



# THE AGE OF GAS & THE POWER OF NETWORKS

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# I. EXECUTIVE SUMMARY

Natural gas is poised to capture a larger share of the world's energy demand. Gas has been a part of the energy landscape since the Industrial Revolution. What is new and changing 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 global energy supply and demand. The world is entering a period in which natural gas is positioned to rival coal consumption as well as take share from oil on the global stage. The world is also entering a period in which gas will increasingly complement wind and other renewable energy sources, particularly in power generation. This is significant because the world continues to shift to electricity to power industry, commercial, residential and most recently transportation systems. We anticipate gas will grow by more than a third over its current global consumption by 2025.

Gas growth is accelerating, in part, because the infrastructure networks that connect supply and demand are becoming more diverse and expanding around the world. The future of gas will not be the same as the past. Gas network growth and new supply options like shale gas, coupled with technology innovation, are contributing to creating greater network density, greater flexibility, and improved economics. Indeed, the power of networks and the Age of Gas are closely inter-linked and will contribute to a range of valuable benefits. These benefits include significantly lower environmental emissions relative to other fossil fuels, synergies with more intermittent renewables, and contribution to overall energy system resilience to disruption.

## Power of Networks

Natural gas requires networks to link sources of production to the various locations where it will be used. One defining characteristic of networks is that they become more valuable with size as more entities join the network. These characteristics facilitate the development of adjacent networks, uncovering hidden opportunities to create value as new links are established. Network growth creates greater flexibility and improved economics, which in turn fosters further growth. Denser networks contribute to making energy systems more robust and therefore more



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resilient to disruption and less likely to exhibit extreme price volatility.

Gas typically travels by one of three means to reach users. One is through pipelines. Gas pipeline systems are mostly land-based and the most common form of transport delivering 89 percent of gas consumed today. The second is by sea. The sea-based network is made possible by the large-scale conversion of gas to liquefied natural gas (LNG) with the use of special-purpose transport ships. About 10 percent of global gas flows

occur as LNG trade on the high seas. International trade in LNG is expected to increase by almost 70 percent over this decade. Finally, there is a small quantity of gas, about 1 percent globally, which is compressed or liquefied in small facilities and transported by rail or truck. In places like North America, where arbitrage opportunities are great between higher cost diesel and lower cost gas, new vertical network linkages are emerging such as rail networks and gas pipeline networks. This will drive fast growth in small scale LNG and compressed natural gas (CNG) systems going forward.

Combining network modes helps gas networks to evolve and grow. The evolutionary process involves a combination of technology deployment and market arrangements that bring together buyers and sellers. The pace of growth varies dramatically around the world and hinges, again, on the degree of network development. In the early phase of development, gas infrastructure is characterized by point-to-point connections. In more mature phases where density is high, there are many opportunities to build linkages within, as well as across, other energy systems including electricity, railroad, shipping, and roads used for long-haul trucking to create sophisticated meshed networks.

Large-scale multi-billion dollar “mega” pipeline and LNG projects will “anchor” future gas network growth. This is the traditional growth path to connect large supply sources with demand centers. Complementing these large-scale systems will be a new generation of smaller modular “satellite” systems. Gas networks will evolve around the world based on the development of anchor systems and satellite opportunities.



As these networks integrate, gas delivery will become more flexible and more resilient. This will support increased use of gas by large-scale power and industrial users, as well as for smaller-scale distributed power and urban heating and cooling needs. The integration of gas systems over the next decade is going to bring unprecedented flexibility to the gas market, driving significant institutional and market changes, and also opens the way for gas to capture a larger share of energy demand.

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### Energy System Resilience

The world needs both resilient and sustainable energy systems. This is particularly true for fuel and electric power infrastructure since they provide the foundations upon which other critical systems rest, such as communications systems, healthcare systems and financial systems. A resilient energy system optimizes the strengths of individual energy networks. It harmonizes their operations to the benefit of consumers. An energy system that relies heavily on any one energy network will be more vulnerable. Furthermore, networks that are optimized to be more efficient with lower losses and reduced transaction cost are more sustainable as well. Gas is well positioned to work with other energy sources to improve overall energy system resilience.

Furthermore, as gas systems become more intelligent with new digital and software technologies, these benefits will likely grow.

Gas networks, which are often underground, in contrast to road and power grids, can often provide stable service during severe weather events. In this way, gas can contribute broadly to economic resiliency by providing diversification, redundancy, and backup systems. Gas technologies are supporting new concepts for grids-within-a-grid and multi-source micro grids to increase resilience and reaction time in the face of disruptions. In addition, distributed power systems built around gas networks can provide fast power recovery for public utilities such as hospitals, waterworks and government agencies, which is very important in disaster relief. However, in other events, for example, earthquakes or typhoons (for LNG ships) gas systems may be disrupted. This is why gas, power, and liquid fuel networks are best when optimized to support each other.



## Technology and Innovation

Technology innovation is at the foundation of the growing role that gas is playing in world markets. Since the era of gas manufactured from coal back in the 19th century to the emerging unconventional gas era of today, technology change and gas industry growth have been closely linked. Presently, innovation is taking place at the component level as well as the systems level. While the building blocks of gas networks, including compressors, valves, turbines, and engines continue to be pushed to their design limits, the most exciting advances are taking place at the systems level. For example, it has been largely the integration of existing technologies which has contributed to making shale gas development such a game-changer for North America.

In the future, we foresee more examples of new technology systems, which will have a dramatic impact on gas network growth including new floating LNG technologies and “mini-midstream” (small gas gathering and conversion and transportation systems) technology sets. We will also see an array of new digital systems for sensing, monitoring, control, and analytics, all of which are a part of the Industrial Internet, which is bringing about deeper integration of the digital world with the world of machines.<sup>1</sup>

Technology innovation can be divided into the different ways that it contributes to gas network development. There are innovations taking place upstream which focus on supplying gas networks. This includes technologies to improve efficiency and lower costs of large-scale remote gas projects such as deepwater gas, sour gas, and other large conventional gas developments. Other technologies will contribute to securing, integrating and optimizing gas systems from an efficiency as well as environmental and safety standpoint. The new technologies that help integrate and transform small-scale LNG and CNG systems into “virtual pipelines” will be important to the rapid development of new gas markets like the transportation sector. Lastly, there are technological innovations focused on expanding the range of applications for gas. The flexibility of natural gas makes it a valuable complement to other generation sources like renewables. Across each of these areas, advances in the Industrial Internet, including data analytics, machine-to-machine and machine-to-human interfaces will have a powerful effect on the productivity of gas related facilities, fleets and networks.



## Gas Outlook to 2025

Global gas demand today is about 3,500 billion cubic meters per year (Bcm) or about 70 percent of the size of the global oil market. The GE Age of Gas outlook projects global consumption will grow by nearly 1,300 Bcm of gas by 2025, which is a 36 percent increase relative to the present. This would increase gas to 26 percent of global primary energy consumption. Over

half of the incremental growth in this period will take place in China, the Middle East, as well as Southeast and South Asia. Under the right conditions, including an increase in supply, additional policy support, and network growth, natural gas could achieve a 28 percent share of global primary energy consumption. This is equivalent to, or slightly larger than, expected coal and oil share in 2025.

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The power sector will be the key driver of future gas demand growth. As the world power systems expand, we anticipate that gas used to produce electricity will expand by nearly 50 percent. Economic and environmental factors are driving the shift away from oil and coal toward natural gas and renewables in the power sector. There is a window of opportunity for gas to be developed profitably and still compete effectively against internationally-traded coal if it falls within the right competitive pricing range. This “strike zone” varies by region and with the degree to which gas prices are linked to oil prices.

Getting gas into the “strike zone” can be accomplished through traditional vertical integration between buyers and sellers, but with more flexibility on long-term contracts. As gas markets mature and networks expand, the industry will be increasingly pushed toward a competitive environment with more price convergence. Regional prices will be different because of the underlying cost of supply and transportation and less because of contractual linkage to oil. The slow retreat from oil-linked prices in places outside North America and Northwest Europe will create incentives for the industry to adopt new processes and options as well as widen the spectrum of technologies deployed. In terms of new gas supply, conventional sources will continue to dominate and will make up 70 percent of incremental supply



growth. However, unconventional sources will continue to grow as well. By 2025, we expect that unconventional gas will constitute nearly 20 percent of global gas supply, up from 14 percent today.

Global annual expenditures on natural gas infrastructure now range from \$250 to \$300 billion per year. Of this total, nearly 25 percent of industry spending is devoted to expanding gas transportation networks including pipeline, storage, and LNG systems. Over the next five years, gas transportation network development is likely to account for nearly 30 percent of annual capital spending of the \$400 billion global gas industry. A significant portion of this investment is related to large-scale LNG development, which will exceed pipeline investment over this time period.

### Age of Gas

Expanding the global role of gas will depend on a new wave of investment, additional policy adjustments, and coordination among companies and governments. Future growth will require focus on the key role that networks play in the gas industry. Policy makers will need to give greater attention to the importance of growing gas networks (horizontal growth), and the options available to facilitate the linkages between various energy systems (vertical linkages). Fostering an environment for innovation will also be critical. Tax credits and incentives in the early stages can be instrumental to encourage new supply development. On the consumer side, examining tax policies that distort competition between fuels is also important. For example, current policies often tax LNG based on fuel volume rather than energy content. This increases the effective tax on LNG by 1.7 times the rate applied to diesel fuel, distorting network investments and end-use fuel choice.

There are strong indications from North America that successful gas development can foster economic growth and job creation. This experience demonstrates that gas network development can be a vehicle for economic development, manufacturing competitiveness and increasing energy system resilience. Other catalysts for network investment include efforts to drive international cooperation on gas projects and continued evolution of pricing policies that align with the various stage of industry development.

Natural gas can provide substantial environmental benefits. These benefits are achieved directly when used as an alternative to dirtier fuels, or if



resources, like water, are conserved. They are also achieved indirectly when gas supports other lesser environmentally-damaging energy sources like wind and solar. Realizing these benefits can have long-term and far-reaching positive impact on the economy and society. These benefits can already be captured where gas is economically competitive. These environmental value drivers, if accounted for in developing projects, can at least partly offset the current price differentials between natural gas and competing fuels. At the same time, natural gas will only be able to reach its potential if technologies are deployed that can support safe, efficient and reliable capture and extraction. Specifically, this means redefining what is possible in gas operations including: enabling oil substitution, improved water management, reduction of fugitive emissions and gas flaring, and other new approaches to advance efficiency and electrification.

The Age of Gas outlook presented here is not a foregone conclusion. Many complex pieces need to fall into place. However, there is real potential for natural gas, enabled by the power of denser and more flexible global networks, to win global market share from coal and oil, and in so doing transform the global energy landscape in beneficial ways.





## II. THE AGE OF GAS

The history of natural gas traces the slow, steady progress of a valuable but marginal fuel gradually advancing toward becoming a global fuel. In the last 50 years, there have been defining energy trends in each decade. In the 1970's and 1980's, it was the oil price shocks and the rise of coal and nuclear power, in the 1990's it was deregulation, in the 2000's, it was carbon and clean energy policy — a direct response to the surge in coal use over the last two decades. The challenges and complexity facing the energy industry today have developed from each of these previous trends while being shaped by new ones as well. There is a unique opportunity for the next defining energy trend to be the "Age of Gas." To understand the emerging Age of Gas, what it means, and how it can be realized, it is helpful to begin by briefly exploring the historic role of natural gas as a direct and indirect energy source.

### Natural Gas in History: Three Eras

The history of natural gas can be divided into three eras. The first was the manufactured gas era which lasted for a century, from 1810 to approximately 1920. This was followed by the conventional gas era, spanning the period from 1920 to around 2000. The unconventional gas era is just getting underway.

#### Manufactured Gas Era

At the start of the Industrial Revolution, factories and whole cities went dark at night, save for the light that could be produced from candles and oil lamps. The invention of gas lighting changed this. Cities all over the world embraced gas as a way to light city streets, squares and railway stations and numerous other locations, as the Industrial Revolution spurred rapid growth. British, Belgian and American cities were at the forefront in building these systems. By the 1860's, gas lighting and the small supply networks that were built to support them had spread to cities such as Sydney, Buenos Aires, Calcutta, Tokyo, Hong Kong and Singapore.<sup>2</sup>

The fuel to supply these early networks was manufactured gas derived primarily from coal, but other materials were also converted into gas



including oils, wood, and pine tar.<sup>3</sup> Thousands of gas works were built around the world and new gas light companies emerged to build gas lighting systems. However, these nascent gas networks were challenged by Thomas Edison's introduction of commercially viable incandescent light in the 1870's. Electric lighting was widely considered a superior technology since it provided a light of better quality, consistency, and without soot and fumes. One observer of the time called Edison's electric light "a little globe of sunshine," which provided "bright, beautiful light, like the mellow glow of an Italian sunset."<sup>4</sup> Incandescent light quickly gained share over gas. The gas industry responded by seeking out new uses for gas such as industrial applications, and uses in homes for cooking, and water and space heating. However, the gas industry found it hard to compete especially when the cost of coal feedstock rose in response to shortages caused by World War I. As a consequence, the role of gas in the global energy mix remained low.

### Conventional Gas Era

The 20th century ushered in the conventional gas era with significant changes in the source, distribution and end-use technology. Manufactured gas faded and the industry turned increasingly to conventional sources of gas with the discovery of major gas fields, made in the pursuit of oil. Prospectors discovered gas underground in discrete reservoirs or so-called non-associated gas. Some of these reservoirs were massive, such as the Hugoton reservoir in Kansas (1922), the Groningen field in the Netherlands (1959), and the Urengoy gas field in West Siberia (1966).<sup>5</sup> Large quantities of gas were also found dissolved with oil. When brought to the surface, the gas dissolved much like a carbonated drink when the cap is removed. But in many cases, this "associated gas" was considered a nuisance and ended up being vented into the atmosphere or flared if there was no economical way to get it to market.

In time, innovation and investment in gas transportation expanded and more gas found its way to market. Technology breakthroughs in the construction of steel pipelines helped to make it more economical to transport. Pipeline networks became larger and more efficient by the 1950's as they captured considerable economies of scale with larger, higher pressure pipes. A few large transcontinental pipelines were built, as well as more regional networks. Innovations in the 1960's also opened



## “This was the era of the race for industrial scale.”

the opportunity to trade gas across oceans. This was made possible with the development of techniques for super-cooling the gas to reduce its volume to 1/600 of its atmospheric volume. Special cryogenic LNG tankers began to ply the oceans with names like Methane Princess and Methane Progress. Commercial trade in natural gas (LNG) commenced between Algeria and France and the UK, and from Alaska to Japan.

More rapid expansion of natural gas began in the 1970's and 1980's, with a number of intersecting factors playing a role. The oil shocks of 1973 and 1978 caused governments and utilities to actively diversify their fuel mix, often to the benefit of gas. Conventional gas also received an important boost from changes in end-use technology,

such as the introduction of the combined cycle gas turbine for power production. Breakthroughs were made in applying jet engine gas turbine technology to produce electric power.<sup>6</sup> Utility companies and industrial users increasingly embraced these technologies on the basis of cost, efficiency and environmental performance. This was the era of the race for industrial scale. With the introduction of new technologies, the use of gas contributed to this race. In the late 80's and early 90's, regulatory changes also played a role. In the UK, the changes involved the privatization of state-owned companies and opening the gas pipeline network to competition. In the US, the most significant changes were opening the network and removing price controls. This contributed to creating a more competitive and efficient gas industry.<sup>7</sup>

With these developments, gas utilization and the networks that supported it spread significantly in North America, Europe and Northeast Asia. Natural gas use has expanded as economies and population have grown. In 1970, global gas consumption was 1,000 billion cubic meters (Bcm) per year with 80 percent of consumption in North America and Eurasia.<sup>8</sup> In 1990, gas use had grown to 2,000 Bcm representing about 20 percent of global primary energy supply. By the year 2000, natural gas had grown in volume (2,400 Bcm), and captured share, reaching 22 percent of global primary energy use. Yet, owing to the competitiveness of alternative hydrocarbons, gas continued to lag coal and oil as a primary energy source. End-use supply



concerns, both real and imagined, periods of price volatility, as well as limitations of networks in much of the world, worked to keep gas in third place. Thus, while it was an increasingly important part of the global energy mix—overtaking hydro and nuclear energy—natural gas still trailed oil and coal.

### **Unconventional Gas Era**

It was recognized as far back as the 1820's that natural gas accumulated not only in discrete underground pockets (usually porous sandstone or limestone reservoirs) but was present in the larger underlying rock formations. Potential unconventional gas sources included methane trapped with coal seams, coal bed methane (CBM), gas present in low permeability sandstone (tight sands), and even in dense organic-rich shales (gas shales). For shale, the difficulty was liberating it from the fine-grained, clay- and organic carbon-rich shale rocks in an economic fashion.

Cycles of abundance and scarcity in the US gas market after 1950 drove bursts of intense interest in developing unconventional gas. Small research and development projects were launched in the mid-to-late 1970's. However, successful development (supported in part by tax incentives) of CBM resources in Black Warrior basin in Alabama, in the Fruitland coal seams of northwest New Mexico, and in the Powder River basin of Wyoming in the 1990's, showed unconventional resources could be a significant source of continental gas supply. Today, CBM production is about 10 percent of US gas supply and is becoming a contributing unconventional gas supply source in China and Australia. Later, in the 1990's, experimentation with fracturing technology opened up large tight sands developments in the Rocky Mountains, principally in the Green River, Piceance, and Uinta Basins of Wyoming, Colorado, and Utah. Similar tight sands efforts in parts of east and central Texas also emerged during this time. Nearby, another unconventional source, the Barnett Shale, had been quietly investigated since the late 1980's.

In 1992, George P. Mitchell drilled the first horizontal gas well in the Barnett. By 1997, he was experimenting with "light sand fracturing." At the time, shale gas production in the US was an insignificant part of US supply—only 1.6 percent of total US gas production in 1999.<sup>9</sup> The breakthrough occurred in the late 1990's, aided by the persistent experimentation by independent



companies like Mitchell Energy. Trial and error efforts continued with various forms of fresh water hydraulic fracturing techniques—known as fracking — and proppants designed to keep rock structures open to release the gas. These early efforts evolved into today’s advanced horizontal drilling and “slickwater” fracturing techniques, aided by new micro-seismic imaging and manufacturing-based approaches to development. A surge in supply followed.

Other companies quickly adopted the techniques and applied them to other shale formations in Arkansas, Oklahoma, Louisiana, Texas, Pennsylvania and Western Canada. Since 2000, aided by a period of high gas prices through 2008, shale gas production surged up at an unprecedented rate. Unconventional gas (shale, CBM, and tight sands) in the US grew by 223 percent through 2012 and now represents about 55 percent of US gas supply. Today, technological advances in the gas shales have lowered costs while increasing well productivity. This is the reason shale gas is considered a “game changing” resource. Furthermore, as these techniques have been applied in oil-prone shales, there has been a renaissance in US oil production. The implications and scale of this oil renaissance are uncertain, but it is clear that the significant growth in “light tight oil” will bring with it significant quantities of associated gas, adding yet another large source of gas supply to the US market.

So far the shale boom has been heavily concentrated in North America. Within less than a decade, the United States has become the world’s largest producer of natural gas and in combination with Canada, accounts for 25 percent of global production. Today, US producible reserves alone are estimated to be in excess of 2,500 trillion cubic feet.<sup>10</sup> This is 1.5 to 3 times what total recoverable reserves were estimated to be in 1980.<sup>11</sup> If these recovery estimates prove accurate, there are nearly 100 years of US gas supply available at expected future consumption rates. Largely on the back of the North American shale development, in 2012, unconventional gas rose to 14 percent of the global gas supply mix, up from 6 percent in 2000.

The success of these developments has contributed to lifting the global role of unconventional gas in the supply mix. New estimates point to large potential shale gas reserves around the world including China, Australia, Argentina, Brazil, Algeria, Saudi Arabia, and parts of Africa, among other countries. The unconventional resource wave in North America is driving



job creation and changing national competitiveness. Furthermore, it is shaping expectations of major shifts in the geopolitical landscape of energy in the years ahead. While questions remain on the future of shale resources outside North America, there is good reason to believe we are entering the unconventional gas era.

### Global Gas Landscape Today

In 2012, global gas demand reached 3,500 billion cubic meters (Bcm) per year and gas now represents about 24 percent of primary energy supply. This level of demand is equivalent to 63 million barrels of oil per day. The gas industry is therefore about 70 percent of the size of the global oil market today. Global gas demand has been growing over the past decade at a steady rate of approximately 3 percent a year but with significant variation between regions (see Figure 1).

The big mature gas regions like North America, Europe and Eurasia constitute 57 percent of global demand, but growth has slowed to a rate of about 1 percent per year- or has contracted recently in the case of Europe. China's gas consumption has gained pace, growing at approximately 11 percent a year over the past decade, but started from very low levels of consumption. Currently, China consumes 140 Bcm or about 4 percent of global demand. This is approximately the same as Africa's consumption and less than an eighth of North American consumption. Other regions are also growing rapidly. The Middle East, for example, has had a growth rate of 7 percent and now consumes 556 Bcm or 13 percent of the world total. The balance of global gas consumption is comprised of the rest of Asia (15 percent) and Latin America (7 percent).

Gas serves a variety of end-users competing differently in each of its key markets. The largest share of gas finds its way into power generation, which currently makes up 41 percent of global consumption. A portion of this gas is used to fire "peaking" units, which run periodically to meet periods of highest electricity demand. The other portion is used for "mid-merit" or cycling and "base-load" power generation, in which gas-fired turbines operate in the daytime or in all hours of the day. The second-largest demand for gas is for industry, where gas is used as a process feedstock to produce fertilizers, chemicals, plastics, and a wide range of other products. Industrial use makes up 24 percent of global gas



Figure 1. Regional Gas Demand by Source, 2013

Source: GE Global Strategy & Analytics, 2013

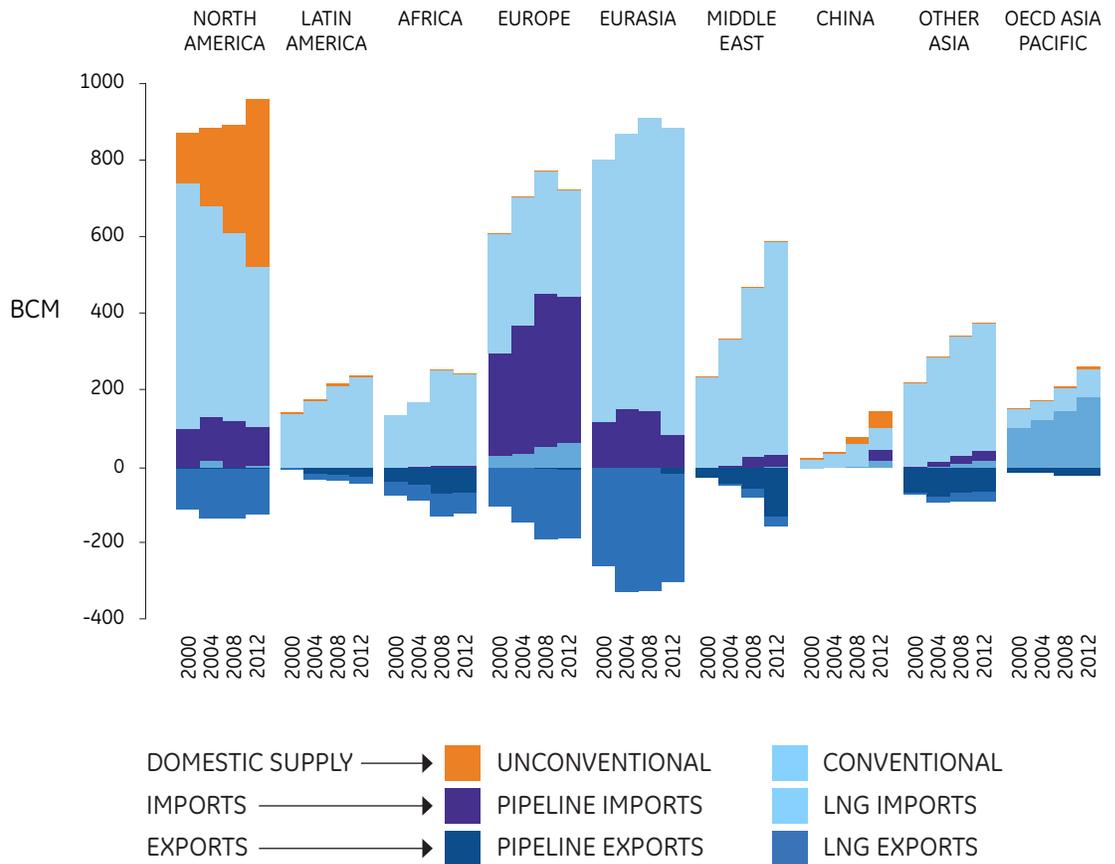


demand. The unique applicability of gas to some industrial processes, like ethylene production, can give gas a competitive advantage. The third major source of demand is for buildings which make up another 20 percent—largely for space heating, cooking and in some cases, cooling. Gas is a premium fuel for space heating needs and is prized for certain commercial uses like cooking or drying. Finally, there are other uses, primarily in the energy sector and transportation sectors. For example, gas is used as a source of hydrogen in refineries to make diesel fuel. In some of these applications gas competes directly with oil in remote operations. It powers



Figure 2. Global Gas Supply and Trade, 2000–2012

Source: GE Global Strategy and Analytics, 2013



NOTE: Unconventional gas includes gas shale, CBM, and tight sands supplies. Conventional includes all other gas sources in the region. European pipeline exports aggregated intra-regional gas trade primarily from Norway and the Netherlands to other parts of Europe.

the compressors and processing equipment used to purify and transport gas for delivery. Gas is also increasingly being used directly as vehicle fuel. Collectively, these and other uses account for 15 percent of global gas consumption.

There is robust cross-border trade in gas. More than 30 percent of gas now moves from one country to another, either through pipeline networks or by sea via the LNG network. As shown in Figure 2, the largest pipeline exporting regions are Eurasia, parts of Europe (e.g. Norway), and North America, which largely involves flows from Canada to the US, and smaller



flows from the US into Mexico. While more gas is traded by way of pipelines than by LNG, the share of LNG has been gaining. LNG imports more than doubled to 327 Bcm in 2012 up from 140 Bcm in 2000. The largest LNG exporters today are Qatar, Australia, Malaysia and Indonesia. The largest LNG importers are Japan and South Korea followed by the UK and southern Europe.

### Outlook for Gas Growth to 2025

Gas is poised to capture a larger share of the world's energy needs. Our Age of Gas forecast envisions total world gas demand reaching approximately 4,800 BCM by 2025, which is 36 percent more gas than is produced and consumed today.<sup>12</sup> Over half of the incremental growth will take place in China, the Middle East, as well as Southeast and South Asia (Figure 3). The growth in the Middle East is predicated on availability of new gas supplies and finding agreement between producers and consumers concerning investment and pricing policy. The growth story in most of Asia is linked to timely infrastructure development and the competitiveness of gas versus oil and coal.

Infrastructure development will be critical in Africa and Latin America as well. Gas will be attractive as an alternative to oil in transportation and other distributed energy settings as new supplies are brought online. Further, as regional economies grow, Africa will increasingly look to supply its own needs as well as export gas.

In the mature regions, growth will be slower albeit from a much larger base. Growth in North America is expected to accelerate in the second half of the decade as new facilities are built to capture the value of low cost shale gas. Russia and the Caspian region will continue to rely on abundant gas resources, but are expected to increasingly focus on improving the energy efficiency of their operations. The region will continue to be a major supplier to Europe and will increasingly export gas to Asia. The European gas market is expected to grow very slowly in the near-term. In fact, gas use has been declining since 2010 as coal has become more competitive and economic conditions have been challenging. However, we expect Europe to return to its growth path by the end of the decade.



Figure 3. Natural Gas Growth Outlook, 2012-2025

Source: GE Age of Gas Outlook, 2013



In terms of supply, conventional sources will continue to dominate and will make up 70 percent of incremental supply growth. Russia’s conventional gas resources remain vast but somewhat more costly to develop as traditional dry gas reservoirs are supplemented with large Arctic gas deposits under the Yamal peninsula and deeper, more complex, finds in western Siberia.<sup>13</sup> These supplies will meet domestic needs and remain an important part of the European supply. In addition, the initial phases of eastern Siberian gas development will be underway by decade’s end.



“By 2025, we expect that unconventional gas will constitute nearly 20 percent of global gas supply, up from 14 percent today.”

Nearby, Turkmenistan and other Caspian producers will increase exports into China as new pipelines are finished and investment in the super-giant Galkynysh gas field continues.<sup>14</sup> In the Middle East, Qatar and Iran will continue gas development. However, Iran’s gas resources are expected to remain largely out of international markets in the near-term amid ongoing geopolitical tension. Elsewhere, massive new offshore conventional gas finds on the northwest shelf of Australia, in Mozambique and Tanzania, and in the Mediterranean will anchor large LNG projects over the next ten to fifteen years.

Bolstering these conventional supplies, unconventional gas is forecasted to grow at twice the pace of traditional gas sources. By 2025, we expect that unconventional gas will constitute nearly 20 percent of global gas supply, up from 14 percent today. Most of the gas will be developed in the United States and Canada, led by the Marcellus shale region centered in Pennsylvania and the Eagle Ford shale of south Texas. By some estimates, Eagle Ford has become the largest oil and gas field development in the world on a capital expenditure basis. Outside North America, Australia’s CBM resources are in full development, anchoring several LNG projects in Queensland. In Argentina, excitement about the prospects of the Neuquén Basin is building. In China, shale gas exploratory work is continuing in the Sichuan region and other parts of China. Developing shale gas in China presents many challenges, but we think material volumes will emerge after the end of the decade. The unconventional gas outlook shown here is conservative in some respects. Across the world, from Australia, Algeria and Brazil to Mexico, Turkey, and Russia, shale optimism is growing. However, unconventional gas growth will be paced by several key factors including infrastructure that are discussed in more detail below.

The power sector will be the key driver of future demand growth. Gas complements steady baseload sources like coal and nuclear fuel as electricity demand changes through the day, and balances intermittent renewable supplies when the sun is not shining or the wind is not blowing. As the world power systems expand, we anticipate gas used to produce electricity to expand by nearly 50 percent. There are uncertainties concerning the growth of each specific generation technology. For example,



Japan's future gas demand will be closely tied to post-Fukushima decisions on the future of nuclear power. It will also be influenced by the rate of new nuclear power plant construction around the world.<sup>15</sup>

An even larger question for the future of gas concerns the generation share it will capture from coal. There is a window of opportunity or "strike zone" for gas to be developed profitably and still compete effectively against internationally-traded coal. However, if gas prices are too high, coal will gain share. Likewise, when gas prices fall, gas becomes highly competitive, but investment in new supply falters. These dynamics are not the same across the world. Different regions currently fall in different places across this strike zone, as illustrated in Figure 4. In North America, the recent decline in gas prices has placed natural gas clearly within the strike zone in the US (fully independent pricing from oil), which has helped gas win share. The competitive dynamics are different in Europe where prices are higher and there is tighter correlation to oil prices. Prices are even higher in Asia, creating more competitive challenges. We expect gas demand in the power sector to grow, but gas will need to stay in the strike zone to do so.

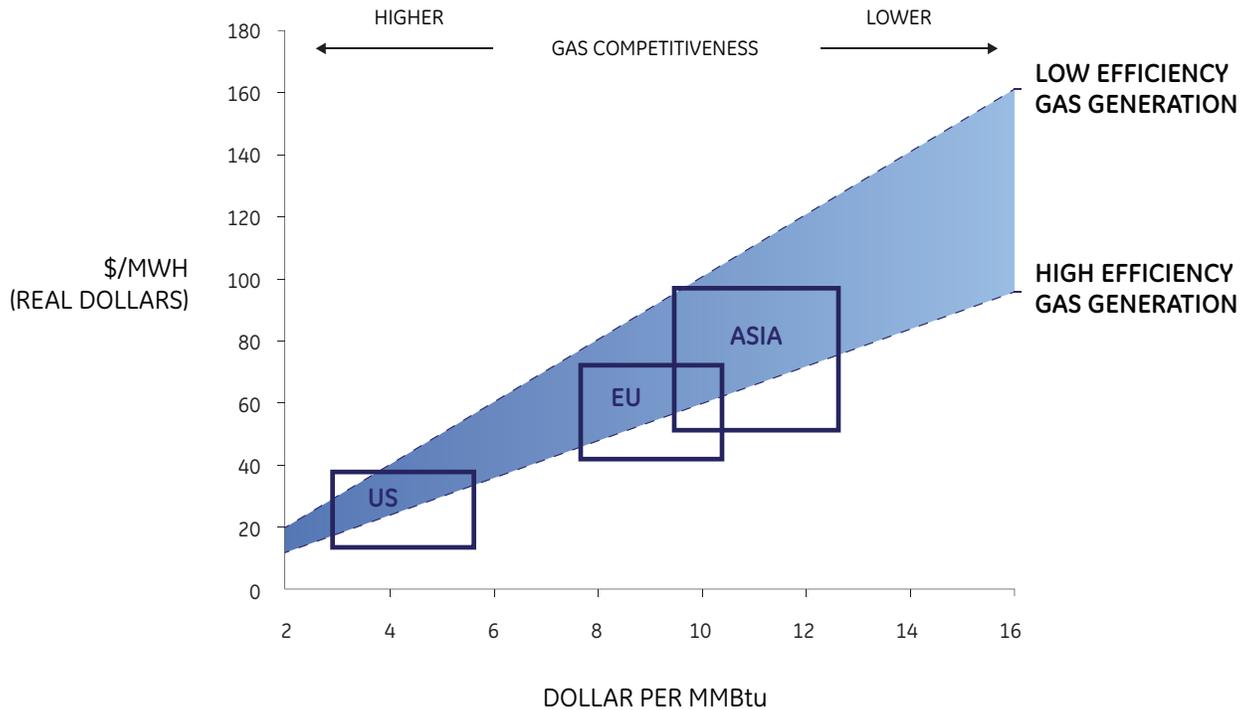
There are other factors beyond current prices which influence the role of gas in power generation. Gas contributes to the diversification of the fuel mix. Since it can ramp up quickly and follow load, it can contribute to flexibility. The environmental advantages of gas as a generation source are also well documented. Because it is composed primarily of methane, the main products of natural gas when burned are carbon dioxide and water vapor. Coal and oil, by contrast, are composed of much more complex molecules, with a higher carbon ratio and higher nitrogen and sulfur contents. This means that when combusted, gas releases much lower levels of harmful emissions than coal or oil. High concentrations of these pollutants also form PM<sub>2.5</sub> (dust particles which measure less than 2.5 microns—small enough to get deep inside human lungs). Producing 23 percent of nitrogen oxide (NO<sub>x</sub>), 50 percent of the carbon dioxide (CO<sub>2</sub>), and virtually no sulfur dioxide (SO<sub>2</sub>), particulate matter or ash, gas has a much more favorable environmental profile than other fossil fuels.

More recently there has been growing attention to the need for energy systems that reduce environmental impact, but also have the ability to better withstand or recover quickly from disruptions like hurricanes and severe winter storms. Gas-fired combined heat and power plants, which



Figure 4. Competitive Strike Zone For Natural Gas Varies By Region

Source: GE Age of Gas Outlook, 2013



NOTE: Estimates of high efficiency natural gas are based on 6,200 heat rate, while lower efficiency estimates are based on a 10,000 heat rate.

are highly efficient but can “decouple” from the central grid if necessary, are an example of resilient and sustainable infrastructure.<sup>16</sup> Further, gas-fired power generation can be combined with renewables to create a stable source of power that has less price exposure and a much lower emissions profile. The flexibility, versatility, and relative cleanliness of gas are well matched to the energy needs and market structures of developing economies, where demand for new sources of energy is the highest. Gas technology fits well with a world demanding more resilient and distributed energy sources along with traditional centralized energy supplies.

To a large degree the Age of Gas is about the ability of natural gas to catch up with and compete head-to-head with oil and coal. Today, oil, coal, and natural gas account for 83 percent of primary energy supply. Hydrocarbons are expected to provide more than 80 percent of the world’s energy in 2025.



Economic and environmental factors are driving increased fuel substitution away from oil and coal toward natural gas and renewables. Oil represents 31 percent of global energy use today, but should fall to 27 percent by 2025 as efficiency gains, conservation, and substitution effects take hold. This decline is largely from high prices further squeezing oil out of stationary applications, and the slow but steady adoption of alternative transportation fuels.

Fuel technology choices made over the next fifteen years will largely define the structure of the energy industry for decades to come. This brings concerns about path dependency, meaning it will be hard to change the path of development once technology choices are made—owing to the long asset life and slow capital turn-over of major energy systems.<sup>17</sup> If coal becomes the primary fuel in emerging power systems, the transition timeline toward a low carbon system will be extended. Coal has been the fastest growing fuel over the past seventeen years, gaining more than 3.5 points in share of primary energy consumption. Coal will clearly have a large role in generation going forward, and will remain a primary generation source in many parts of the world, but natural gas is positioned to capture more of the incremental growth.

There will be challenges for gas to win decisively and edge out the incumbent fossil fuels. It is uncertain if market forces and policies will align for natural gas to compete effectively against coal beyond a few regions of the world. The expectation in the GE Age of Gas outlook is that coal will hold at about 28 percent of primary energy through 2025, while natural gas gains another 3 points of share, reaching 26 percent of world primary energy. However, under the right conditions, including abundant supply, policy shifts, and network growth, gas could gain an additional 1 to 2 points of market share (5 percent growth total), achieving 28 percent share of primary energy consumption equivalent to, or slightly larger than, coal and oil in 2025.

Expanding the global role of gas will require a new wave of investment, additional policy adjustments and coordination as well as continued technology innovation. It will also require focus on the network aspects of the gas industry. While there has been growing attention to the multiple benefits of gas and the synergies that are possible with other energy options, there has been less attention paid to the importance of establishing gas networks and the options available to facilitate the



links between various energy systems. To appreciate how gas is likely to grow and evolve in the coming years, it is valuable to assess the role that networks play at all stages of the gas industry. There are different types of networks which operate in different ways and are enabled by different types of technologies. The primary focus of the remainder of this paper will be the pivotal role played by these networks in supporting and creating the Age of Gas.





## III. GROWTH AND TRANSFORMATION OF GAS NETWORKS

Gas is fundamentally a network industry. Networks are necessary to move gas from the source of production to the location where it will be used. There are different elements to these networks that are important to consider. One is the power of networks themselves; a key element is that as networks grow they become increasingly valuable. Another aspect concerns the different transportation modes by which gas can be transmitted, namely pipelines and oceans but also road and rail networks. There are also the different levels of network development around the world, with some large, dense and competitive gas networks, and others just starting to build connections. Last but not least, there are the interconnections and interdependencies between gas networks and other networks, both physical and digital. In short, understanding the Age of Gas includes an appreciation of the different types of networks that exist, how these systems operate and how their value changes as they evolve.

### Power of Networks

Networks are an important feature of modern economies. Reduced to their most basic level, they consist of patterns of interconnections between different things.<sup>18</sup> Some networks like telecommunication systems support the transfer of different forms of data, such as voice, video and computer files, from one point to another. Other networks have grown to enable heavy physical goods to be moved, such as rail networks and roads. In the case of gas, networks are essential to transmitting a valuable fuel from the point of supply to the point of end use. The most basic is a unidirectional link in which gas is moved from one point to another point. More advanced gas networks involve hub and spoke structures and more transmission options, and some even are designed to permit flows in reverse so that they can be bidirectional.

An important feature of networks is how their value changes as they become denser and more complex. Networks tend to become increasingly



valuable with size due to reinforcing positive feedback that occurs as more entities join the network. These characteristics facilitate the development of adjacent networks, uncovering hidden opportunities to create value as new links are established. Networks create opportunities to bring buyers and sellers together both on the upstream to supply the network and among downstream users of the network. Network growth contributes to lowering costs and creating greater flexibility in the system, which in turn fosters further growth. Capturing these economies, or what economists refer to as economies of scope and scale, serve to lower transaction costs and create more efficient markets.<sup>19</sup> There can, of course, be downsides to networks. For example, networks, or portions of networks, can become less valuable if they become congested with excessive use. Parts of a network can become stranded, or overbuilt, as resources deplete or markets shift, creating cost recovery challenges. This is where appropriate pricing, investment, optionality, and storage become critical to optimizing the scale of the network to match supply and demand.

### Network Modes

Natural gas systems around the world depend on three types of networks to support the transportation of natural gas.<sup>20</sup> These network modes and examples of the technologies that enable these modes are illustrated in Figure 5. By far the most significant mode today is pipelines, mostly land based, which transport approximately 89 percent of gas through a global network of over 1.4 million kilometers. Most of these pipelines, or about 70 percent, are regional lines that support gathering on the upstream and distribution within their domestic markets. The balance consists of large-diameter continental scale pipelines found in places like the US, Canada, Russia and increasingly China.

Pressure is essential to moving gas through the pipeline system. This is achieved through compressors that are located at regular intervals along the pipeline. With compression, gas moves about 25 miles per hour (40 km per hour) through long distance pipelines. For example, gas takes about three days to travel the 2,000 mainline miles from the Eagle Ford shale in south Texas to New York City. Another example is the recently constructed Nordstream offshore pipeline extending 1,224 km from Vyborg, Russia to Greifswald, Germany. This pipeline uses special coatings to reduce friction,



Figure 5. Gas Network Transportation Options

Source: GE Global Strategy and Analytics, 2013

NETWORK TYPE	% OF GLOBAL GAS TRANSPORT	ENABLING TECHNOLOGIES		
		COMPRESSION	TRANSPORT	REGAS/STORAGE
LAND-BASED PIPELINES	89%			
OCEAN-BASED LNG SHIPS	10%			
PUBLIC ROADS & RAILROADS	MICRO LNG			
	CNG			

enabling the gas to traverse the Baltic Sea in little over a day. More than the speed, they move energy; the value of pipelines is that they have the ability to transport energy relative to other options.

The second mode is the LNG network, which constitutes 10 percent of global gas trade. This sea-based network is made possible by the invention of LNG and large special-purpose transport ships that ply the oceans linking exporters with importers. The facilities that compress the gas to a liquid state for transportation are highly sophisticated and complex operations that can often cost \$10 to \$50 billion. These investments enable large quantities of gas to travel very long distances. For example, it takes about 20 days for gas to arrive in Japan, the largest LNG importer in the world, from Ras Laffan, Qatar, the world’s largest exporter.



Finally, transportation networks can be used to move gas by piggy-backing on already existing road and rail infrastructure. This is made possible through compression technologies like CNG and small-scale LNG. Compressing or liquefying gas reduces natural gas so it can be transported in steel tanks, tube trailers, or tanker trucks. One problem is CNG and LNG are less dense than gasoline or diesel fuel. A gallon of CNG has about 25 percent of the energy content of a gallon of diesel fuel. LNG has 60 percent of the volumetric energy density of diesel fuel. Liquefying the gas creates a denser fuel. Lower energy density limits gas efficacy in some applications, but the cost difference between the fuels can make CNG or LNG a smart choice—especially if the size of the project or other constraints preclude pipeline development. Since the LNG trucks or CNG tube trailers serve the same function as a pipeline, this mode is sometimes called a “virtual” pipeline. This is a relatively small but a growing portion of gas transportation. Virtual pipeline concepts are emerging as a way to quickly enable use of gas as a transportation fuel or in distributed power plants. While these smaller scale systems have been around for years, economic and technological factors are creating new opportunities for rapid growth within integrated energy infrastructure projects.

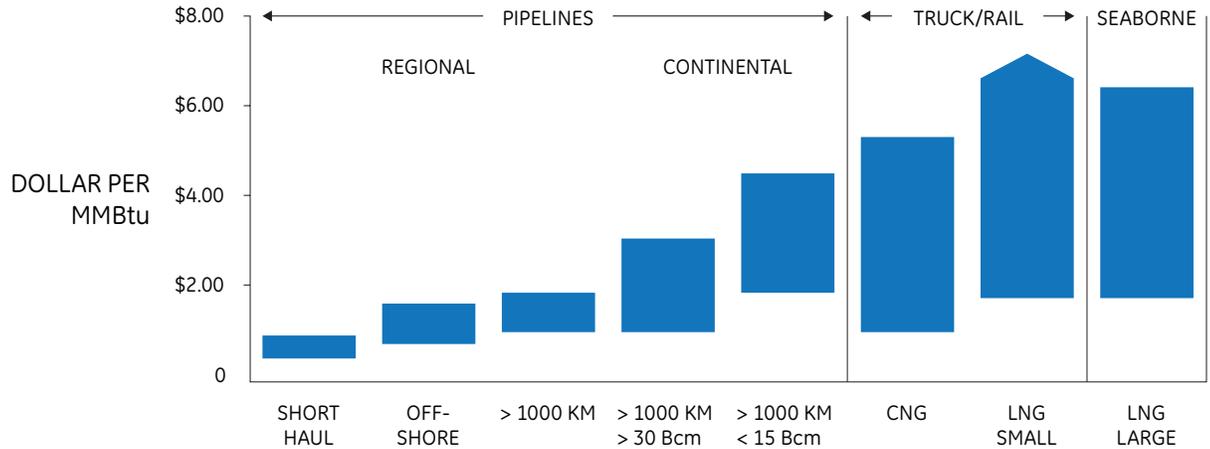
In contrast to oil, transportation costs comprise a significant portion of the total cost of delivered gas. Each of these network modes has a different cost structure, illustrated in Figure 6. The short haul regional pipelines are the least expensive at less than a dollar per MMBtu. The large-scale pipelines that move gas 1,000 kilometers can range from \$1.50 to \$3.75 per MMBtu.

LNG transportation solutions have a much wider range with costs from as low as \$1.75 up to \$6.00 per MMBtu or more. Much depends on the location and scale of the liquefaction facility and the cost of the specialized ships used to transport the super-cooled liquefied gas. Trucking and rail options also vary widely in cost, ranging from as low as \$1.75 to \$6.50 per MMBtu or more. The compression technology and special pressure vessels make a significant portion of the investment required for this mode. Economics plays a large role in determining which solution is selected to move gas from sources of supply to ultimate demand.



Figure 6. Cost Of Natural Gas Transport

Source: GE Global Strategy and Analytics, 2013



NOTE: Small CNG and small LNG include local distribution and storage costs.

### Network Evolution

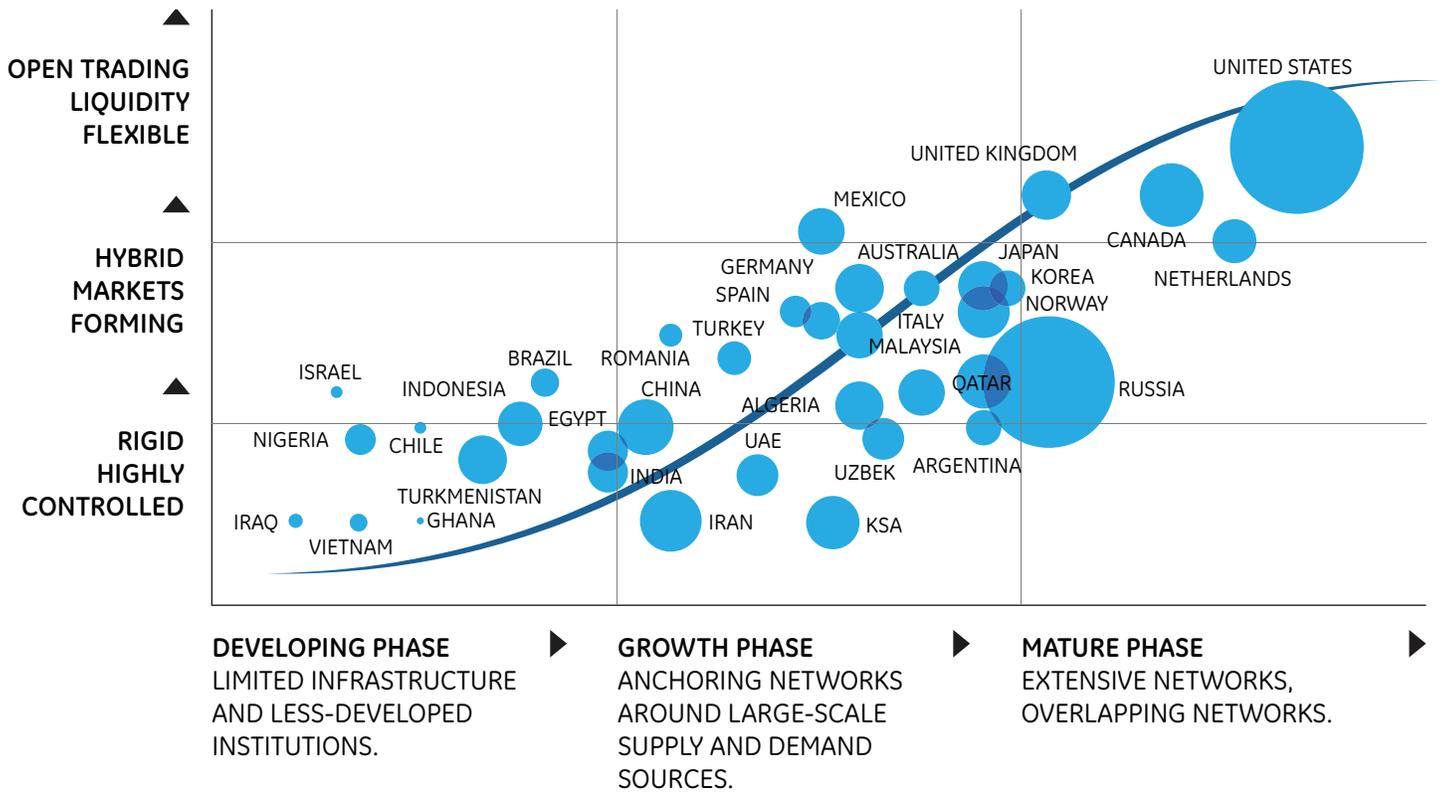
There are important differences in the level of network development around the world. The growth of networks is shaped by two broad elements as shown in Figure 7. One dynamic involves the level of physical network development within countries and between countries and regions. There is the *development phase* where gas infrastructure is very limited; the *growth phase* where infrastructure is being built out, anchoring networks around large-scale supply, and the *mature phase* where density is high and there are many opportunities to build linkages between networks. The other dynamic concerns the level of market and institutional development. Markets can be rigid where prices and allocations of gas and infrastructure are highly controlled by governments.

At the other extreme, markets can be open, highly liquid and very flexible. There are also hybrid markets, which sit somewhere between, and have elements of both rigidity and openness. Developing new energy infrastructure is costly, but there are high levels of systems benefits if a level of transparency and interoperability can be achieved.



Figure 7. Gas Network Growth Curve

Source: GE Global Strategy and Analytics, 2013



● GAS MARKET SIZE

NOTE: Illustrative rankings based on subjective institutional variables related to market liquidity and openness and a combination of quantitative and qualitative measures related to gas infrastructure. Bubbles show gas market size in 2011.

There is an evolutionary path for gas networks that involves both infrastructure and markets. Today, the early stage gas grids found in countries like Ghana, Vietnam and Iraq, are typically point-to-point, based on monetizing stranded assets. During the growth phase, a more diverse set of supply and demand sources emerge and delivery systems expand toward hub-and-spoke or rooted-tree based designs as is happening in Algeria, Turkey and China. Mature gas networks are complex, with access to multiple sources of supply, demand, interconnections, and buyers and sellers. Furthermore, there is typically more interconnection with other energy networks.

More mature networks will typically have more liquidity, pricing options, and regulatory structure. In fact, the regulatory structure is a key element



“Finally, deeper integration of networks both vertically and horizontally will enhance the overall resilience of energy systems, making them more impervious to disruption.”

in infrastructure development. Uncertain regulation can slow investment, but static regulation that supports entrenched monopolies reduces competition and can slow innovation. There are a number of forces that determine how fast gas networks evolve; factors include the economic base, demography, climate, geography, resource endowment, technology access, and strength of governmental institutions. The nature of these factors determines evolutionary pace from simple to complex, or if a gas

network will evolve at all. As the networks grow, the options for the users of those networks grow, whether they are producers or consumers, assuming access to the networks is allowed. Value can come from trading in the commodity (natural gas), converting gas into more easily transportable or useful products (LNG, CNG, electricity, ethylene, methanol, ammonia, or gas liquids), or an “intangible asset” like a capacity right to move gas across a segment of pipeline. The additive nature of gas networks is one of their essential features.

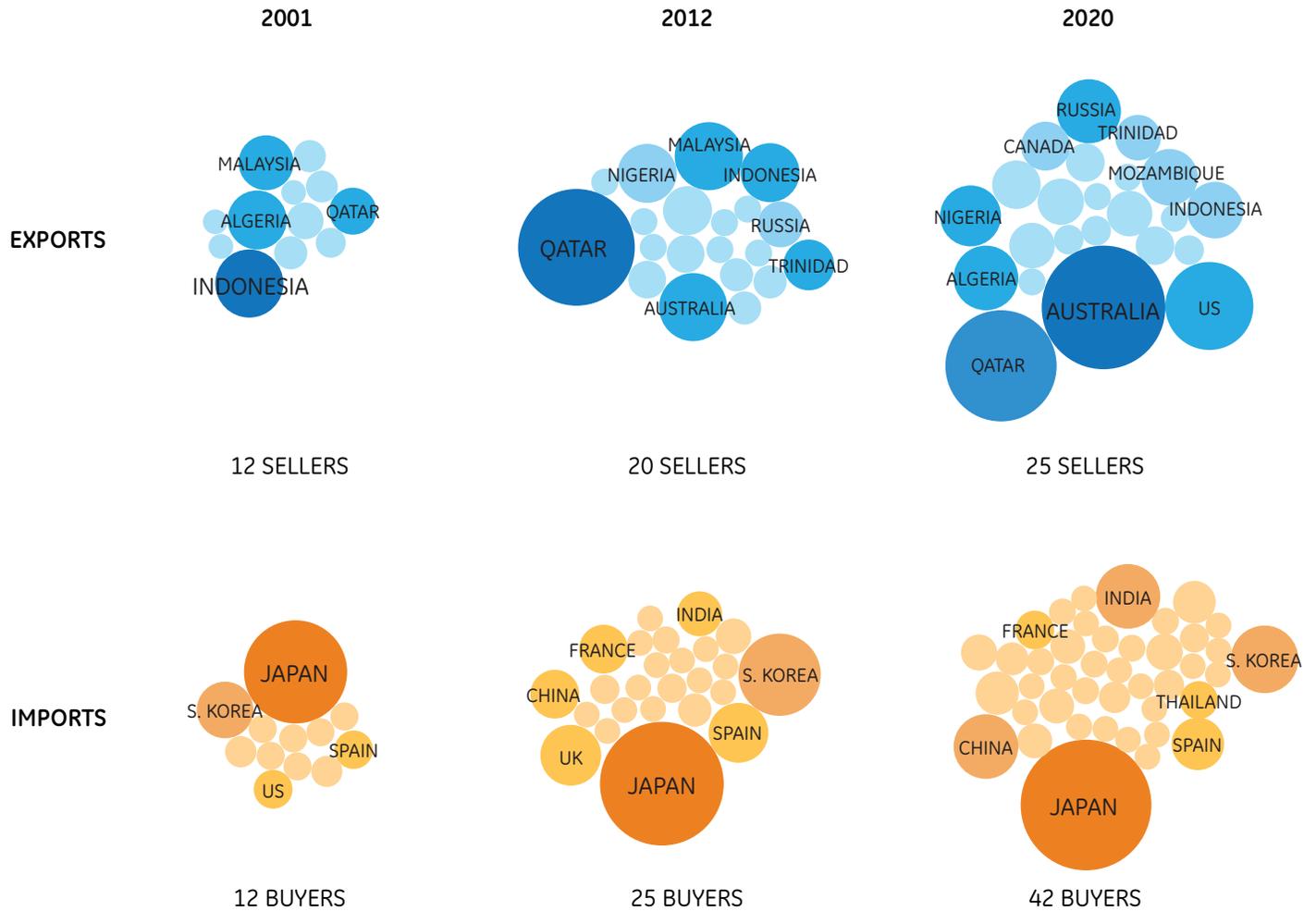
### Network Density: LNG

As the network connections grow, there will likely be more inter-regional trade. Furthermore, increased network density enhances the redundancy and flexibility of the gas system. Deeper integration will also create the potential for greater competition across networks. Shorter-term trading in both gas supply and capacity are likely to increase. However, the old contractual trading models are not likely to be abandoned. In the future, there is likely to be more of a hybrid structure designed for greater customer flexibility. As the complexity of gas systems increase, they tend to become more flexible, offering expanding options. This contributes to changing risk profiles for various stakeholders in positive and negative ways relative to current practices. Finally, deeper integration of networks both vertically and horizontally will enhance the overall resilience of energy systems, making them more impervious to disruption. In general, as networks become larger they also become more efficient, more flexible and more resilient. While expansion is happening at different rates, the less developed gas networks of the past are very different from more developed networks today.



Figure 8. Deepening Global LNG Market – More Buyers And Sellers

Source: GE Global Strategy and Analytics, 2013



LNG trade provides a good example of network linkages that have grown over time. As shown in Figure 8, there were 12 countries exporting LNG and 12 countries importing LNG in 2001. By 2012 the number of exporters had expanded to 20 and the number of buyers to 25. By 2020, we estimate that the number of countries involved in trading LNG will grow to 25 sellers and 42 buyers. Their net position will change. On the export side, Qatar, which had grown to 30 percent of the market, will fall in relative terms to approximately 17 percent as Australia and the United States grow as suppliers. New suppliers will also enter the market, such as Mozambique.



On the import side there will be some shift in position, particularly the greater role that China and India will play as importers. Brand new importers will also arise with countries like Poland, Bangladesh, Thailand, the Philippines and South Africa entering the market looking for supply. While not currently importing, a number of other countries could join the ranks of LNG importers over the next decade including Uruguay, Croatia, Lithuania, Ivory Coast, Costa Rica, or Jamaica, creating an even larger pool of buyers. By 2020, internationally-traded LNG could make up as much as 20 percent of global gas supply with significant changes in the relative roles of exporters and importers. The growth in the number of buyers and sellers will create deeper networks as shown in Figure 9 and open up new flexibility in the market and new competitive dynamics.

### Network Interconnections and Interdependencies

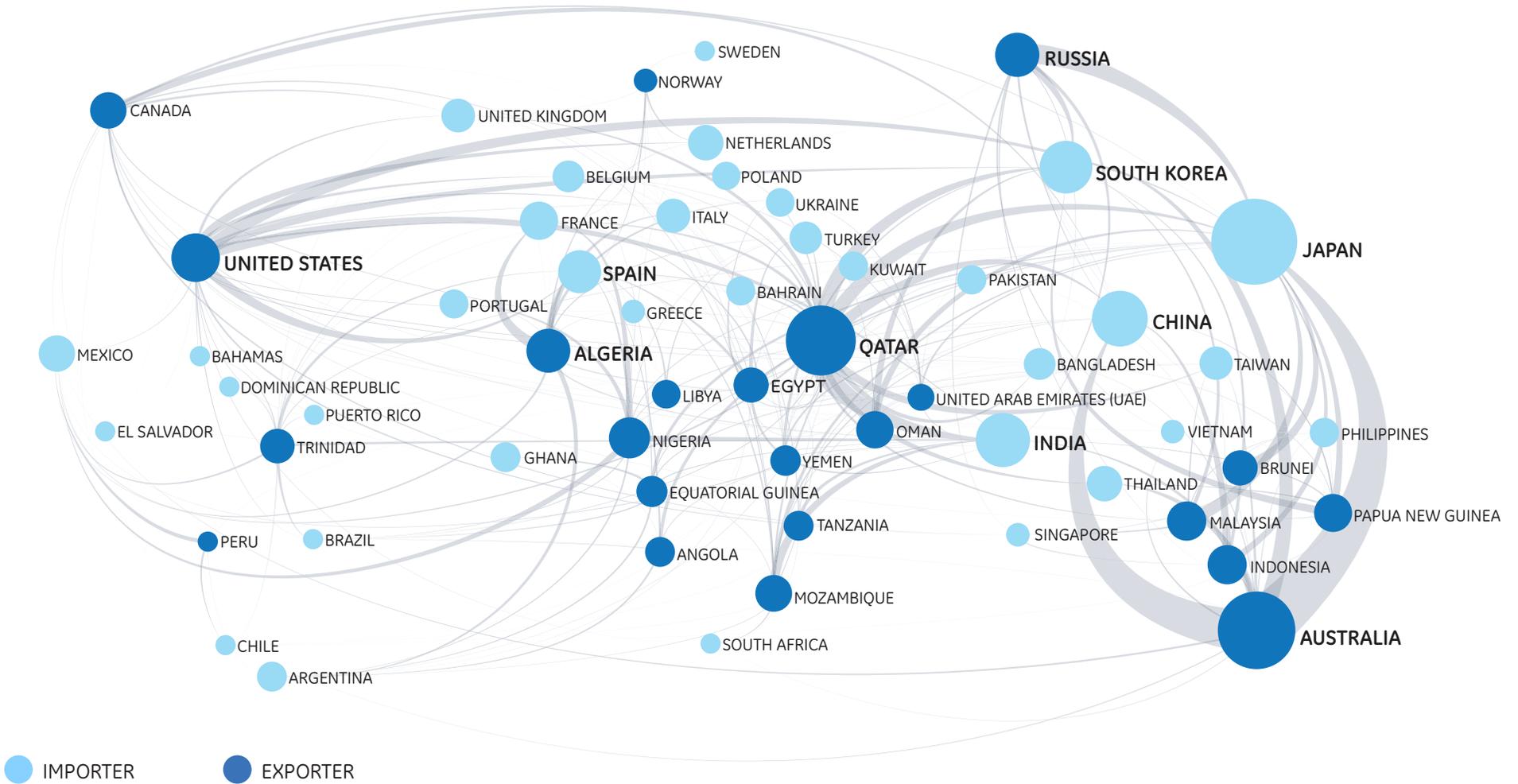
A final element to consider is the relationship between gas infrastructures and other networks. At this level, there are multiple complex connections that create a web of functionality. New interconnections create more supply diversity and customer options. As the layers build, different parts of the gas system, gathering and processing, storage, LNG systems at large scale, LNG or CNG systems at small scale, distribution grids, and the complex control and software systems needed to monitor, track and trade natural gas, create a powerful network—a system that is far more than just interconnected pipelines. However, even as pipeline networks become denser and supply sources diversify, backhaul and other types of displacement services start to emerge in the pipelines. New supply sources, coupled with modifications in compression systems, can allow flow from either end of the pipeline to effectively double throughput capacity. Simply put, as new components are integrated into gas systems they become more powerful.<sup>21</sup>

Not only are we likely to see the various gas transport modes become more fully integrated horizontally over the next decade, we are likely to see greater vertical integration as well. The deepening connections between gas supply and electricity generation is an obvious example. Another example is the potential for gas to become more commonplace in supplying fuel to rail and trucking. In the US, 42 billion gallons of diesel are used to fuel the fleet of approximately 2.3 million heavy trucks and



Figure 9. Global LNG Network In 2020

Source: GE Global Strategy and Analytics, 2013





24,000 locomotives. The higher cost of oil is driving strong interest in gas substitution through small-scale LNG. Lower cost natural gas can be tapped with the development of large “joint-use” LNG fueling stations with capacity of 250,000 gallons per day. Various companies are looking at the opportunity, and it seems that modest investment could yield big fuel savings in the heavy-duty fleets. Strategically-located liquefaction plant investment of \$15 to \$20 billion has the potential to reduce US diesel use in transportation by up to 30 percent.<sup>22</sup> As long as the economic incentives remain in place, the technology to transport and utilize gas in heavy-duty engines will mature as the market grows.

More broadly, many new technologies that support the further development of gas networks globally are emerging. These enabling technologies are discussed in more detail in the next section.





## IV. ENABLING TECHNOLOGIES AND THE INDUSTRIAL INTERNET

Technology innovation has been a critical enabler throughout the history of the gas. This will continue to be true as gas networks expand over the next decade. Innovations are occurring both at the component and systems levels. The building blocks of gas networks including compressors, valves, turbines, and engines continue to be pushed to design limits. These advances are important, but the transformational impact is coming from new combinations of existing, and even mature, technology into smarter, cleaner, and more efficient systems. New technology systems like those developed for unconventional gas, floating LNG, and advanced monitoring and control will be important to gas network growth. These and other new technologies can be divided into the roles that they play in supporting future gas network development. There are innovations taking place upstream focusing on supplying gas networks. Others contribute to securing and optimizing gas systems from a productivity as well as environmental and safety standpoint. Lastly, there are technology innovations focused on growing and expanding the range of applications for gas. Each of these technology developments will play a key role in to the development of the Age of Gas.

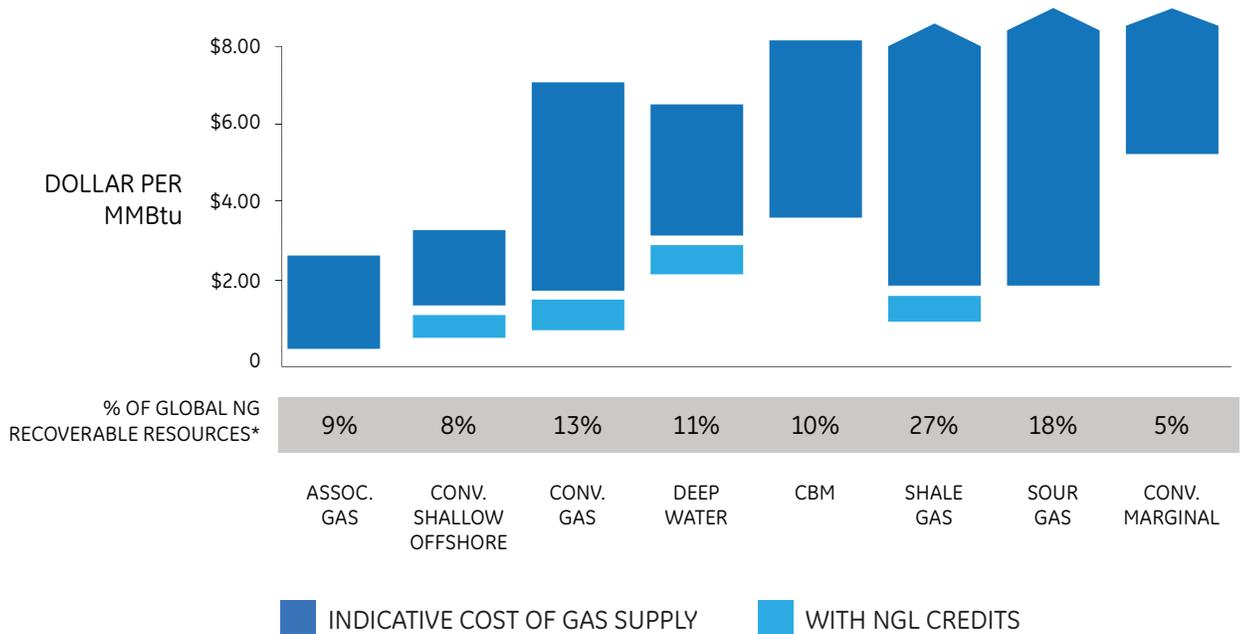
### Supplying the Network

Innovations in the upstream natural gas industry are taking place at the fastest pace in decades. We are seeing a proliferation of new ways to produce natural gas more efficiently at lower cost and in a more sustainable way. Two big drivers of gas supply growth over the next decade will be remote gas mega-projects and the rise of unconventional gas. Each of these supply categories has different attributes and will require special technologies unique to its development. We turn first to the role that technology plays in determining the cost of gas supply.



Figure 10. Indicative Costs Of Gas Supply

Source: GE Global Strategy and Analytics estimates, IEA Resources to Reserves 2013, EIA stranded gas 2013, USGS



NOTE: Technically recoverable gas resources are approximately 800 trillion cubic meters (28,248 trillion cubic feet) or about 230 years of gas consumption at current rates; NGL (natural gas liquids) credits refer to the additional revenue generated from extracting ethane, butane, and other oil liquids within the gas stream as it is produced.

### Costs of Gas Supply

To understand the impact of technology on the cost of gas supply, it is useful to look at some of the types of supply available and the range of costs required to bring those supplies out of the ground. Supply costs, combined with the transportation costs previously discussed, determine the full cost of natural gas shipped to end-users. Figure 10 shows ranges of costs for various types of gas supplies. The actual costs of gas from any particular location are dependent on a large variety of factors including gas reserve potential, field equipment and operational costs, tax and land costs, gathering or processing requirements, and the necessary return on capital investment.

It is clear from these estimates that there is a wide range of costs from most potential gas sources. We think a large quantity of gas supply,



perhaps 65 percent of the recoverable gas resource base, can likely be produced when gas price in production areas range from \$4.00 to \$8.00 US dollars per million British thermal units (MMBtu). As technologies advance, more gas resources will likely become economical within this range.

The lowest cost gas comes from supplies that are co-produced with oil (associated gas). For associated gas, the oil production “pays” for the infrastructure to drill for gas, but specialized separation and processing equipment is required to make the gas viable. The highest cost sources of gas are marginal gas supplies that come from small fields with low quality prospects or from fields laden with contaminants like hydrogen sulfide (H<sub>2</sub>S). Gas fields that contain toxic gases like H<sub>2</sub>S are called “sour gas” operations and require specialized equipment that resists corrosion and provides leak-proof operations. Gas fields with varying degrees of “sourness” make up nearly 20 percent of potential recoverable resources—so they remain an important source of future gas supply. For example, many parts of the Middle East and the Caspian region have successfully and safely developed sour gas, and are expected to continue to do so.

Shallow and deepwater offshore gas are additional sources requiring a variety of specialized technologies. Offshore systems consist of a variety of fixed and floating technologies along with unique logistical, communication, and safety considerations related to a marine environment. Deepwater gas plays are estimated at about 11 percent of the global recoverable gas resource base. The cost of deepwater gas depends on issues like the water depth and subsurface conditions including reservoir temperature and pressure. The development of technology that sits on the sea floor has been one way to access new resources without using large, expensive floating platforms. This has made new gas fields cost-effective to develop and is an exciting area for technology development. Deepwater plays based on large conventional gas resources with NGL’s have the lowest costs. Deepwater gas based on medium-sized reserves is expected to cost in the range of \$3.50 to \$4.50 per MMBtu including the costs of bringing gas to shore on dedicated gathering lines.

Unconventional gas sources like CBM and shale gas are potentially 30 percent of global recoverable gas reserves.<sup>23</sup> CBM and shale are fundamentally different than traditional gas supply sources because the hydrocarbon source rock is also the reservoir (the rock formation that



holds the gas). The potential cost of unconventional gas depends more on the ability to produce the gas from the reservoir than the absolute amount of gas in place. Next-generation CBM and shale gas sources are expected to have similar costs in the range of \$4.00 to \$8.00 per MMBtu. The mature developments of shale gas in North America are on the low-end of the cost range. Expected costs for other regions will initially be 2 to 3 times the cost of North American supply. Hopefully, technology can be deployed to drive these costs down.

Two broad supply categories will be the focal points for gas technology development over the next decade. The first is *remote gas mega-projects* including many deepwater, sour gas, and large conventional gas developments. The second category is *unconventional gas*, which includes shale gas and CBM. Each of these categories has different attributes and will require special technologies unique to their development.

### **Remote gas mega-projects**

The term mega-project typically refers to any gas development that requires capital investment in excess of one billion dollars. Some natural gas mega-projects can have capital cost 10 to 20 times this level especially if LNG liquefaction plants are part of the development plan. The increasing scarcity of low cost oil, and limits on the ability of international oil companies to access conventional oil resources, have supported mega-gas developments of remote or stranded gas resources in recent years. This, in turn, has driven waves of technology development to bring these supplies to market.

Remote gas mega-projects tend to feature:

- Concentrated resources, typically conventional gas integrated with LNG or pipelines;
- Large upfront capital outlay and long lead time to first gas;
- Harsh environments, often in deepwater or arctic conditions; and
- Vertically-integrated project structures with risk sharing.

There are a number of examples around the world. In Russia, the Sakhalin Island LNG project in far eastern Russia or the Bovanenkovo field development in the Yamal peninsula feature Arctic gas challenges



with the need for significant supporting infrastructure (railroads, roads, port facilities). Large offshore gas projects can also need integrated infrastructure development. For example, the Shah Deniz project in Azerbaijan is linked to major gas pipeline development efforts into Turkey; or the Gorgon LNG project in Western Australia has natural gas liquids extraction facilities, a large CO<sub>2</sub> injection system, and an offshore pipeline to bring domestic gas from Barrow Island to mainland Australia. These examples highlight the need for complex systems integration and coordination for remote mega-projects.

The complexity of mega-projects can drive cost inflation. Technologies that improve hydrocarbon production, reduce expenditures, or decrease start-up time in the field are essential. Examples include tested modular designs that can be scaled up, or the ability to fully test critical components before arriving on location to insure field performance. Two interesting technology areas, among many, that could be transformational for mega-projects in the future are new floating LNG systems and the Industrial Internet.

### **LNG technology: super-cool floating systems**

The core technology in LNG systems cools natural gas to -260 ° Fahrenheit (-160 ° centigrade) until it condenses into a liquid at atmospheric pressure. This reduces the gas to 600 times less than its gaseous volume so it can

be transported. Large LNG liquefaction plants contain massive refrigeration trains and a variety of systems to prepare the gas for liquid transport. One key trend in LNG technology is related to the development of floating LNG liquefaction plants (FLNG).<sup>24</sup> FLNG combines production and liquefaction on a single vessel so there is no need for an offshore pipeline to shore. Floating LNG allows gas producers to access medium sized offshore gas reserves that are not sufficient to support larger onshore facilities. FLNG ships can potentially be moved

to new gas fields as reserves deplete, giving them mobility that onshore LNG cannot match. FLNG liquefaction projects (1.2 to 5.0 Bcm per year) are typically one-fifth to half the size of traditional LNG supply projects (7-20 Bcm per year). One advantage of FLNG is that many components

“Floating LNG systems are likely to be one of the fastest growing parts of the gas network over the next decade.”



“As the shale industry expands and matures with a continuous improvement mindset, it is likely that environmental performance will improve as well.”

can be assembled in the controlled environment of shipyards. This reduces some of the location-specific issues, like skilled worker shortages, that hurt the economics of onshore plants. Further downstream, FLNG is also making an impact through floating regasification and storage units (FRSU) technology. These ships dock with LNG tanker vessels to store and regasify

LNG for delivery in the gas system. FRSU projects can be developed quickly (12 to 15 months) and can deliver large quantities of gas (2 to 10 Bcm), allowing rapid deployment of LNG into new countries where domestic supply is scarce and pipeline development is slow. FRSUs are also a good option for countries looking for a quick back-up to domestic supplies. Floating LNG systems are likely to be one of the fastest growing parts of the gas network over the next decade.

### **Industrial Internet for natural gas mega-projects**

Digital and automation technologies will continue to be customized for upstream oil and gas duty and increasingly be incorporated into next generation mega-projects. Advanced sensors are allowing real-time monitoring of operations for safety and efficiency. The combination of software embedded with hardware allows unprecedented performance-monitoring, as well as field- and asset-level optimization. The new approaches are moving the industry from a “when it breaks—fix it” mentality to more asset life-cycle optimization with integrated hardware and software approaches. Furthermore, remote monitoring and control tools are becoming more advanced, allowing for improved predictive analytics. Critical data feeds can be processed and routed to operators with timeliness and precision, allowing key personnel more time to make critical decisions and adapt to events. Increasing safety and reducing down-time will likely shape investment decisions in these technologies, but the solutions can be leveraged for other benefits like asset optimization around supply chains or to provide data transparency for regulatory needs or other reporting purposes.

### **Unconventional gas: a network of fractures**

The most publicized gas supply revolution has come from the unlocking



of unconventional gas resources through horizontal drilling and hydraulic fracturing. Unconventional gas and oil development has high drilling intensity, meaning the industry will require constant infusions of drilling capital to maintain and expand production.<sup>25</sup> As a result, unconventional gas development has a large operational footprint with many services including drilling rigs and crews, pressure pumping units and crews, water handling and processing, sand, chemicals, and drill pipe deliveries.

Unconventional gas projects, which have more of a manufacturing type approach to extraction, often have:

- Distributed resources, typically basin-wide, requiring large land positions;
- Ongoing capital outlay over the project life to offset rapid decline rates in individual wells;
- Variation in resource quality that makes identification of productive “sweet spots” critical;
- Continuous improvement to lower costs, increase productivity, and boost sustainability.

Fortunately, performance has been improving. The shale industry is taking less time to drill horizontal wells. Two years ago the average shale well in the US took 35 days to drill and complete. Today it is being done in 20 days. These kinds of efficiency gains are being achieved concurrently with higher productivity from each well drilled. Technologies that improve efficiency and productivity are critical to unconventional gas. Digital solutions for shale gas recovery and technologies that support sustainable operations are two examples.

### **Advanced imaging and data processing**

Industrial Internet solutions are also making an impact on unconventional operations. New concepts are emerging that can expand shale gas supply by using data and analysis to more rapidly de-risk unconventional gas in new regions. One of the reasons shale gas was so successful in the US was because the sub-surface geology was fairly well understood. There was more than 50 years of well data accumulated in shale areas that could be studied and processed before drilling and fracturing began. This is





not the case in emerging shale plays, where only a handful of wells have been drilled. New technology integrates advanced imaging with well data cataloging. The idea is to build the knowledge base of rock properties and then be able to quickly match results to a historic catalog of wells. This allows producers to design well programs that can be more quickly adapted to each new piece of information—a critical part of the “learning by doing” nature of unconventional gas.

### Technology for sustainable operations

The sudden success of shale and the impact on the environment has sometimes created sharp criticism. This has driven keen interest in the development of new technologies to mitigate the environmental impact of shale development. If the environmental benefits of utilizing gas are

part of the core value proposition relative to alternative hydrocarbons, then focus on reducing the environmental impact is essential for the industry to reach its potential. A host of technology options are available to improve well integrity, manage water production and disposal, reduce fugitive emissions, reduce diesel use, and optimize operations. Integrating gas and using electricity to drive pumps and compressors in field operations is one way to reduce emissions and often lower costs. Water management is improving through a variety of processing, purification, and reuse systems. As the shale industry expands and matures with a continuous

improvement mindset, it is likely that environmental performance will improve as well. In the end, while it appears shale can be developed safely relative to other energy sources (all of which hold some negative impact) individual societies will have to decide if the benefits of shale outweigh the risks.

Our view is gas supply diversity is increasing. There will be many new options to supply the gas networks of the future. These gas supplies, with the help of new technology, will be cheaper and can be produced with lower environmental impact than ever before. However, the upstream part of the gas industry is not the only fertile ground for new technology; midstream and consumer technologies are also advancing.

“The Industrial Internet will play a growing role in securing and optimizing networks through technologies that monitor, analyze, control and help maintain pipelines.”



## Securing and Optimizing the Network

There is significant opportunity to further optimize and secure the sea and land-based components of natural gas systems. Two areas where technology is making an impact are related to digital monitoring and control of pipelines, and optimization of CNG/LNG fueling systems. Both examples feature innovation through integrating existing technology in new ways.

### Digital networks and the intelligent pipeline

In many mature networks, critical infrastructure is aging. For example, in the US, 50 percent of gas pipelines are more than 25 years old. It is widely appreciated that the cost of network failure can be enormous. Safety and the need to better understand asset integrity are the core reasons digital infrastructure is being more deeply imbedded into the fabric of energy networks. The Industrial Internet will play a growing role in securing and optimizing networks through technologies that monitor, analyze, control and help maintain pipelines.

Some aspects of digital systems are not new; they have grown around the pipeline networks in the form of supervisory control and data acquisition (SCADA) systems or through increasingly advanced scheduling systems. More and more sensors are being deployed to transfer data collected from inside and outside pipelines to the control stations. However, the volume of data from increasingly complex systems is outpacing older technologies. The next generation of digital systems will employ technologies including: satellite, wireless, cloud storage, and software tools for remote monitoring and control and predictive analytics.

The goal is to integrate data collection, processing, reporting, and analytics in smart ways. Physical systems can often mirror biological systems. There is a growing field of study that is looking for insights from biological systems to manage complex physical systems in simple and efficient ways. The lessons from health care can help. How do you create a system that can “feel pain” or heal in a dynamic way?<sup>26</sup> How do we create an intelligent pipe? Responding to a crisis with “situational awareness” or remotely identifying weak spots in networks, detecting leaks to reduce fugitive emissions, and faster asset recovery are just a few benefits of this technology.



## “Gas generation technologies are continuing to be pushed to new design limits.”

While safety and reliability concerns will drive deployment, over time we see additional benefits related to optimization and transparency. Better data and deeper analytics may allow operators to push the operating envelope of pipeline systems allowing additional throughput and revenue due to better business insight. Further, improved underlying data systems can provide shippers on the network near-real-time information, allowing for increased transparency and price fluidity in market-based systems. This becomes even more critical as constraints and costs of new infrastructure are driving multiple energy networks to become integrated. The need to manage gas networks for the hourly variations in electricity generation due to renewables is just one example. More broadly, the need to capture the value across energy networks will only increase and digital technologies will play a key role in allowing this to happen.

### Fuel systems for “mini-midstream”

While technologies for small-scale natural gas recovery have been available for years, new efforts are underway to integrate technology and use a variety of “mini-midstream” offerings. Midstream refers to the part of the gas industry between the producing fields and the consumers and the “mini” explains the scale of these facilities relative to traditional plants. Integrated designs typically have some element of gas pre-treatment, CNG compression, LNG conversion, leak-proof operation, and rapid distribution, along with storage or delivery systems optimized for safety. The sizes of these systems are very small compared to larger gas options (0.04 to 0.2 Bcm per year). There are a variety of target markets for these technologies including the transportation sector (heavy-duty, light-duty, and marine fleets), small-scale power generation, and for upstream or remote mining operations. In most applications, natural gas can closely match performance of gasoline or diesel-based networks. Storage is a challenge for both CNG and LNG, so this is a key area for technology innovation. The lower energy density of CNG requires special steel tanks that are heavy. Lighter and stronger materials are becoming available, but tend to be more costly. LNG has a much higher energy density, but requires special insulators and thermal tanks that keep the LNG cool and special cryogenic systems to pump the LNG.



The critical hurdle to scale-up of these small gas systems is the lack of fueling stations and infrastructure. New technology solutions will be focusing on removing this barrier to development. Innovative approaches feature smaller modular designs, portable and re-deployable solutions, and factory-tested or preconfigured solutions for shorter permitting and installation. Rapid deployment is a key element in these new network systems. Most systems can be running in 12 to 18 months, and even as fast as 6 months in some cases. Cost savings come from standardized designs that can be scaled and customized to particular applications.

### Growing the Network

Natural gas is a versatile fuel. Environmental advantages coupled with high efficiency and flexibility make natural gas a great choice for power generation and many other uses. Unlike coal or nuclear fuel, it can be cost-effective when used in both large and small-scale applications. Furthermore, as gas networks become available, it can become an alternative to oil. The technologies being deployed today are designed to bring flexibility to operations, help consumers capture value and create security of supply. Effectively mobilizing these demand-side technologies are an important part of achieving the sustainability, resilience, and competitive benefits of natural gas.

In this section, we briefly highlight key gas generation technologies and the relative costs of gas versus other fuels in power generation. These and other demand-side technologies will be discussed more fully in the next section in the context of the future of gas networks, recognizing that this is only a small sample of the technologies that are available to utilize natural gas.

### Flexible power with natural gas

Gas generation technologies are continuing to be pushed to new design limits. The latest flexible combined cycle power plants are reaching thermal efficiencies in excess of 61 percent<sup>27</sup>—meaning almost two-thirds of the energy in the natural gas is converted into electricity. If built at large scale, for example 750 megawatts (MW) of power, one plant can provide the annual needs of almost 600,000 US homes.<sup>28</sup> These plants can start-up in fewer than 30 minutes and increase power output at 100



MW per minute. When necessary they can be turned down to 14 percent of their baseload capacity to adjust to changes in system demand or the introduction of intermittent renewables. Simple cycle gas turbines are used for peaking duty and renewables balancing. For situations where a wider operating range is necessary, the latest generation of flexible, combined-cycle technology can capture most of the benefits of a peaking unit in a high efficiency system. Furthermore, the integration with renewables can occur through the electric grid at the system level or within the design of the power plant itself. For example, integrated solar combined-cycle technology is a hybrid system that uses a solar collector system to heat the water that is fed into the gas plants steam system. This reduces fuel use and improves thermal efficiency to nearly 70 percent while improving the economics of solar power.

At a smaller scale (typically 10 to 120 MW), gas-fired combined heat and power (CHP) systems using gas turbines, or gas engines for small plants, are an interesting gas technology option. CHP systems use the same fuel to create both electricity and steam. The steam is then converted into heat, or through condensers, into cooling for large commercial buildings, hospitals, airports, or industrial sites. Utilizing CHP, also called cogeneration, these power plants can achieve thermal efficiencies in excess of 80 percent, often with lower emissions and losses than grid-supplied options. Furthermore, CHP operations can be designed to disconnect from the larger grid in the event of a disruption, allowing critical facilities to be operated in “island” mode during natural disasters. However, CHP systems do have disadvantages. CHP projects can require customized designs and are tricky to develop in existing buildings. Additionally, coordination between electric grid operators and CHP operators is critical on a number of issues including excess power flowing back to the grid, back-up power requirements if the natural gas supply is disrupted, or safety concerns that might result from miscommunication.<sup>29</sup> Finally, the complexity of CHP relative to traditional boilers requires the training and development of skilled service technicians so systems run optimally. While barriers do exist, the potential benefits from a sustainability and resilience perspective can make CHP an attractive option.

Another gas technology for smaller applications (0.3 to 10 MW) is the natural gas engine. These engines can have high efficiencies (up to 45 percent thermal efficiency) relative to other simple combustion technologies. These



engines can be used in CHP configurations to achieve higher efficiency or in other distributed settings. They have low emissions relative to their diesel-fired counterparts and can run on a wide range of natural gas qualities (from rich to lean) and a variety of other gases including biogas, landfill gas, coal mine gas, sewage gas, and combustible industrial waste gases. The ability of some gas engines to burn natural gas with higher liquids content (rich gas) is ideal for oil and gas field power generation applications such as drilling and enhanced oil recovery.

Combined-cycle technology, CHP, and gas engines are three key gas generation technologies that will continue to advance. However, other technologies are emerging, such as fuel cells and small biogas systems.

### **Gas generation and the Industrial Internet**

Like upstream and midstream operators, power generators can benefit from the same preventative maintenance or fleet optimization ideas that are being used elsewhere in the gas industry. Data compression techniques are allowing plant operators to track changes in massive data streams instead of tracking every piece of data all of the time. As a result, operators can now better visualize the correlation between key data streams like temperature, system loads, humidity levels, and poor plant performance. Operators can query the system concerning an irregularity, and historic analogs are mined across thousands of units in service. Just as in shale gas, this enables companies to engage constant learning to improve efficiencies and reduce costs.

### **Capital intensity of power generation options**

Cost is one of the key factors driving choice of power generation technology. One of the key advantages of natural gas generation is that it often has lower capital intensity than other sources of electricity. As shown in Figure 11, on a dollar per kilowatt (\$/KW) basis, the cost of installing gas technology is one-third to one-fifth of the estimated cost of coal or nuclear plants, respectively.<sup>30</sup> Although regional factors can alter the relative capital cost advantage of gas technologies they typically have lower capital costs, but higher fuel costs. To understand the full cost of electricity, analysts examine the cost on a dollar per megawatt hour (\$/Mwh) or dollar per



kilowatt hour (\$/Kwh) basis. The cost of electricity is driven by a number of factors including the cost of fuel, the utilization rate of the power plant, the financing term and asset life of the project, along with the capital costs of plant construction, and in some regions, costs associated with emissions.

When evaluated on levelized cost basis, gas is still competitive against other technologies, but as previously discussed, fuel prices are a critical driver of energy costs. Changing the cost of fuel from \$5.00 to \$12.00 per MMBtu can change the cost of electricity for combined-cycle plants from \$40 to \$110 per Mwh. While the cost is important, other factors like capital intensity or water requirements can be important in some regions. Multi-billion dollar projects, like coal and nuclear, have long development timelines and are difficult to build if institutional structures are weak and or electric networks are immature. Water use is another limiting factor for some thermal technologies. Natural gas generation typically has one-quarter the water requirements of coal or nuclear plants depending on what type of cooling system is in place.

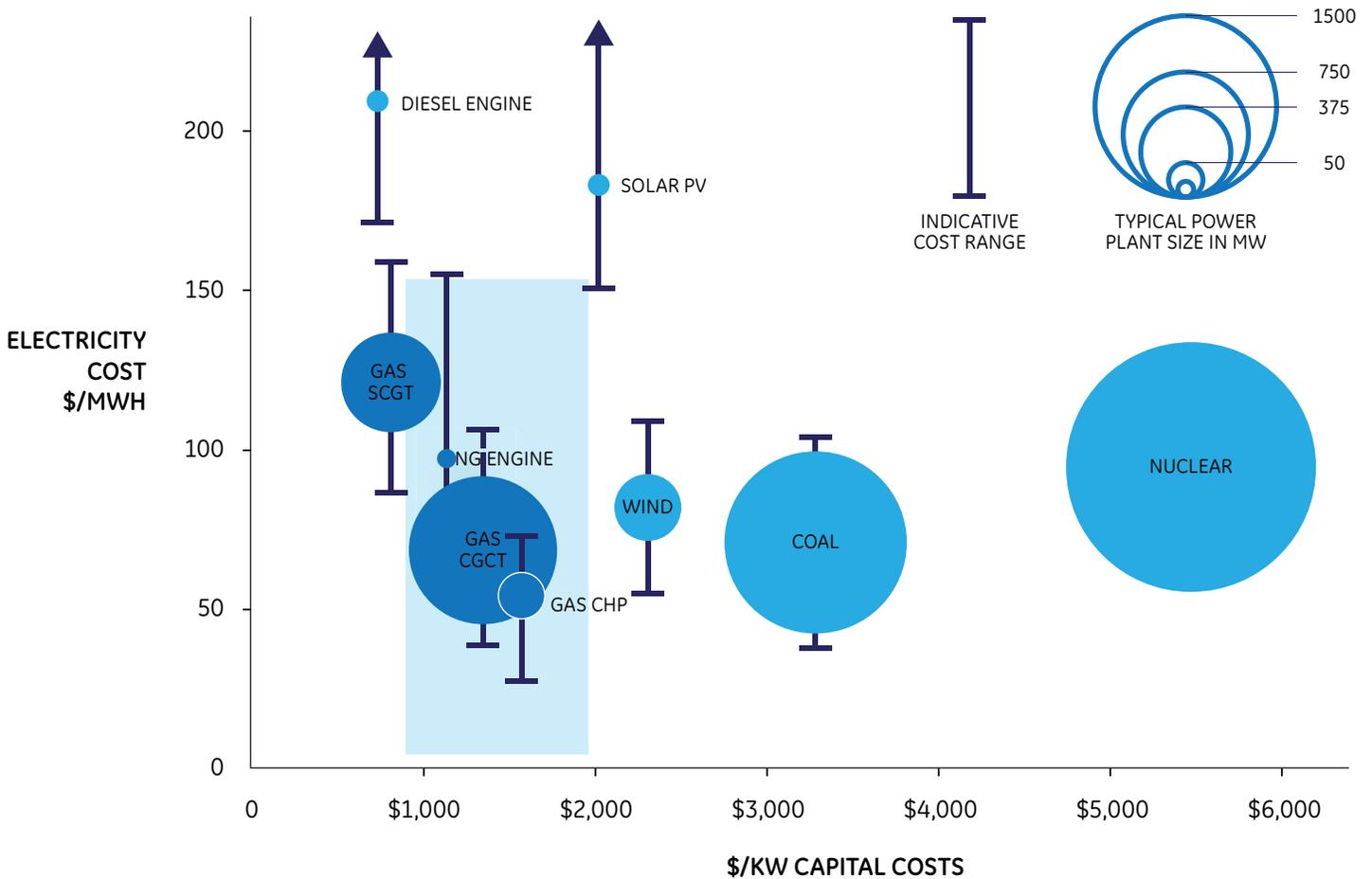
### **New technologies are driving network growth**

Technological advances have been vital to the expansion of the natural gas industry over its history and will be just as important in the future. New technologies are expanding gas supplies, which can now be produced with reduced environmental impact. Digital technologies and the Industrial Internet will also play a large role across the value chain. Gas-generation technologies are becoming a preferred energy platform because of their versatility and flexibility in supporting other energy sources like renewables. Technology is playing a critical role in supplying, securing, and growing the gas networks of the future.



Figure 11. Gas Generation Has Lower Capital Costs

Source: GE Estimates, GE Power and Water, EIA, JISEA, IEA



NOTE: All prices are in real 2010 dollars; no carbon prices included. Gas prices range between \$5.00 and \$12.00 per MMBtu; coal prices range between \$2.00 and \$4.00 per MMBtu; Diesel prices range between \$15.00 and \$25.00 per MMBtu; Gas SCGT capacity factor <10%; Wind capacity factor ranges between 25% and 40% without tax credits. Solar capacity factor ranges between 25% and 35% without tax credits. 10% IRR and 30 year asset life, except engines and solar have 10 year life.

SCGT: Single Cycle Gas Turbine; CGCT: Combined Gas Cycle Turbine; CHP: Combined Heat and Power





## V. FUTURE OF GAS NETWORKS

Gas networks will continue to grow and evolve. Exactly how and where this will happen is uncertain, but several patterns seem likely. Mega-pipeline and LNG projects will continue to be the anchor systems for global network growth. This is the traditional growth path to connect large supply sources with demand centers. Complementing these large-scale systems will be the next generation of smaller modular systems or satellites. Gas network development will involve the interplay between these anchors and satellites around the world. Another important trend will be the continued integration of gas with other energy network systems. Two are of particular interest—one involves the synergies that can be achieved by more deeply joining gas and renewables for electricity generation; the second is the inroads that gas will continue to make into as a transportation fuel.

### Developing New Gas Networks: Anchors and Satellites

The future development of gas will evolve across a range of development models—from state-owned vertically-integrated systems, where the state controls all aspects of development and trade; to the highly competitive networks of North America where government provides only the institutional structure for private investment.<sup>31</sup> Across this spectrum, the development of large-scale projects combined with smaller offshoots will continue to evolve.

### Anchoring big projects in the future

The idea of “anchoring” is fundamental to all large gas developments.<sup>32</sup> Projects are physically anchored on large supply and demand centers, but also anchored in a contractual and financial sense. Anchoring describes the matching of producer and consumer interests across the value chain that allows multi-billion dollar gas projects to move forward. The idea of anchoring is important because these large anchor gas projects become the critical infrastructure that gives natural gas a foothold in new regions—becoming the hubs that other smaller projects can build around.



“In competitive markets the role of the state is to establish the institutions that protect consumers and let the private players innovate, take on risks, and create value.”

The traditional model for anchoring pipeline and LNG projects has been vertical integration across the value chain.<sup>33</sup> For mega-projects, this will likely be true in the future as well. In fact, this practice has been increasing, particularly in Asia, as a way to offset mega-project cost pressures.<sup>34</sup>

Backwards integration by large gas consumers, such as power generators, into LNG upstream activities is also fairly common and may be more prevalent in the future as supply diversity increases. There are strong arguments from producer countries on the merits of the long-term contracting model to finance large gas projects and maintain security of supply and demand.<sup>35</sup> The challenge is that the traditional system can be rigid and poorly equipped to withstand changes in market conditions.

In the future, as gas networks expand and market structures change, it seems likely that competitive gas market models will advance.<sup>36</sup> In competitive markets the role of the state is to establish the institutions that protect consumers and let the private players innovate, take on risks, and create value. Competition is a natural outcome of an increasing diversity of supply options, more destination-flexible LNG supplies, new unconventional and conventional gas discoveries, and a larger integrated gas network. However, the specialized nature of gas network assets and the large financial risks involved mean that “merchant” approaches will be difficult for large anchor projects, except in the most mature parts of the gas network.

Around the world, a large number of anchor gas projects are likely to advance over the next decade. There are a variety of examples, some with different development models.

Selected examples include:

- Deepwater gas projects in India, China, and West Africa
- Shale-based LNG projects in the U.S. and Canada for export
- New or expanded regional pipelines
  - Iraq to Turkey
  - Turkmenistan to China



- Russia to China
- Southeastern Europe (Russia and Azerbaijan)
- Mozambique to Kenya and South Africa
- Indonesia (Sumatra and Java).
- Brazil (Northeast and shale region) and Argentina (shale region)
- US to Mexico
- US Northeast (Marcellus shale region)

Most of these regional anchor projects will use traditional development models. However, projects within—or originating from—North America, or connected to Western Europe, will be influenced by competitive dynamics. How these two development models interact and reshape the gas market going forward is one of the big questions facing the industry. Institutional structure and gas networks are evolving simultaneously. The ability of countries and companies to anchor big network projects are subject to a host of regional factors and market constraints. In growth regions, traditional development with long-term contracts will continue, but the terms will start to reflect a more hybrid gas market. Increasing options for gas consumers and the competitive dynamics against alternative fuels, particularly in power generation, will likely drive the need for multiple approaches.

### Satellites

The idea of satellite or “step out” expansions around existing gas developments will continue to grow over the next decade. The development of a large offshore platform or pipeline and processing facility creates opportunity for incremental development of smaller and isolated resources that otherwise would be uneconomical. An extension of this concept is the idea of satellite opportunities around existing midstream operations. This idea is not entirely new. Traditional compression or “looping” expansion of existing transmission pipelines is an example, as is process de-bottlenecking at liquefaction or fractioning plants to increase throughput, or simply the extension of distribution systems to new communities.



“Given uncertainties and the pace at which larger central generation projects may be built to meet demand, distributed energy provides a viable alternative.”

In the future, the combination of new technology with the growth of major gas infrastructure will offer expanded opportunities for incremental expansion. This will occur through a new generation of smaller modular systems and with digital systems—allowing additional optimization of latent capacity. For example, there may be an opportunity to squeeze LNG

cargo out of an existing liquefaction plant, or better measurement and control of pipeline operations that allow safe operation at higher pressures and increased throughput. Clearly expansion around existing systems brings questions of security, interconnection, access, and collaboration that need to be managed in order for these opportunities to be realized. However, the increasing network density and interoperability of gas systems are creating new growth opportunities.

### **Distributed power with natural gas**

Distributed power is poised for rapid growth. As gas engine and smaller-scale gas turbine technology has evolved and become more efficient, distributed power options are able to compete more effectively against centralized generation. Moreover, in emerging markets, where infrastructure is limited and regulatory and financial institutions are underdeveloped, distributed energy is an attractive choice. The flexibility of natural gas makes it an ideal fuel for a variety of distributed power opportunities including:

- Electricity and heating or cooling in cogeneration applications
- Pipeline and processing plant compression in gas networks
- Electricity islands in developing markets with weak or unstable grids
- Off-shore applications like ships and drilling platforms
- Electricity generation for remote sites, such as mines and oil and gas fields
- Fast-track deployment of generation to meet emergency power needs
- Next generation fuel cell or micro-turbine technologies



The lower levels of capital expenditure (lower capital intensity) and the faster timeline to “first power” or the initial production of electricity are key attributes of distributed power with natural gas. The trade-off is that unit costs can be higher. However, to the extent that modular growth is possible, these distributed sites can be replicated and integrated into larger transmission networks as they develop. Distributed power, and/or virtual pipeline concepts, can be a smart way to trigger economic development by initiating new energy networks or leveraging existing networks for incremental benefits.

Today, the high-cost oil and environmental concerns are driving incentives for oil/diesel substitution. The costs of oil-fired generation can easily be in excess of \$0.25 per kWh. Small-scale gas solutions, like gas engines, can often cut the cost of power by more than 50 percent, even after accounting for the cost of gas delivery. However, building dedicated gas infrastructures for smaller gas projects is challenging. Instead, leveraging existing gas pipeline infrastructure, and/or using small LNG or CNG systems are solutions, especially if stranded or low cost gas supplies are relatively close geographically. Furthermore, there are now opportunities to combine gas with other sources like solar. Gas can also complement small PV solar systems to overcome intermittency issues. This is where gas generation is an option to “firm-up” solar.

Distributed power opportunities are, by nature, driven by very region specific-issues. Developments that are taking place in Mexico, Egypt and Myanmar, and the special case of flare gas reduction, provide specific examples that help define the opportunities as well as challenges.

### **Mexico**

Mexico provides an example of how distributed power opportunities are emerging—anchored on larger natural gas projects and tapping neighbors with lower cost gas supply. There are currently proposals to build 8,800 km of new gas pipelines across the country.<sup>37</sup> Most of the projects are looking to draw on lower-cost US shale gas 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 decentralized 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. 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 small self-supply, cogeneration and renewables with various payment structures including net-metering (credits for self-generated power). The cost of electricity could fall to \$0.7-0.8 per kWh if gas can be delivered for around \$8 per MMBtu.<sup>38</sup> With gas coming into Mexico at the US border at \$4.00 per MMBtu this seems possible. Leveraging the expansion, low-cost gas supply is likely to create new opportunities for commercial and small industrial users, as well as possibilities for remote mining or oil and gas operations to switch to gas.

## Egypt

Egypt is at a critical juncture in the development of its energy system. Egypt has the advantage of fairly mature gas and power grids, but it is concentrated along the Nile river region. Most of Egypt's oil and gas resources are relatively remote—in the midst of deep desert or in deep water off the coast. 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. A diversified electricity strategy is attractive as fuel risk increases and new large centralized generation projects face delays.<sup>39</sup> Given uncertainties and the pace at which larger central generation projects may be built to meet demand, distributed energy provides a viable alternative. 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 around \$2.00 to-\$4.00 per MMBtu for small industry and commercial sites.<sup>40</sup> Low gas and power prices have hurt distributed renewables, but gas-based distributed power can serve to avoid peak-period constraints even at current prices. While distributed gas generation is increasingly attractive to overcome supply bottlenecks in the near-term, Egypt will need both centralized and distributed resources from a variety of sources to meet growing energy needs over the long-term.



## Myanmar

Recent reforms are spurring new economic opportunities in Myanmar. The prospects for demand growth are enormous and the country's electrification rate is estimated at only 26 percent. Power market reforms and progress on new pricing policies will be critical to drive investment, but if these efforts advance, the potential for growth is good. Conservative expectations call for a doubling in power consumption in 3 to 5 years if supplies can be made available.<sup>41</sup> While Myanmar is fortunate to have large natural gas resources, the current gas infrastructure is highly limited. The gas pipelines serving the domestic market are in need of upgrading and repair. The gas generation capacity in service today in Myanmar is highly inefficient.<sup>42</sup> The leveraging of existing gas export infrastructure offers the potential to accelerate domestic gas-based power generation.

Taking advantage of these opportunities and making improvements to the existing domestic distribution system could roughly triple gas availability into the capital city of Yangon and surrounding areas.<sup>43</sup> This expansion will create opportunities for small and medium-sized generation and cogeneration plants. These high-efficiency generation "islands" can be built within a few years and set the stage for larger, more integrated development down the road. 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 economical. To be successful, the government and operators will need to consider how these modular and isolated systems can be efficiently integrated into the larger centralized grids over the long-term. A building block approach of small island grids with appropriate voltage and network protocols will ensure that the larger transmission systems can be linked together to benefit the overall evolution of the integrated gas and power networks.

These examples illustrate only some of the ways in which gas can complement or substitute for centralized power as gas networks evolve:

- The potential to lower electricity costs and potentially drive economic development and industrial competitiveness



- The ability to overcome constraints on the development of new centralized generation
- The potential to utilize distributed gas-power “islands” for fast access to energy with the option to integrate these “islands” into the larger grid as transmission expands.

### Flare gas reduction

Natural gas flaring traditionally occurs in places where remoteness or economic considerations have driven governments and producers to burn away unmarketable gas during oil extraction.<sup>44</sup> The economics of gathering and transport can be marginal and if gas infrastructure does not exist, gas flaring occurs.

Despite progress in this area, natural gas flaring remains an important issue. At present 140 BCM gas is flared each year on a global basis.<sup>45</sup> This is equivalent to approximately 5 percent of global production. Since gas is often present when drilling for oil, gas flaring has been part of the oil industry since its inception. What is striking in the recent data is that in just a few years the US, largely as a result of oil growth in the Bakkan in North Dakota, has become a top-five flaring nation. The World Bank’s Global Gas Flaring Initiative has challenged gas producers to reduce gas flaring by 30 percent by 2017.<sup>46</sup> The Age of Gas outlook is more optimistic, envisioning 50 percent reduction by 2020. New technology, strong regulatory practices, and finding ways to utilize new and existing gas networks will contribute to making this happen.

Leveraging existing gas infrastructure has traditionally been one of the best ways to reduce flaring at smaller onshore fields. Often, smaller satellite plants can be managed with modest gathering pipeline and processing investments. In other cases where little infrastructure exists, possible solutions might include mobile power generation to utilize gas in field operations, reinjection of gas back into the formation, and micro LNG or CNG offer solutions. Natural gas is cleaner burning—and typically less expensive—than diesel trucked onsite, making it a great option if gas recovery is viable. All of these technology solutions effectively leverage power generation technology or road systems as ways to reduce flaring.



Another option that is gaining traction is the use of onsite flare gas to power artificial lift technologies. Artificial lift includes a range of technologies that are used to increase oil production from existing facilities after natural reservoir pressure begins to decline. Power generation is integrated with the lift technologies and a common set of monitoring and control systems. The advantage is that there is no waiting for availability of new electric grids. Also the systems are modular and can be redeployed at new fields as necessary. This approach will grow as a solution to flaring.

Offshore gas flaring poses a different set of issues. Space is limited at offshore sites, so reinjection or power generation is a good option. More recently, mid-scale gas-to-liquids (GTL) technology has advanced. The advantage of GTL is that it can leverage existing oil takeaway infrastructure and avoid costly gas pipelines for low gas flow rates.

Finally the expansion of gas networks will also make a contribution to the reduction of gas flaring. Projects like Angola LNG, Kuwait's one-percent flaring program, Iraq's southern gas system, Mexico's gas processing expansion, Qatar's Al-Sheen an associated gas projects, or Russia's use of gas reinjection and remote power generation have reduced gas flaring. Going forward, the oil and gas industry will continue to have to find innovative solutions to avoid the waste and environmental impact from gas flaring. In addressing these issues, it will be critical to identify opportunities to deploy technology to leverage gas, power, and transport networks.

### Future Network Integration

The economics of energy transportation are greatly improved when there is an ability to leverage existing infrastructures. The incumbent hydrocarbons in the world today, oil and coal, have been able to avoid some measure of transportation cost by leveraging existing road and rail networks that had been built to meet other transport needs. Over the last few decades, robust digital networks have been built upon early defense-related communication systems and other fiber-optic communications links. Natural gas pipelines and LNG networks have followed a similar evolutionary path to power systems. At times, gas systems have been able to utilize conversions of existing oil pipelines, but for the most part the gas network has been built-up over decades. More recently, the networks supporting shale gas development have expanded. For example, rail and trucking systems are



“As economies diversify and expand, more regions will have highly variable electric load profiles similar to advanced economies.”

used to bring sand and water into the well sites and move natural gas liquids and produced water away.

Constraints in one network can provide incentives to expand other networks. Constraints on the bulk power transmission system create opportunities for gas-fired power close to load centers. Constraints related to building oil pipelines create the opportunity for liquids shipments by terminal and rail. Similarly constraints on

the gas pipeline network create opportunities for distributed LNG systems to provide peak-period support or present new options for distributed generation. Constraints on fuel or allowable emissions drive renewable development. Figure 12 shows a schematic representation of various energy networks. The natural gas system is uniquely situated to support other energy networks. From flexible and high efficiency power generation options to a variety of industrial, transportation, marine, or remote applications, multi-network optimization is about the role of technology in facilitating network switching in a proactive way.<sup>47</sup> The intersection of the various technology and market trends discussed so far offers a picture of what we will see in the energy networks of the future.

Several broad topic areas offer insight on gas network evolution including the role of gas in supporting renewables development and natural gas as a transport fuel. While not exhaustive, both of these topics feature issues related to the overlap between gas, power and gas and oil networks, respectively. Natural gas and carbon policy is a third topic where we highlight a few issues relevant to the future of gas networks. Collectively, these topic areas with the earlier distributed energy discussion, illustrate how energy networks work together today. Furthermore, they highlight the potential for further integration to drive economic development, sustainability, and energy security.

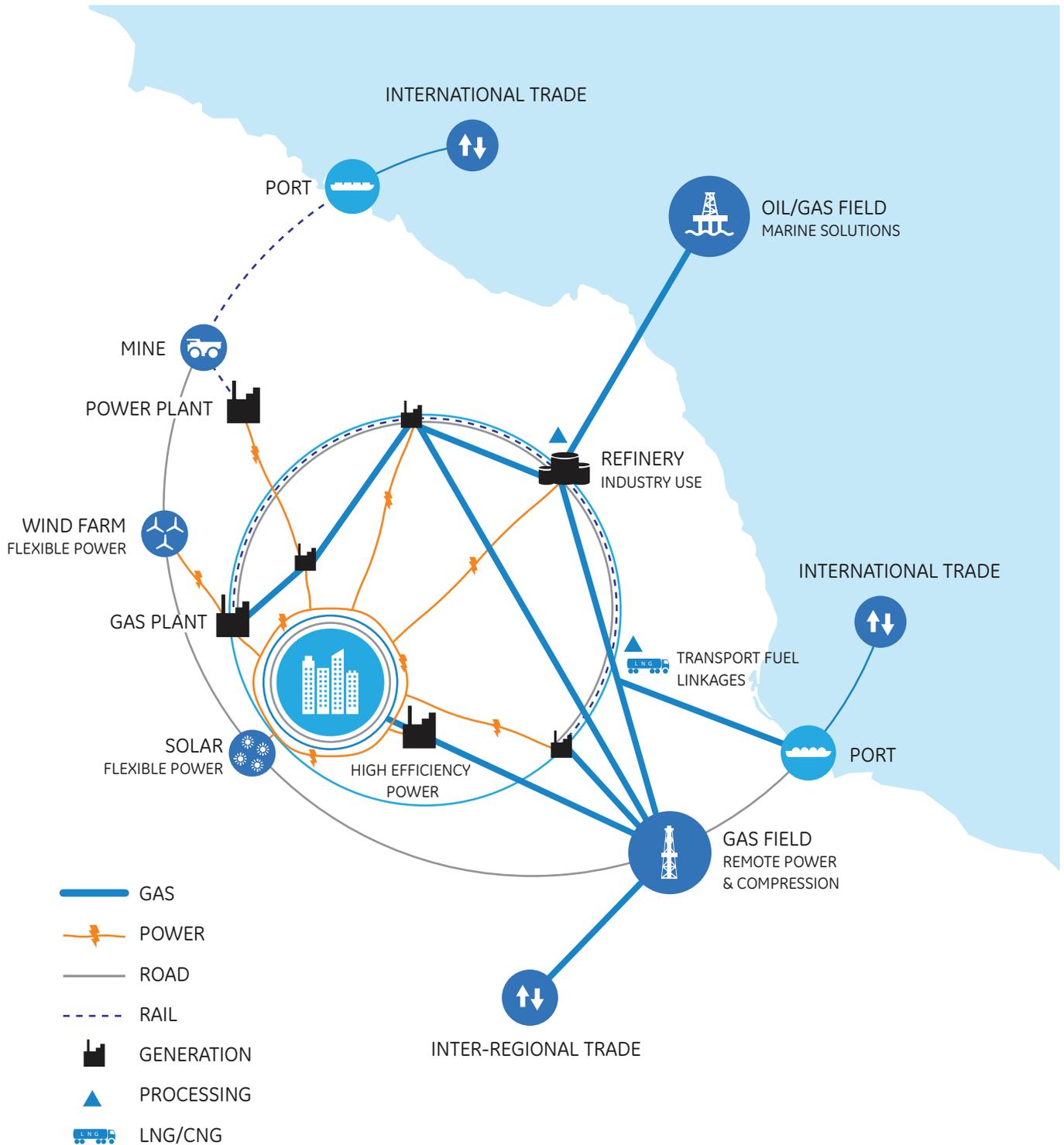
### **Joining Capabilities: Gas and Renewables**

How the relationship between gas and renewables will evolve is one the most important questions facing the power sector over the next decade. Gas is considered a threat to renewables in some regions because it is a low cost option to wind and solar.<sup>48</sup> Our view is they both will grow and complement each other more often than compete.<sup>49</sup> The partnership



Figure 12. Multi-Network Integration: Gas, Power, Road and Rail

Source: GE Global Strategy and Analytics, 2013





between gas and renewables is built on supporting each other's weaknesses. The variability of renewable sources can be complemented with the flexibility of gas-fired power. At the same time, the zero fuel cost associated with renewable generation can provide a valuable hedge against potential gas price volatility. When combined, the resulting energy source has a relatively low emissions profile and lower capital intensity than other options.

Managing the increasing load variability from supply and demand sources is a growing challenge for network operators. Because electricity is created as it is used, consumption varies significantly hour-to-hour depending on the climate and economic base. As economies diversify and expand, more regions will have highly variable electric load profiles similar to advanced economies. Further, as renewables penetration increases, electric supply will be more intermittent. As a result, more regions of the world, like parts of Europe and North America today, will face growing power system integration issues.<sup>50</sup> There are various options available to grid operators. Conservation and "load shedding" in peak periods is one option. However, consumers dislike having their power shut off. Large-scale electricity storage options are available but expensive today.<sup>51</sup> "Smart grid" and incentive-based mechanisms using price signals are expanding. For example, demand response technology that is fully automated and invisible to the end-user shows increasing promise. As a result, natural gas used as a stand-by option is often the most cost effective way to manage this variability.

While gas generation is well suited for highly variable power loads, this creates complications in the gas network. Rapid changes in gas generation create large swings in the need for high volume, high pressure supply from the gas network. Hourly variations can be substantial and must be managed through the inherent flexibility of the pipeline, underground storage, or LNG systems. However, when generator demand is coincident with other loads, like winter heating needs, shortages can develop.<sup>52</sup> Generators that can comfortably rely on excess pipeline capacity and interruptible services in the summer season can be caught short in the winter.<sup>53</sup> The opposite problem happens when gas networks are dedicated only to variable and intermittent generators. For example, this is a problem in Brazil where gas-fired power is used to balance variations in abundant



hydro generation. Low utilization rates hurt pipeline development economics by driving up costs to provide flexible services.

Coordinating grid operations will be important for gas and renewables to work together effectively. In gas and power networks, the industry debate centers on how to allocate systems costs; who benefits and who pays. Solutions are elusive, but finding ways to increase real-time communications between operators, build new infrastructure, and expand system flexibility is vital. If generator gas supplies are going to need to be more firm, yet more variable, there are costs transferred back to the gas network that need to be addressed. However, when flexible electric grids can be expanded at the same time, the ultimate integration costs across both the gas and power sectors might be less. A purely gas-based or power-system based solution is likely to be sub-optimal to a more holistic approach. And furthermore, there may be ways to leverage other networks as well. For example, in mature grids it might be possible to use small LNG or CNG facilities in a flexible way—perhaps by serving power generation or heating needs during peak periods, but then switching back to serving transport markets in other periods.

Going forward, renewables will be a bigger part of the energy mix for a variety of reasons. Natural gas will be as well. Both power and gas network operators will have to adapt to that reality for the potential of these two energy sources to be realized.

### **Links to Transportation**

Natural gas vehicle growth is expected to grow sharply over the next two decades. However, since 2008, the natural gas vehicle (NGV) fleet has grown at around 15 percent annually, and today there are about 15 million light duty vehicles (CNG) and one million heavy duty vehicles and buses (LNG).<sup>54</sup> Most of this recent growth has been in emerging markets. Iran, Pakistan, China, India, Brazil, and Argentina have large and growing numbers of vehicles. Government policies have incentivized NGV growth, mostly as a way to avoid importing finished oil products. As natural gas has become scarce or more expensive in some of these countries, this model for NGV growth is slowing.



Today there is growing promise for a new NGV development model in countries with extensive energy networks. Economic incentives based on the upward structural shift in global oil prices, coupled with low natural gas prices, are driving growth.<sup>55</sup> Oil is and will continue to be a highly-prized fuel. However, higher prices are creating incentives to find substitutes. In the last three years, the divergence between gas and oil has become sizable. Today, in North America, the cost of natural gas is less than one-third the cost of diesel or gasoline on a wholesale basis. Even in Europe, spot-traded natural gas is 60 percent below wholesale diesel prices. Other regions with abundant natural gas like Russia, Qatar, and Nigeria, are investigating the possibilities for further development. The GE Age of Gas outlook anticipates global NGV gas use to grow at 6 to 8 percent annually, led by growth in North America and China.

Heavy-duty fleets, railroad operations, and some shipping applications have great potential as a market for LNG. The pro forma economics are compelling for high-mileage vehicles that return to a central depot like buses, taxis, refuse trucks, and some trucking operations. In North America, payback on new natural gas powered “class 8” trucks can be in the range of 3-5 years.<sup>56</sup> Payback on engine and fuel system investments relative to diesel for larger vehicles like locomotives or small vessels like tugboats, is 4-9 years depending on assumptions.

The full environmental consequences of moving to NGVs are uncertain. The use of natural gas sharply reduces traditional pollutants like sulfur and nitrogen oxide. Additionally, carbon emissions are typically 30 percent less than oil. However, methane is a potent greenhouse gas and there are concerns about upstream fugitive emissions and leaks from the LNG and CNG delivery infrastructure. In the case of large vessel shipping, the lower sulfur emissions from LNG solutions are a positive and should drive gas growth as regulations on burning heavy fuel oil in coastal areas become more restrictive. The elimination of fugitive emissions will rely on the technology options discussed earlier, and if successful, should not create a major constraint on NGV growth.

Infrastructure is the critical issue in expanding the NGV market. The share of NGV vehicles relative to the global fleet today is around 1 percent.<sup>57</sup> The costs of development depend greatly on what kind of fleet is adopting natural gas. Urban fleets that operate in a concentrated area or private



heavy-duty vehicle fleets that have a concentration of demand are likely to be the first to switch. Later as broader networks are assembled, light-duty and personal vehicles will adopt.<sup>58</sup> There are several ways to expand fuel delivery networks including leveraging existing gas infrastructure, developing NGV corridors, and hybrid vehicle options.<sup>59</sup> Another important factor is the need to develop new business models to advance the market, since traditional fuel and natural gas distributors may not have strong incentives to develop new infrastructure. It may also involve shifting natural gas back to a utility or LNG into small-scale power generation when economics dictate. Retaining options in the fuel network may also help if oil prices cycle down for a period of time. In general, taking advantage of the NGV's potential can provide a new source of flexibility for the gas, oil, and power markets, but also a new element of competition.

### Natural Gas and Carbon

The discussion of natural gas from a long-term carbon policy perspective is an important topic within the overall natural gas debate. Detailed technology and policy discussions are beyond the scope of this paper, but a few observations related to the development of gas networks are worthwhile to outline. Carbon concentrations are continuing to climb. Global carbon emissions are reported to have increased by 1.4 percent in 2012, with CO<sub>2</sub> concentrations hitting nearly 400 parts per million—5 percent higher than a decade ago.<sup>60</sup> International government response to climate change has been slow, and within the climate debate there is more focus on adaptation strategies in addition to mitigation. Natural gas is seen by some as a pragmatic fuel option that offers environmental benefits and lower costs. This may be a sub-optimal outcome to some, in terms of the desire to shift away from all hydrocarbon energy, but one that is happening anyway because of the relative energy costs of gas to renewables, and the relative environmental attractiveness of natural gas to oil or coal in many parts of the world.

There are a mix of environmental benefits and costs to natural gas. In advanced power generation, carbon-dioxide from natural gas combustion is roughly 50 percent lower relative to coal-fired technologies and 30 percent lower than oil. There are significant local pollution benefits in terms of reduced sulfur, nitrogen, and volatile organic compounds. However, gas



is still a hydrocarbon and there are losses that occur in the development and transmission of natural gas, which is mostly methane. Methane, when vented directly to the atmosphere, is a powerful greenhouse gas. Issues related to water pollution and shale development are also well-documented. For the most part these facts are undisputed.

However, the scale of waste and leakage from the global gas system remains uncertain today. Furthermore, there are questions on how fast fugitive emissions may increase with the advent of new supplies like shale gas. These are legitimate concerns; however, with a focus on reduction technologies, and appropriate regulatory policies, many of these negative externalities can likely be mitigated. Actions that can improve emissions monitoring and ensure greater adoption of technologies that can cost-effectively reduce methane leakage, while maintaining safety and reliability of the network, should be pursued. More broadly, natural gas is more likely to reach its potential if it is accepted as a safe, sustainable, efficient, and reliable energy source.

Perhaps the larger issue is what will happen if natural gas is not competitive in Asian power markets and other developing nations. The scale of carbon emissions growth from the emerging economies will dwarf the growth rates from advanced economies if coal maintains a dominant share of the generation growth. Even if the US and Europe pursue aggressive renewables policies with significant increases in energy efficiency and sharp declines of coal use, the future of Asian coal growth will likely mean a future of increasing carbon emissions globally. The unfortunate implication is that the developing world will likely see more negative effects from climate change and have fewer resources for adaptation. Alternatively, the successful development of shale gas and aggressive development of the global natural gas network over the next decade is part of the foundation for a lower carbon energy system in the long-term.





## VI. CATALYSTS AND CONCLUSIONS

The natural gas industry is set to take on a larger role in the global energy landscape. However, there are still tremendous challenges to overcome. The high cost of network development and entrenched institutions in the gas industry could cause slower energy market transformation than envisioned here. There will need to be greater systematic attention to the importance of building out gas networks and taking advantage of the vertical linkages between various energy systems. As a result, policy and innovation catalysts will be important in facilitating network growth and enabling the Age of Gas.

Three broad areas for policy efforts include:

- Investment
- Technology innovation
- Environment, health and safety

### Driving Network Investment

Policy catalysts that support investment in anchor gas projects in new regions are essential. As networks mature, the role of government to drive investment will change with each stage of network evolution. In mature networks, market forces have been successful in creating innovation and investment. However, in many parts of the world, state-sponsored energy companies will be the key actors driving expansion of the gas industry. Governments need to explore the way investments in gas infrastructure and other associated energy networks can help state utilities deliver improved operations and lower transaction costs. There are strong indications from North America that successful gas development can foster economic growth and job creation. In this way, gas network development is a vehicle for economic development and increasing energy access in developing economies.

International cooperation is another important catalyst for investment. Supplies of gas and the location of ultimate gas demand are often not well



“Creating durable, yet flexible, international relationships that foster investment even as the industry changes will be crucial.”

aligned. A significant portion of gas must cross state borders. There remains significant need for international cooperation to support expansion of gas networks and trade across these networks. The ability to find common ground between buyers and sellers, importer and exporters will be pivotal in mobilizing new mega-project investments. As a result, buyers and sellers need to recognize that security of supply and demand not only comes from traditional transactional models, but from increasing diversity and flexibility in the marketplace. Those forces will create contractual practices that are more often shaped by the competitive dynamics between natural gas and alternative fuels. Creating durable, yet flexible, international relationships that foster investment even as the industry changes will be crucial.

Pricing policies are another fundamental issue pacing gas network investment in the developing regions of the world. There are numerous examples of places where an aggressive subsidy policy has driven rapid growth of inefficient consumption, while placing large burdens on government budgets. As early discoveries are depleted, insolvent national utilities are unable to make incremental investments in networks or resources until shortages become acute—creating further stress on governments and populations. Subsidy reform for fuel and electricity is challenging but there are examples of efforts that have been deemed successful including Brazil, Chile, Turkey, Philippines, Indonesia, and Kenya.<sup>61</sup> Individual countries will have to assess the viability of these types of policies, and in some cases the benefits may outweigh the costs. For some countries, the inability to address pricing issues may result in constricted investments and unsustainable growth.

Examining tax policies that distort competition between fuels is also important. For example, current policies often tax LNG based on fuel volume rather than energy content. This increases the effective tax on LNG by 1.7 times the rate applied to diesel fuel. Unequal taxation distorts the price spread between fuels and therefore influences the pace of capital investments in LNG refueling infrastructure—effectively slowing opportunities to provide consumers with a low-cost, cleaner alternative to diesel fuel.



## Supporting Technology Innovation

Technology innovations have been instrumental in unlocking low cost natural gas in new regions. From a regulatory and policy perspective, fostering an environment for innovation is critical. Early support through tax credits and incentives was instrumental in the US's unconventional gas development in the 1990's. Later, shale gas was supported by price triggers from competitive markets, the ability to draw on a large pool of talented oil field service professionals and dense accessible pipeline networks. With the support system for shale gas in place, operators were able to focus on acquiring and testing the technology to "crack the code" of individual shale plays and get rewarded for their innovations. Looking beyond North America, shale gas resources appear abundant, but each shale play has unique attributes that must be well understood before gas can be produced economically. Technology will likely need to be adapted, and unique innovations, like the ones that unlocked the initial opportunity in the Barnett shale, will have to be replicated. This is where policy and incentives can help to find ways to customize technology for new regions. This does not mean that knowledge from other regions is not transferable or competitive markets need to be replicated all around to find success. Instead it is about finding the spaces within large national entities to allow experimentation, drive pilot projects, and establish appropriate joint ventures to share risks and transfer technology. The benefit of these efforts will hopefully be more rapid development of valuable domestic resources, at lower cost, and with fewer environmental implications.

Regulatory policy can also influence how technology is adopted to help secure and optimize gas and electrical networks. Natural gas and electricity markets will become more connected over time as networks continue to grow and system complexity increases with new supply and demand options. Supporting Industrial Internet innovations can help drive coordination between networks—with the goal of helping to standardize business practices, increase transparency for grid operators and regulators, and improve analytics to better predict operations and prepare for contingencies. Achieving the benefits associated with the deeper penetration of digital technologies will require effective security at both the network level as well as at the level of cutting-edge devices that are connected to the network. This will require all stakeholders to become proactive participants in security management.



“Natural gas will only be able to reach its potential and win share against coal and oil if technologies are deployed that can support safe, efficient and reliable capture or extraction.”

### Encouraging Safety and Sustainable Development

Natural gas will only be able to reach its potential and win share against coal and oil if technologies are deployed that can support safe, efficient and reliable capture or extraction. Complex regulatory frameworks often govern operations today and policy efforts support technological innovations that can improve the safety and security of gas networks, particularly in remote areas. New practices and technologies will be required as projects push further into deepwater regions and into Arctic waters. For unconventional gas operations there will continue to be a learning process as the industry grows. Specifically, this means redefining what is possible in gas operations including: enabling oil substitution, improved water management, reduction of fugitive emissions, and other new concepts for efficiency and electrification.

### Conclusion

Countries and regions that move early to get energy infrastructure models right are likely to be better positioned for future growth. This may require adapting to new business models and regulatory frameworks. Expanding gas networks starts with solid national energy planning with regional government engagement. Early thinking on cross-leveraging and transitioning energy systems in a scalable and modular way can be important. For countries in the network development phase, early consideration should be given to establishing the role of the regulator, including how access to networks will be managed and what revenue model will support investment. This can have large implications in terms of how systems are managed for open access, cost of services, and transparency. If scaling up with big blocks of energy is problematic in that it creates vertical integration, rent seeking, and insular negotiations, the ability instead to drive development along the distributed pathway might be beneficial.

Tailored solutions will be important. For countries trying to develop new gas infrastructure, having a solid legal foundation and credibility that supports direct foreign investment and contracting is important. In most parts of the world, the ability to efficiently develop effective public-private partnerships



is essential. International companies are often willing to take significant financial and operational risks to develop resources, build infrastructures, and link markets if governments can create a stable environment for business. This is even more important for gas supply projects that have 20 to 30 year investment horizons.

A strong enabling environment for gas network development is built on:

- A clear and durable governmental vision with commitment
- Regulation that is transparent, reasonable and responsive to the pace of business
- Market structures that support investment
- Public outreach and worker education and training
- Support for innovation
- Attention to environmental externalities
- Building the service eco-systems around the network

Without significant focus on gas network development from a physical infrastructure and a market development perspective, the industry will not reach its potential. Traditional energy network revenue models will struggle to work in much of the emerging market or they will work too slowly. The need for diversity, scalability, and sustainability makes distributed energy increasingly attractive. Joining power, gas, and renewables in distributed settings in optimized networks is likely to bring latent benefits that traditional isolated business models fail to capture.

A world in which natural gas can take on a much larger role in the global energy mix is not only possible, but perhaps likely, with the combination of innovative technology, externality management, and continuing collaboration. There will continue to be significant regional variation in gas dynamics around the world. However, the broad points remain. Harnessing the power of networks and investing in the technologies that enable them, promises to yield significant benefits. Many elements are coming together to create the opportunity for a much more significant role for gas on the world stage, with valuable contributions to national competitiveness, sustainability and energy system resilience. This is the Age of Gas and the power of supporting networks.





# VII. DATA APPENDIX, ENDNOTES, REFERENCES, ACKNOWLEDGMENTS

## Global Fuel Share of Primary Energy Consumption

GE "Age of Gas" Outlook 2013

Primary Energy MTOE	8,848	10,096	13,292	15,594	16,905	CAGR	
						'90-'12	'12-'25
						2.3%	2.1%
Energy Source (%)	'90	'00	'12	'20	'25	Change in Share	
						'90-'12	'12-'25
Oil	36%	36%	31%	29%	27%	-4.8%	-4.4%
Gas	20%	22%	23%	26%	26%	3.1%	2.4%
Coal	25%	23%	28%	27%	27%	2.8%	-0.8%
Nuclear	6%	7%	5%	5%	6%	-1.1%	1.5%
Hydro	2%	2%	2%	2%	2%	0.2%	-0.2%
Wind, Solar & Other	0%	1%	1%	3%	4%	0.8%	2.6%
Biofuel and Waste	10%	10%	9%	8%	8%	-1%	-1%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>		

Note: These data are based on IEA World Energy Statistics, EIA, BP Statistical Report information, and GE internal analysis and modeling.



## Global Gas Balance

GE "Age of Gas" Outlook 2013

Billion Cubic Meters per Year (BCM)

Sector	'00	'12	'15	'20	'25	CAGR	
						'00-'12	'12-'25
<b>Demand:</b>							
Power Gen	880	1,433	1,592	1,887	2,097	5.2%	3.6%
Industrial	724	853	921	1,036	1,111	1.5%	2.3%
Buildings	644	717	774	811	871	0.9%	1.7%
Other	352	515	580	676	728	3.8%	3.2%
<b>Total</b>	<b>2,600</b>	<b>3,518</b>	<b>3,867</b>	<b>4,410</b>	<b>4,807</b>	<b>2.9%</b>	<b>2.8%</b>
<b>Supply:</b>							
Conventional	2,456	3,003	3,282	3,654	3,952	1.9%	2.4%
Unconventional	144	495	582	793	898	20.3%	6.3%
<b>Total</b>	<b>2,600</b>	<b>3,498</b>	<b>3,865</b>	<b>4,447</b>	<b>4,850</b>	<b>2.9%</b>	<b>3.0%</b>
Imbalance	1	-20	-2	37	43		

Note: These data are based on IEA World Energy Statistics, EIA, BP Statistical Report information, and GE internal analysis and modeling. Imbalance differences between supply and demand statistics are the result of variations in stocks at storage facilities and liquefaction plants, together with unavoidable differences in data, resulting from gas composition and quality issues and other measurement or conversion issues related to the range sources underlying the supply, demand, and trade data.



## Global Power Generation by Fuel Type

GE "Age of Gas" Outlook 2013

TerraWatt Hours per Year (Twh)

Fuel Type						CAGR	
	'00	'12	'15	'20	'25	'00-'12	'12-'25
Oil	1,126	1,111	935	779	678	-0.1%	-3.0%
Gas	2,730	5,177	5,784	6,962	8,134	7.5%	4.4%
Coal	5,909	8,931	9,709	10,946	12,988	4.3%	3.5%
Nuclear	2,591	2,443	2,968	3,276	4,097	-0.5%	5.2%
Hydro	2,687	3,491	3,725	3,896	4,150	2.5%	1.5%
Wind, Solar & Other	84	654	1,078	1,611	2,588	56.5%	22.8%
Biofuel and Waste	324	526	582	711	1,013	5.2%	7.1%
<b>Total Global Power</b>	<b>15,452</b>	<b>22,332</b>	<b>24,781</b>	<b>28,181</b>	<b>33,647</b>	<b>3.7%</b>	<b>3.9%</b>

Note: These data are based on IEA World Energy Statistics, EIA, BP Statistical Report information, and GE internal analysis and modeling. These data include utility and independent power generation including industrial cogeneration and the electricity sector's own use. Gas demand for power estimates are based on the wider definition of the power sector, which may create differences with other sector forecasts.



### GE “Age of Gas” Outlook

Billion Cubic Meters per Year (BCM)  
Regional Gas Balance Summary

							CAGR
Fuel Type	Sector	'00	'12	'15	'20	'25	'12-'25
North America	Power Gen	158	282	256	296	312	1%
	Industrial	237	214	231	244	249	1%
	Other & Buildings	359	334	355	383	400	2%
	Production	774	858	865	1,030	1,087	2%
	LNG (Net Trade)	5	5	7	-66	-76	
	Pipeline (Net Trade)	-3	-19	-21	-30	-40	
	Imbalance	14	5	0	0	0	
China, OECD Asia Pacific, Other Asia	Power Gen	171	295	364	485	534	6%
	Industrial	92	167	191	227	263	4%
	Other & Buildings	92	208	246	312	357	6%
	Production	300	515	623	768	800	4%
	LNG (Net Trade)	29	133	123	162	218	
	Pipeline (Net Trade)	-0	27	66	121	157	
	Imbalance	-30	-51	-29	-29	-30	
Eurasia	Power Gen	239	294	323	338	344	1%
	Industrial	95	129	130	135	132	0%
	Other & Buildings	185	178	184	190	191	1%
	Production	687	803	915	1,043	1,136	3%
	LNG (Net Trade)	0	-13	-14	-26	-61	
	Pipeline (Net Trade)	-138	-197	-273	-359	-410	
	Imbalance	27	-10	-12	-9	-6	
Europe	Power Gen	145	194	205	236	293	4%
	Industrial	163	122	131	141	145	1%
	Other & Buildings	207	251	254	257	262	0%
	Production	315	281	267	253	236	-1%
	LNG (Net Trade)	33	62	73	107	131	
	Pipeline (Net Trade)	166	204	255	275	331	
	Imbalance	-3	-23	5	0	-2	



Fuel Type	Sector	'00	'12	'15	'20	'25	CAGR '12-'25
Middle East	Power Gen	91	201	249	294	329	5%
	Industrial	54	110	117	138	161	4%
	Other & Buildings	67	142	155	169	190	3%
	Production	237	556	640	721	843	4%
	LNG (Net Trade)	-26	-123	-128	-116	-126	
	Pipeline (Net Trade)	3	7	9	-2	-35	
	Imbalance	0	-15	-1	0	0	
	Africa	Power Gen	31	74	90	109	125
Industrial		17	28	33	48	59	9%
Other & Buildings		17	30	34	41	49	5%
Production		137	240	285	341	413	6%
LNG (Net Trade)		-37	-64	-78	-93	-113	
Pipeline (Net Trade)		-34	-46	-50	-43	-60	
Imbalance		-0	-3	-1	4	4	
Latin America		Power Gen	44	93	105	130	160
	Industrial	65	81	89	103	116	3%
	Other & Buildings	47	88	93	95	107	2%
	Production	151	245	270	291	334	3%
	LNG (Net Trade)	0	-3	8	21	19	
	Pipeline (Net Trade)	7	20	21	28	37	
	Imbalance	-2	-12	-0	-0	-0	



## GE “Age of Gas” Outlook

TerraWatt Hours per Year (Twh)  
Regional Generation by Fuel Summary

Fuel Type	Sector						CAGR	
		'00	'12	'15	'20	'25	'12-'25	
North America	Total Generation	4,658	4,706	5,088	5,319	5,563	1%	
	Oil	128	21	6	4	3	-7%	
	Gas	668	1,302	1,168	1,313	1,467	1%	
	Coal	2,240	1,604	1,995	1,940	1,928	2%	
	Nuclear	871	876	915	963	968	1%	
	Hydro	639	637	650	651	652	0%	
	Wind, Solar and Other	21	175	267	341	415	11%	
	Biofuel and Waste	92	92	86	108	130	3%	
China, OECD Asia Pacific, Other Asia	Total Generation	4,244	9,092	10,573	12,815	16,757	6%	
	Oil	353	392	286	225	226	-3%	
	Gas	2,145	5,544	6,003	7,187	9,443	5%	
	Coal	2,145	5,544	6,003	7,187	9,443	5%	
	Nuclear	505	394	858	1,064	1,705	26%	
	Hydro	530	1,234	1,396	1,469	1,611	2%	
	Wind, Solar and Other	26	180	372	612	1,067	38%	
	Biofuel and Waste	99	129	145	198	393	16%	
Eurasia	Total Generation	1,246	1,501	1,579	1,684	1,832	2%	
	Oil	57	43	43	42	41	0%	
	Gas	484	659	718	753	786	1%	
	Coal	257	323	315	339	376	1%	
	Nuclear	210	224	247	282	331	4%	
	Hydro	227	228	229	232	239	0%	
	Wind, Solar and Other	0	2	4	11	25	83%	
	Biofuel and Waste	11	22	22	24	34	4%	
Europe	Total Generation	3,429	3,794	3,870	4,127	4,495	1%	
	Oil	183	68	68	60	55	-1%	
	Gas	527	773	819	898	1,194	4%	
	Coal	991	1,034	947	964	719	-2%	
	Nuclear	971	902	904	880	915	0%	
	Hydro	627	558	568	575	592	0%	
	Wind, Solar and Other	29	267	358	504	726	12%	
	Biofuel and Waste	101	193	206	247	294	4%	



Fuel Type	Sector	'00	'12	'15	'20	CAGR	
						'25	'12-'25
Middle East	Total Generation	471	1,031	1,195	1,407	1,620	4%
	Oil	195	315	275	277	206	-3%
	Gas	237	628	819	961	1,123	6%
	Coal	29	44	33	32	35	-1%
	Nuclear	0	0	0	40	90	
	Hydro	8	17	19	20	21	2%
	Wind, Solar and Other	0	2	4	29	94	438%
	Biofuel and Waste	0	25	46	48	51	8%
Africa	Total Generation	435	722	843	991	1,234	5%
	Oil	47	74	71	46	46	-3%
	Gas	91	233	313	363	357	2%
	Coal	207	287	315	363	357	2%
	Nuclear	13	12	12	12	38	16%
	Hydro	75	101	103	118	157	4%
	Wind, Solar and Other	1	5	18	38	91	133%
	Biofuel and Waste	1	9	10	13	22	11%
Latin America	Total Generation	971	1,485	1,643	1,838	2,145	3%
	Oil	163	197	186	126	102	-4%
	Gas	137	362	434	576	727	8%
	Coal	40	96	102	122	130	3%
	Nuclear	20	35	32	35	50	3%
	Hydro	583	716	761	831	878	2%
	Wind, Solar and Other	8	23	53	75	169	49%
	Biofuel and Waste	20	57	65	72	88	4%



## Author Bios

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## Endnotes

1. Peter C. Evans and Marco Annunziata, "Industrial Internet: Pushing the Boundaries of Minds and Machines," General Electric, November 26, 2012.  
[http://www.ge.com/docs/chapters/Industrial\\_Internet.pdf](http://www.ge.com/docs/chapters/Industrial_Internet.pdf).
2. Malcolm Peebles, *Evolution of the Gas Industry* (New York: New York University Press, 1980), 9-17.
3. Arlon Tussing and Bob Tippee, *The Natural Gas Industry: Evolution, Structure, and Economics*, 2<sup>nd</sup> edition (New York: PennWell Books, 1995), 61-65.
4. Ernest Freeberg, *The Age of Edison: Electric Light and the Invention of Modern America* (New York: Penguin Press, 2013), 35.
5. James J. Parsons, "The Geography of Natural Gas in the United States," *Economic Geography*, vol. 26, no. 3 (Jul., 1950): 162-178.
6. Jim Watson, "The Technology that Drove the 'Dash for Gas'," *Power Engineering Journal*, vol. 11, (1997).
7. David Newbery, *Privatization, Restructuring, and Regulation of Network Utilities* (Cambridge: MIT Press, 1999), chap. 8.
8. We use metric measures for gas supply and demand in this paper as it is more consistent with international reporting. Dividing billion cubic meters per year (BCM) by ten approximates the conversion to billion cubic feet per day (Bcfd) commonly used in the US gas industry. The generic conversion between BCM and BCF is 35.31. For example, 100 BCM per year multiplied by 35.31 and divided by 365 days equals 9.67 Bcfd.
9. John Curtis, "Fractured shale-gas systems," *AAPG Bulletin*, vol. 86 (November 2002): 1923-1924.
10. The US National Petroleum Council's *Prudent Development* study (2011) indicated 1,500, 2,500, and 4,000 trillion cubic feet (Tcf) in their low, mid, and high gas resource estimates, respectively.
11. For past estimates, see International Energy Agency, *Natural Gas Prospects to 2000*, OECD, Paris 1982, Table 5.18.
12. The "Age of Gas" outlook is based on a view of future economic growth, energy prices, environmental policy, and infrastructure development. The outlook assumes a return to the economic growth potential of the advanced industrial countries and continued stable, relatively strong economic growth in the developing countries; relatively high oil prices; and ongoing decoupling of gas prices from oil that allows gas to be increasingly competitive against coal and oil. Environmental policies are significant in some regions, but this outlook does not, for example, incorporate aggressive carbon policy assumptions. Instead, we assume a collection of country-specific and regional environmental programs that remain active through the forecast horizon. New gas infrastructures are assumed to be built in a cost effective way. Advanced technologies are assumed to be deployed to increase the efficiency and productivity of the energy, but no hyper-disruptive technologies, for example ultra-low cost solar panels, emerge over the horizon to 2025. The "Age of Gas" outlook assumes moderate improvements in electricity intensity of GDP with significant variation on a regional basis. These assumptions determine how much energy is required to meet the economy's needs. Energy intensity improvements are assumed to occur at about 1 percent per year through 2025. These rates are a slightly faster improvement than the annual average improvement over the past 15 years. Some nations like China (1.8 percent) and US (1.5 percent) are expected to show faster energy intensity improvements. However, for some emerging markets we expect



modest increases in energy intensity to increase over this horizon as access to electricity and electricity use rapidly increases. Examples include India, Indonesia, and parts of Africa.

13. These resources are more costly, but also will yield more valuable natural gas liquids that can help offset the decline in the mature oil fields of Russia.

14. Reuters, "Turkmenistan has High Hopes as Giant Gas Field Nears Output," May 22, 2013.

15. The "Age of Gas" outlook assumes further growth in nuclear power. While costs are a challenge for nuclear, the outlook assumes that policy and industry action will align to expand nuclear by approximately 200 GW. Most of this new nuclear capacity will only become available toward the end of the 2025 forecast horizon. The capacity included in the outlook comes from currently identified nuclear projects and existing plants. Japanese nuclear capacity is assumed to return to about 60 percent of pre-Fukushima levels. China is assumed to build about 100 GW of new capacity representing nearly 50 percent of global new nuclear capacity additions. In addition, France and the US are assumed to keep most of their existing nuclear capacity online through this time period. Other regions balance out the nuclear growth outlook. India adds about 18 GW; Saudi, UAE, and Turkey add about 15 GW; S Korea adds about 14 GW; ASEAN countries add about 5.5 GW; Russia and other eastern European countries add about 11.5 GW. To the extent that these nuclear projects are unable to advance as projected, there will be additional potential for natural gas in power generation along with coal and renewables. Shifting any of these assumptions in a meaningful way would clearly lead to different outcomes.

16. Peter C. Evans and Peter Fox-Penner, "Resilient and Sustainable Infrastructure for Urban Energy Systems," *The Solutions Journal* (forthcoming).

17. The high upfront capital costs of coal also make plants difficult to displace once they are built. This is because the variable costs of the fuel are typically lower. Furthermore, with large state-owned entities as the primary builders of coal-fired power in many parts of the world, access to low-cost capital relative to independent developers drives utilities to more capital-intensive technologies.

18. David Easley and Jon Kleinberg, *Networks, Crowds, and Markets: Reasoning about a Highly Connected World*, Cornell University, Cambridge University Press (2010); [www.cs.cornell.edu/home/kleinber/networks-book/networks-book.pdf](http://www.cs.cornell.edu/home/kleinber/networks-book/networks-book.pdf).

19. Jeff D. Markholm, "The Political Economy of Pipelines," 2012, University of Chicago Press. See Markholm for a detailed and fascinating discussion of the economics of pipelines including issues on institutional drivers, asset specificity, and the development of competitive markets of gas transportation services.

20. Other transportation modes might be considered such as gas to oil liquids (GTL), or gas to chemicals or fertilizers. Gas could be converted to power and transported by wire. While these gas conversion pathways are effectively gas transportation modes, they are also gas uses; to simplify the discussion we use the three primary modes: pipeline, LNG, and CNG.

21. Jean Michel Glachant and Michelle Hallack, "The Gas Transportation System as a LEGO Game: How to Play with It?" EUI working papers, Robert Shuman Center for Advanced Studies, Loyola de Palacio Program on Energy Policy, 2010.

22. D. B. Lewis, "Natural Gas for Freight Transportation" (presentation at the National Association for Business Economics Industry Conference, Houston, TX, May 16, 2013).

23. For this discussion of supply costs, tight sands gas sources are included as part of conventional gas resources. There is considerable overlap between conventional and tight sands developments as both



tend to use hydraulic fracturing to some degree.

24. Shell Oil and Gas is pioneering the development of large floating LNG at its prelude development in offshore Australia. They are trying to standardize the technology for replications for other medium-sized offshore gas fields. Other developers are also working on various types of simpler and modular floating LNG designs.

25. Leonardo Maugeri, "The Shale Oil Boom: A U.S. Phenomenon," (Harvard Kennedy School, Belfer Center for Science and International Affairs) June 2013. This report has an in-depth discussion on North American shale and upstream production dynamics. The concept of drilling intensity and the implications for the elasticity of gas and oil supply explain how unconventional gas development differs from conventional gas development.

26. Massoud Amin, "Toward Self-healing Energy Infrastructure Systems," IEEE Computer Applications in Power, 2001.

27. Combined cycle refers to the combination of two gas combustion turbines and one steam turbine operated in sequence in which the exhaust heat from the gas turbines heats the steam that drives the generators of the steam turbine. GE's FlexEfficiency combined-cycle plant can deliver 61 percent thermal efficiency. See [www.ge-flexibility.com](http://www.ge-flexibility.com) for more information on the GE combined-cycle portfolio.

28. Source: US Energy Administration Agency. Assumes average US household electricity consumption of 11,040 kilowatt hours per year or 1.259 kilowatts per home based on 8,765 hours per year.

29. For more on combined heat and power (CHP) systems see Center for Climate and Energy Solutions (C2ES), "Leveraging Natural Gas to Reduce Greenhouse Gas Emissions," Technology Survey, June 2013, pp. 59-60.

30. The dollar per kilowatt capital costs are based on indicative North American costs. Actual project costs can be significantly different depending on regional conditions. These costs are indicative to show the general relationship between the technologies.

31. David Victor, Amy Myers Jaffe, Mark Hayes, "Natural Gas and Geopolitics 1970-2040," Cambridge University Press (2006) p. 322. David Victor and Amy Myers Jaffe et al. categorize the role of the state in gas markets into two "worlds." In the "old world," the state controls production, pricing, and terms of trade, which are dictated by state-to-state negotiations. The alternative is the "new world," where the state creates the institutional structure for private companies to take risks and capture value. However, the point is made that there is no pure example on either end of the spectrum as governmental oversight and market forces are always present.

32. The term "anchor" shipper is used quite often in the gas industry to describe the key customer that has committed to the project through long-term contracts.

33. Gas systems have a high degree of asset specialization (for example gas pipelines only move gas) and high costs. This means that producers or consumers at either end of the pipe are beholden to each other. As noted by Markholm in "The Political Economy of Pipelines" p.159, and others, this drives buyers and sellers toward vertically integrated structures. There are several studies on the level of vertical integration in the LNG industry. A good summary of recent research is in *SECURE*, "Vertical Integration in Natural Gas," Project 213744, 2009. Accessed at [http://www.feemproject.net/secure/plastore/Deliverables/SECURE\\_D5-2-5.pdf](http://www.feemproject.net/secure/plastore/Deliverables/SECURE_D5-2-5.pdf)

34. Examples include China's Sinopec that in 2011 initiated a 20-year annual purchase of 4.3 million metric



tons of (MTPA) LNG from the first train of the Australia Pacific LNG (APLNG) project along with a 15 percent stake in upstream operations. Later in 2012, Sinopec bought another 3.3 MTPA of LNG and increased its upstream operating stake to 25 percent of the LNG plant. Source: Gastech News and Resource Center "Legendary Growth of an LNG Giant," January 2013. Accessed at <http://www.gastechnews.com/lng/legendary-growth-of-an-lng-giant-2/>

35. One example "Gas Exporters Defend Oil Link," *Platts' International Gas Report*, Issue 728, July 15, 2013.

36. Competitive gas markets are an alternative model to vertically integrated project structures. North America is the primary example. Private companies engage in a bidding process to develop projects. "Open seasons" are held to identify shipper interest, hopefully culminating in a group of "anchor" customers that sanction the pipeline, storage, processing plant, or LNG terminal. Gas supply is then purchased separately and transported, stored, or converted through the asset on a contractual basis. Price signals play a major role in driving investment and create efficient gas flows to end-users. While efficient in allocating capital and mobilizing investments, competitive markets are subject to price volatility, gaming, and "boom and bust" cycles. As a result, even in competitive gas markets there is often a high level of government oversight.

37. *Platts' International Gas Report*, "Mexico's Impact on SW US," June 17, 2013. Canadian company TransCanada has a 25-year contract from CFE to build the Mazatlan and Topolobampo pipelines; US-based Sempra Energy also has a contract to build part of the Northwest pipeline system.

38. GE Distributed Power marketing analysis, 2012.

39. Ahrm Online, "Construction of 3 New Power Plants Across Egypt Delayed by Strikes," February 2013.

40. Hussam Beides, Hossien Razavi, Venkataraman Krishnaswamy, "Regional Gas Trade Projects in Arab Countries," Report No. 76114-MEN, World Bank-PPIAF, February 2013.

41. Thura Swiss Research, "Electricity Myanmar," April 2012.

42. David Dapice, "Electricity Demand and Supply in Myanmar," December 2012. Rajawali Foundation Institute for Asia, Harvard Ash Center for Democratic Governance and Innovation.

43. Id. David Dapice (2012). Current onshore domestic capacity is estimated at around 70 MMcf per day. The pipeline from Yadana gas field to Yangon is being expanded from 150 to 200 MMcf per day in 2014. Upgrading of the southeast pipeline now flowing about 30 MMcfd could bring an additional 150 MMcf per day into the domestic market. In addition, almost 100 MMcf per day from the new Shwe pipeline to China is expected to serve generation or industry close to the pipeline route.

44. Michael F. Farina, "GE Flare Gas Reduction," January 2011. See for a detailed discussion of the gas flaring issue and technology solutions available at GE reports. <http://www.genewscenter.com/ImageLibrary/detail.aspx?MediaDetailsID=3691>.

45. Source: World Bank GGFR site. <http://go.worldbank.org/G2OAW2DKZ0>

46. World Bank, "World Bank Urges Oil Producers to Reduce Gas Flaring, Increase Gas Utilization for Development," press release, October 24, 2012.

47. There is substantial literature on pipeline and gas system optimization and gas and power system optimization in the context of cogeneration and district heating. Literature review finds less discussion of these concepts at a strategic level. One example is the complex discussions on regulatory and market design concerning NERC gas and power market cooperation efforts.

48. See IEA "Are We Entering a Golden Age of Gas?" for concerns about gas replacing renewables. See



Citigroup Equities Research, "Shale & Renewables: a Symbiotic Relationship," September 2012 for a detailed discussion on the economics of gas versus renewables.

49. Renewable energy sources, like wind and solar, are continuing to grow. The costs of renewables are falling with expectations that this trend will continue. Wind costs could decline by another 20 percent over the next decade and photovoltaic (PV) solar costs could fall by 40 percent. The increasing competitiveness of renewables relative to fossil fuels, (even without policy drivers) will increase in the future. Today, renewables only account for about 1 percent of global primary energy supply, but about 5 percent of electricity generation. In this outlook, renewables will grow to 4 percent of primary energy and 11 percent of electricity generation by 2025, assuming modest policy support.

50. A detailed exploration of these issues is beyond the scope of this report, but the core issues are: How much load variation? What resources are available at peak? Is there operational impact (voltage, frequency, pressure)? How big is the pool of resources available to balance the system safely? Many of these questions are related to how the renewable system will be deployed and how easy is it to expand the gas and power network in a particular region.

51. Energy storage costs like pump hydro-storage can cost as much as \$35 Mwh with significant capital outlay to develop.

52. North American Electric Reliability Council (NERC), "2013 Special Reliability Assessment: Accommodating an Increased Dependence on Natural Gas for Electric Power Phase II: A Vulnerability and Scenario Assessment for the North American Bulk Power System," May 2013.

53. Id. NERC.

54. Morgan Stanley Global Research, "Natural Gas as a Transportation Fuel: Energy Market Wild Card," April 2013. Accessed at <http://wacleanotech.org/wp-content/uploads/2011/07/Natural-Gas-in-Transportation-MS-Blue-Paper-4.16.13.pdf>

55. Id. L. Maugeri, "The Shale Oil Boom." This report discusses the marginal costs of new oil supplies, including light tight oil from shales, indicating support for long-run marginal full-cycle costs in the \$70 to \$90 per barrel range.

56. Robert LaCount, M.J. Bradley & Associates, "Natural Gas and the US Transport Sector," presentation at the National Association of Business Economics, Energy Industry Conference, Houston, TX, May 2013.

57. Id. Morgan Stanley, "Natural Gas as a Transportation Fuel."

58. U.S. National Petroleum Council (NPC), "Future of Transport Fuels," August 2012.

59. Id. NPC, "Future of Transport Fuels."

60. International Energy Agency (IEA), "Redrawing the Energy-Climate Map," July 2013. Accessed at <http://www.iea.org/publications/freepublications/publication/name,38764,en.html>

61. International Monetary Fund (IMF), "Case Studies on Energy Subsidy Reform: Lessons and Implications," January 2013. Accessed at <http://www.imf.org/external/np/pp/eng/2013/012813a.pdf>

