
- 4 American Public Gas Association. See more at:
<http://www.apga.org/i4a/pages/index.cfm?pageid=3329#sthash.Jlm38wtV.dpuf>
- 5 Edison Electric Institute. *Transmission Investment: Adequate Returns and Regulatory Certainty Are Key*. June 2013.
- 6 Buijs et al., "Transmission Investment Problems in Europe: Going Beyond Standard Solutions," *Energy Policy*, 39, no. 3 (2011): 1794–1801.
- 7 Ibid
- 8 International Energy Agency (IEA), *World Energy Outlook 2008*.
- 9 World Bank, Development Indicators 2013, available at
<http://data.worldbank.org/data-catalog/world-development-indicators>
- 10 This discussion is derived from *Storm Reconstruction: Rebuild Smart, Reduce Outages, Save Lives, Protect Property*. National Electrical Manufacturers Association (NEMA), 2013.
- 11 This information is derived from a forthcoming paper by Peter Evans and Peter Fox-Penner entitled "Resilient and Sustainable Infrastructure for Urban Energy Systems."
- 12 International Energy Agency (IEA), *World Energy Outlook 2004*, Chapter 10. Also see, Niu et al. (2013).
- 13 IEA (2006), *Energy Technology Perspectives*, OECD/IEA, Paris.



Author Biography

Brandon Owens is an economist, energy analyst, researcher and writer. His research has been published in industry-leading journals such as *Public Utilities Fortnightly*, *Energy Policy*, and *Research Evaluation*. Mr. Owens has been a keynote speaker and an expert witness, and has been quoted in periodicals such as *The New York Times* and *USA Today*.

The author of GE's 2014 whitepaper "The Rise of Distributed Power," Mr. Owens is currently the director of Ecomagination Strategy at GE, where he helps guide the strategic direction of GE's corporate sustainability programs. Prior to this role, he was the Manager of Strategy and Analytics within GE Energy's Global Strategy & Planning team. He was a primary contributor to GE's 2012 Whitepaper "Industrial Internet: Pushing the Boundaries of Minds and Machines."

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The Rise of Distributed Power
By Brandon Owens

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