GE

Gas to Power

Fast and flexible electricity for rapidly developing countries

By Michael Farina and Brandon Wilson

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Fast and flexible electricity for rapidly developing countries

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Executive summary

New gas discoveries, in combination with advances in technology, are making it possible to address previously insurmountable energy challenges in underserved regions of the world. These developments are raising hopes and expectations of improving the lives of 20 percent of the world's population that still lives without access to electricity. Industry experts and policymakers alike see the potential of harnessing the ever-expanding world gas supply to drive economic growth and improve the basic human condition in their home countries.

The expansion of global gas networks and the opening of new markets for natural gas are mutually reinforcing, further enhanced by cost-competitiveness, flexible operating characteristics, and environmental advantages of gas. GE is on the cutting edge of this trend, offering the most advanced and wide-ranging power generation systems for everything from mega-cities to isolated villages, from industrial sites to municipal grids. GE's wide array of technology offerings can serve projects that scale to each community's needs, and are in alignment with whatever indigenous resources may be available.

While gas already is addressing some of the most challenging generation problems in the global energy sector, more can be done to bring these resources online faster. International companies are willing to take on significant financial and operational risks to develop resources, build infrastructure, and link markets if governments create a stable environment for business – especially for gas supply projects that have investment horizons of 20 to 30 years. GE's approach involves convening stakeholders along the power generation value chain, including governments, developers, fuel suppliers, construction firms, equipment providers, and financiers. Ultimately, the goal is to deliver— in a holistic, cost-effective way — gas-fired powered generation to underserved markets. GE refers to this approach as its "Gas to Power" (GTP) initiative.

Government officials, regional trade associations, international development organizations, industry leaders and other stakeholders are key components of the strategic partnerships necessary to bring more power to local communities. In tandem, these stakeholders can work together to restructure inefficient, legacy markets and replace them with clear and consistent regulatory regimes. In so doing, they will increase access to risk-shared financing, reinvigorate long-planned but dormant regional infrastructure projects, and encourage investment in each stage of the project value chain. As a result, more households will see the benefit of reliable and affordable power.

GE recommends a fresh look at the new opportunities that GTP promises now and in the future. Policymakers should examine their energy mix in light of emerging trends, amend and develop regulations to support new gas to power projects, and look for opportunities for regional cooperation. Where it makes sense, industry should develop centers of excellence around GTP to seek the strategic alliances needed to bring these complex projects on-stream faster. Development and finance institutions can also take a fresh look at their objectives and priorities to ensure that resources and lending policies reflect emerging trends, and are fully aligned with efforts to increase energy access in the developing world.

Gas to Power and the "Age of Gas"

GE's "Age of Gas" narrative[1] describes a world where natural gas will take on a much larger role in the global energy landscape, delivering economic and sustainability benefits. Led by the power sector, global gas consumption is projected to grow by 33 percent by 2025. The oil and natural gas industry is evolving with new complexities and ongoing volatility. Shale-based resources and massive offshore discoveries are reshaping price dynamics, trade patterns, and business models. The international trade of liquefied natural gas (LNG) supplies will more than double over the next ten years and will feature a variety of new buyers

Key takeaways

GE's Gas to Power initiative involves convening stakeholders along the full spectrum of the gas supply to power generation project value chain, including governments, developers, fuel suppliers, construction firms, equipment providers, and financiers. The goal is to deliver— in a holistic, cost-effective way — gas-fired powered generation to underserved markets.

[1] Evans, Peter and Michael Farina. The Age of Gas & the Power of Networks. General Electric, October 2013.

and sellers and more flexible contracting terms. Furthermore, the increasing divergence between gas and oil prices is creating economic and environmental benefits leading to the displacement of high cost, oil-fired power in isolated locations and for emergency power.

In the power generation sector, the world will require electricity to be generated from every possible source. Renewables will be a major part of future growth as generation costs fall and development is prioritized, but renewables are only part of the solution. There is a growing need for cost-effective flexible power that can follow loads and back up intermittent wind and solar. The world will also continue to rely on large baseload resources like hydro, nuclear, and coal. These large, centralized power plants capture economies of scale in power production and involve fuel choices that are reflective of local conditions and resource distribution. These plants are typically sponsored by sovereign entities or large utilities with costs spread out over many customers and paid-off over many years. However, multi-billion dollar projects, particularly coal and nuclear, have long development timelines and can be difficult to build if institutional structures are weak and/or electric grids are insufficiently robust. This creates an important role for faster, flexible natural gas projects – especially in emerging markets.

By 2025, 60 percent of global electricity consumption will occur in emerging markets, up from 52 percent today.[2] Moreover, emerging markets will represent more than 80 percent of actual growth in electricity consumption between 2013 and 2025. China will represent about half of this growth, but even if the so-called "BRIC" countries (Brazil, Russia, India, and China) countries are excluded, developing countries will account for about 25 percent of power demand growth to 2025.[3] Southeast and southern Asia is an epicenter of this growth, but other large growth centers can be found throughout Sub-Saharan Africa, the Middle East, Latin America, and the Caribbean. The challenge is to adapt the development models for power to these new geographies.

GE's new gas to power (GTP) initiative is supporting electricity development around the globe. With a focus on private sector participation, the effort targets areas where traditional development has stalled or is too slow. We see opportunities to bring technology and capital in an integrated approach for deeper engagement in early stage projects to help them move forward. The basic concept is to efficiently convert gas into electricity for households and business, although there are many variations depending on local dynamics.

Options for different scales of development

To understand GTP, one must start with an examination of the options for different scales of development. GTP has strong advantages in many regions, and the modularity and flexibility of the concept allows for its application to the full range of energy needs – from mega-projects to micro-grids. Figure 1 looks at scales of gas to power development. At the largest scale, mega-gas pipeline and LNG projects will continue to anchor gas networks. These multi-billion dollar projects are critical to advancing gas use on a global scale, linking large gas supply reserves to critical demand centers. Medium–sized, regional gas transit projects, e.g., pipelines, are typically built to unlock domestic gas supplies. Projects of this scale also can include large regasification terminal projects (onshore or floating technology) to enable access to global LNG markets to feed multi-gigawatt power markets.[4]

While these larger networks are critical and will continue to advance, especially in more developed economies, GE believes there will be more opportunities for dynamic growth in smaller scale GTP.

These distributed power-based "satellite" systems can be developed faster and are expected to increasingly augment rather than displace traditional power generation development. Distributed gas-to-power networks can serve many types of consumers, from small power generation plants, to light industry, and to fleet fueling stations. They can also be built adjacent to large existing gas networks or in isolation. GTP technology options, from mega-projects to distributed systems, create powerful options for countries seeking to overcome the full range of energy challenges.

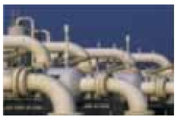
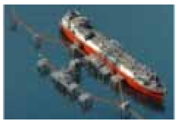
Key takeaways

The oil and natural gas industry is evolving with new complexities and ongoing volatility. Shale-based resources and massive offshore discoveries are reshaping price dynamics, trade patterns, and business models. This creates huge opportunities for GTP.

Emerging markets will represent more than 80 percent of actual growth in electricity consumption between 2013 and 2025. China will represent about half of this growth, but even if the so-called "BRIC" countries (Brazil, Russia, India, and China) countries are excluded, developing countries will still account for about 25 percent of power demand growth to 2025.

[2] Source: OECD vs Non-OECD consumption, International Energy Agency (IEA), World Energy Outlook 2014, www.worldenergyoutlook.org.
[3] IEA WEO 2014.
[4] The generation or use of electric power (watts) over a period of time (hours), is often expressed in kilowatt-hours (KWh), megawatt-hours (MWh) or gigawatt-hours (GWh). One gigawatt hour (GWh) of electricity uses approximately 10 million cubic feet (MMCF) of natural gas in a combined-cycle power plant. "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." How Much Coal, Natural Gas, or Petroleum Is Used to Generate a Kilowatt-hour of Electricity? N.p., n.d. Web. 19 May 2015.

Figure 1: Gas to power at different scales of development. Source: GE Global Gas to Power. Notes: Indicative capital expenditure (CAPEX) estimates based on public industry news reports. BCFD: Billion cubic feet per day, GWe: Gigawatt/Megawatt equivalent. Bcm: Billion cubic meters per year, MMTPA: Million metric tons per year, CAPEX: Capital expenditure, CCGT combined cycle gas turbine conversion at 60 percent efficiency, Distributed power (DP) conversion at 45 percent efficiency.

Gas network options			BCFD (Bcm/MMTPA)	~GWe (CCGT)	Typical project $B CAPEX	Typical aspects
Large		Int'l Mega Pipeline	3.5 (35/25) →	20	$10–30B	Sovereign state-to-state deals
		LNG Mega	2.2 (22/16)	12		Long-term commitments on gas and infrastructure
"Anchor Systems"						
Mid		Regional Pipeline	1.2 (12/8.5) →	6.5	$1–5B	Mix of state-owned & private players
		Floating LNG Regas	.45 (4.5/3.3)	2.5		Gas and infrastructure can be separate (tolling)
"Satellite Systems"			MMcfd	~Mwe(DP)		
Small		Small-scale LNG	8–40 →	40–200	$50–300MM	Single entity or small JV partnerships
		CNG In A Box™	0.5–5	2.5–20		Modular, pre-configured designs

Regional considerations: fast power, flex power, gas monetization, and oil substitution

Countries will find GTP attractive for a variety of applications; from increasing basic energy access and addressing growth-related shortages, to avoiding higher cost oil-fired power or expanding flexible power options. Opportunities also exist on the supply side, where countries are looking to monetize domestic gas production or eliminate and/or reduce flaring of gas associated with oil production. Often, GTP is an attractive alternative and can resolve multiple challenges in a single market, as noted in Figure 2.

Key takeaways

Larger gas networks are critical and will continue to advance, but there will be more opportunities for dynamic growth in smaller scale GTP. These distributed power-based "satellite" systems can be developed faster and are expected to increasingly augment rather than displace traditional power generation development.

Figure 2: Solving energy sector challenges.

	Peaking & flexible generation	Electricity shortage - fast power	Domestic gas monetization	Oil substitution
Chile	X			X
Nigeria		X	X	X
Egypt		X		X
South Africa	X	X		X
Brazil	X	X		X
Indonesia	X	X	X	X
Bangladesh	X	X		
Ghana		X	X	X
Mozambique		X	X	
Caribbean	X	X	X* U.S. Gas	X

A variety of factors will make GTP attractive in a particular country. Key metrics from a power market perspective are included in Figure 3. Strong economic growth, especially when tied to resource development and urbanization, leads to rapid electricity demand growth. Regions with lower electrification rates, high electricity prices and higher percentages of oil or hydro generation, are also good prospects for GTP depending on availability of gas in the region.

There is strong consensus that energy poverty is one of the greatest barriers to global economic development. Currently, 20 percent of the world's population lives without access to electricity – primarily in Sub-Saharan Africa and parts of Asia. While most of those without electricity live in rural areas, urban populations in developing countries are expected to exceed rural populations by 2020.[5]

Inadequate access to electricity limits the ability of low income countries to improve their economic position. For instance, in Sub-Saharan Africa, 30 countries suffer from regular blackouts and brownouts, which can lead to economic losses of roughly two to five percent of GDP.[6] Furthermore, in areas where electricity is available, it tends to be more expensive than in the developed world. Electricity costs in Africa vary widely. Some hydro-based or coal-based systems have low cost power of $0.05-0.07 per KWh, but many of these investments occurred decades ago and the corresponding transmission grids need to be updated and expanded. Shortages prevail in other parts of Africa, where weak and underfunded electricity companies scramble to meet needs through ad-hoc expansions of oil-fired power, often subsidized at great cost to the financial health of the country. Industrials, which require reliable access to power in order to thrive, also rely on expensive small oil-fired generators to provide power for their businesses. In Africa, it is not uncommon to see power costs far in excess of $0.20 per KWh compared to a global average of about $0.10 per KWh.[7] Recognizing the critical role energy plays in alleviating poverty and promoting development, the World Bank ranks providing universal access to reliable electricity as its top energy-related priority. In fact, five of the eight UN Millennium Development Goals hinge upon access to electricity. GE believes that GTP is an important option to support basic human needs and promote investment and economic growth in these countries.

While some countries focus on getting new, incremental power on the grid as fast as possible, others focus on GTP for its ability to create flexibility in the power system. Gas generation is a dispatchable resource (generation that is available for dispatch on demand) that can, for example, back up hydro power in times of drought or ramp up quickly to serve load in markets with a high penetration of intermittent renewable resources. Ultimately, investment in GTP options can displace high cost and environmentally-unfriendly oil-fired peaking

[5] United Nations Population Division, *World Urbanization Prospects: The 2014 Revision*.
[6] "The Issues Affecting Global Poverty: Energy." ONE Campaign. June 2013.
[7] Climate scope 2014, http://global-climatescope.org/en/.

Figure 3: Countries with strong fundamentals for GTP projects. Sources: GE Gas to Power estimates based on various sources, IEA, World Bank, Climate Scope 2014, EIA, African Development Bank, BMI, GE Power and Water. Notes Electricity price based on Industry or average prices latest best estimate.

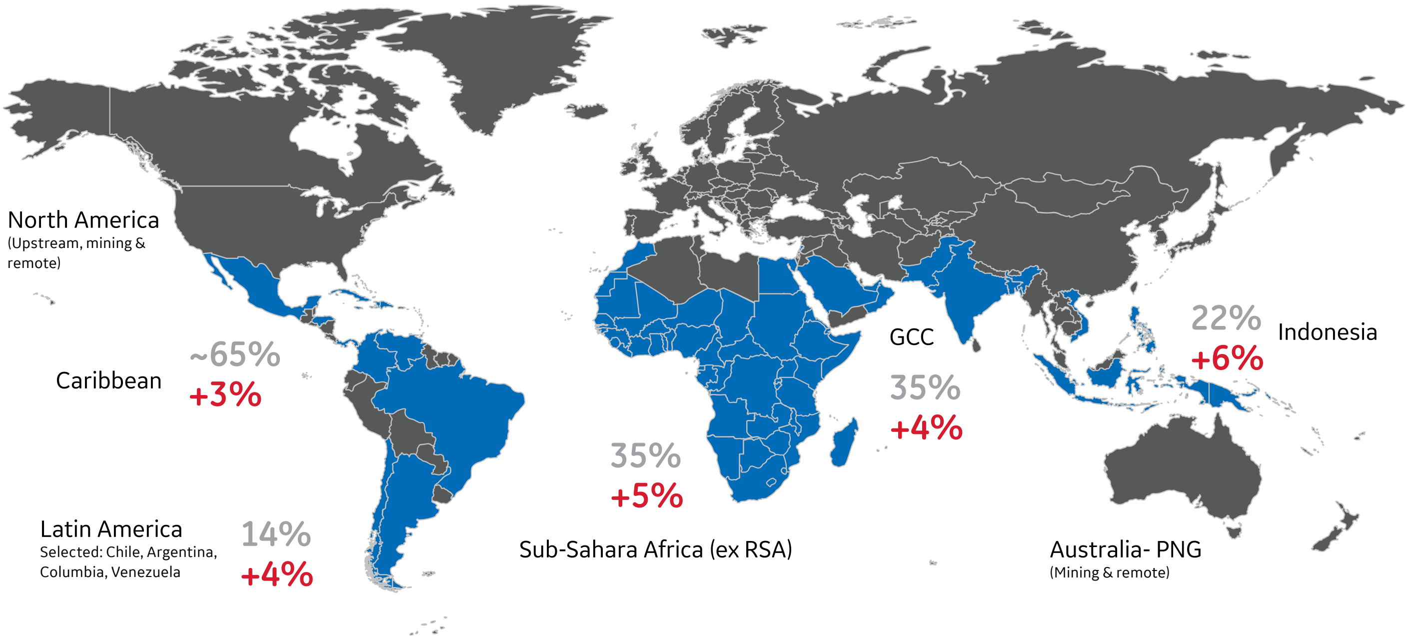
Region or Country (selected)	GDP Growth ('15-'20)	Electricity Consumption Growth ('15-'20)	Percent Electrification (latest data or estimate)	Average price electricity * US Cents/KWh)	Natural gas % of total TWh Gen	Oil % of total TWh Gen	Renewables inc Hydro % of total TWh Gen
Asia							
Indonesia	5%	6%	78%	8.1	21%	22%	13%
Bangladesh	6%	9%	62%	7.8	90%	6%	2%
Vietnam	7%	8%	96%	6.0	41%	3%	37%
Pakistan	6%	6%	69%	15.7	29%	36%	31%
Africa (Sub-Sahara)							
Kenya	6%	10%	29%	13.6	0%	34%	62%
Mozambique	7%	11%	34%	4.9	8%	5%	87%
Tanzania	6%	13%	18%	7.8	44%	10%	46%
Nigeria	5%	9%	56%	12.4	77%	0%	23%
Ghana	5%	8%	72%	17.8	9%	20%	71%
Senegal	4%	8%	50%	25.6	2%	85%	8%
Ivory coast	7%	8%	26%	16.1	67%	2%	30%
South Africa	3%	1%	85%	7.6	0%	0%	1%
Angola	5%	12%	12%	4.5	0%	30%	70%
Namibia	3%	7%	44%	5.3	0%	1%	95%
Middle East & North Africa							
Egypt	4%	4%	99%	8.0	76%	14%	10%
Morocco	5%	6%	99%	14.0	16%	24%	11%
Saudi Arabia	3%	3%	94%	6.0	46%	54%	0%
Latin America							
Brazil	2%	2%	99%	14.8	6%	3%	80%
Chile	3%	4%	99%	13.8	16%	10%	34%
Colombia	4%	4%	97%	15.8	15%	0%	76%
Dominican Republic	4%	3%	96%	20.5	19%	58%	10%
Haiti	4%	5%	28%	33.8	0%	75%	25%
Panama	5%	7%	88%	16.7	0%	39%	58%
Honduras	4%	4%	89%	19.6	0%	56%	41%
Jamaica	1%	4%	92%	37.0	0%	92%	5%

generators. Brazil, Ghana, Chile, Egypt, Indonesia, and South Africa are all examples of more developed nations that have been active in exploring GTP options. In some cases, these countries are looking for fast access to city-scale power solutions, while in others they seek to add flexible seasonal or peaking power to diversify and optimize their existing systems. In still other cases, countries want both fast and flexible power.

The availability of domestic gas or nearby gas resources is a critical driver of GTP projects. The global map of gas supply options is expanding. From the large shale-based resources of North America to the vast offshore gas deposits of East and West Africa, every month seems to yield announcements of new gas discoveries. Further, there are well-known yet still untapped gas resources in Latin America and the Middle East that are waiting for the right political climate and economic opportunity. Another driver for GTP is the focus by certain gas-rich, infrastructure-poor nations such as Nigeria, Mozambique, Indonesia, and Namibia to monetize their domestic gas reserves. Lastly, the abundance of competitive shale-based gas supplies, including LNG, propane, ethane, and pipeline gas from the United States,

Figure 4: Key regions for distributed power and oil substitution. Source: IEA, GE Global Gas to Power. Note data points apply to sub-set of highlighted countries.

Percent share (%) of oil generation 2013
Electricity demand growth rate 2014 to 2020



is creating robust opportunities for oil substitution in the Caribbean, the rest of Latin America, and beyond.

Oil accounts for about five percent of global electricity generation, with approximately 1,100 terawatt-hours (TWh) per year.[8] This is almost equal to the world generation from solar, wind, geo-thermal, and biomass resources combined. Lighter premium oils, such as diesel and kerosene, represent around 50 percent (~570 TWh) of this oil generation. Natural gas is a viable alternative to oil-fired generation in many cases. In others, lower cost fuels like propane can potentially work as a bridge fuel until natural gas becomes available, as today's turbine technology can run – and switch – efficiently on multiple fuels.

Examining just a few target regions, GE has identified nearly 100 TWh of light oil generation, representing 13 gigawatts (GW) of capacity, that can be displaced with natural gas.[9] Small-scale technology platforms have the advantages of lower capital intensity, faster implementation, and can be phased to match load growth. However, these small systems can have reduced economies of scale and therefore higher per unit costs. As a result, it is important to understand the trade-offs to determine the best for each application and challenge.

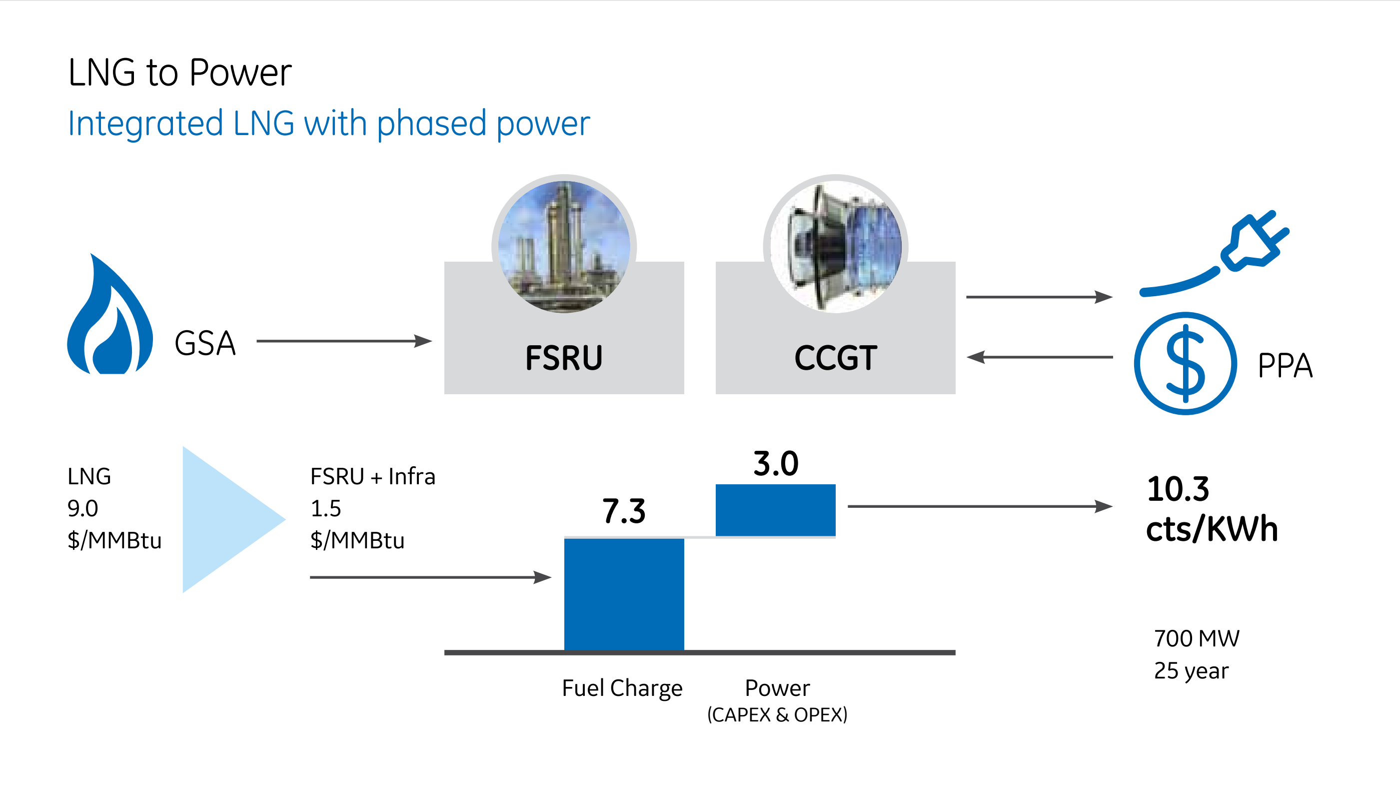
Competitive economics

The viability of any GTP technical approach starts with a value proposition. One of the key advantages of natural gas generation is its lower capital startup costs than other comparable sources of electricity. On a dollar per kilowatt ($ per KW) basis, the capital cost of installing gas technology is one-half to one-fifth of the estimated cost of coal or nuclear plants, respectively.[10] In many cases, GTP projects are a quick, economically-viable means to bridge the gap until larger, centralized projects can be developed.

Integrated GTP projects involving LNG are a potential cost-effective option for countries in need of a larger scale development solution that can be conceived and executed in three to five years. The power station serves as the "anchor" customer for a floating regasification and storage vessel (FSRU). In such circumstances, it is important to combine all of the elements along the value chain, including gas assets, marine facilities, local pipelines and transmission

[8] GE Gas to Power estimates based on IEA generation data 2013 and GE Power and Water forecasts.
[9] GE Gas to Power estimates.
[10] Evans, Peter and Michael Farina. The Age of Gas & the Power of Networks. General Electric, October 2013. 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.

Figure 5: LNG to Power. Source: GE Gas to Power estimates. Notes: FSRU Floating Regas and Storage vessel. CCGT: Combined cycle gas turbine. GSA: Gas sales agreement. PPA: Power purchase agreement. Assumes imported LNG at $9.00 per MMBtu DES into the FSRU. Indicative cost estimate for discussion purposes. Project specific and actual cost structures may vary depending on multiple factors.



connections, and the power plant into an integrated project group. This helps avoid misalignment around timing of investment. The gas assets can be dedicated to a single power station or the project can allocate excess midstream capacity to other gas users. Key drivers of the cost of power include LNG supply, the gas infrastructure and the duty cycle (baseload, cycling or peaking), and efficiency level of the power plant.[11]

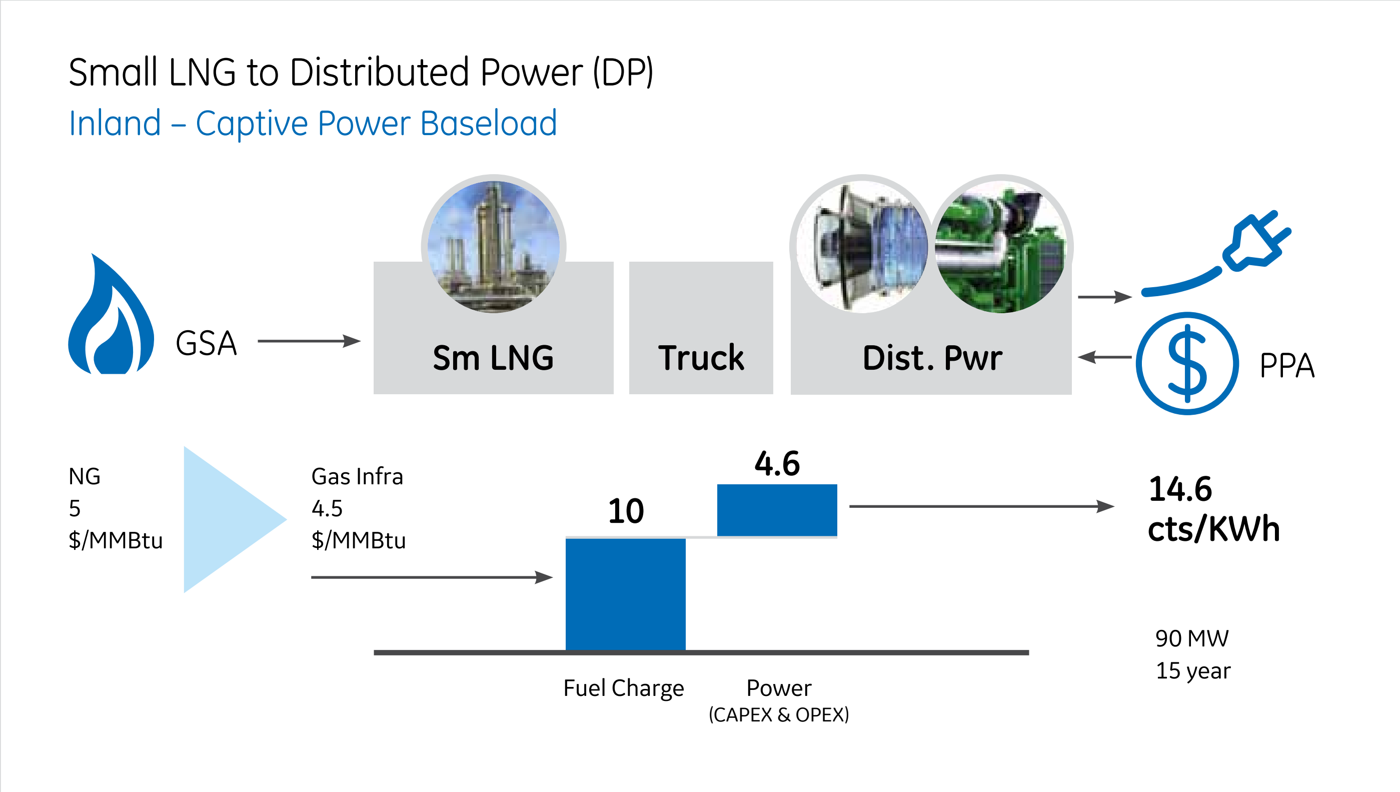
Figure 5 shows an indicative example of the economics of an LNG to Power concept. The design is based on delivery of 700 MW of power generation in several phases of development. LNG supply would be contracted separately to feed the plant. Fuel procurement options might include portfolio suppliers with multiple sources of supply or direct purchase from a sovereign entity. The LNG price may be tied directly to the price of oil or linked to a liquid gas market, as exists in the United States, with infrastructure tolling contracts associated with the LNG producing plant. There are also a variety of new hybrid structures that are somewhere between these two models.[12] The gas supply contracts must be securitized within the project structure. The combination of downstream and midstream elements within an integrated project, removes pressure on upstream companies to develop the entire gas value chain. Producers can focus on what they do best – finding and developing gas resources.

Assuming LNG prices of around $9 per MMBtu and a tolling fee of $1.50 per MMBtu (assuming partial utilization of the FSRU), GE estimates fuel costs at 7.3 cents per KWh, based on a 60 percent efficiency level for a combined cycle power plant and a 25-year asset life. The plant capital and operating expenditure (CAPEX and OPEX) of a combined cycle gas turbine (CCGT) is roughly $.03 per KWh.[13] This yields an estimate for the levelized cost of power of 10.3 cents per KWh in real 2012 U.S. dollars. While many factors might alter these numbers, GTP involving LNG appears to be a competitive and relatively fast solution for city-scale power, especially near coastal regions.

LNG-based power is only one option for large scale supply. A variation on this concept would be to use domestic offshore gas or gas pipeline options. There are examples of projects where

[11] Baseload refers to power plants that run virtually year round, Cycling plant may only run in the day-time hours, or seasonally (e.g. dry season), while peaking plants only run in the hour of highest demand.
[12] A detailed discussion of the gas supply structures, contracts, financing and pricing is beyond the scope of this paper. However, as the largest component of cost, the details around the LNG purchase agreements a key in every project.
[13] This example assumes capital costs of 850 per Kilowatt, 20 percent of owners costs, 70/30 debt equity ratio.

Figure 6: Small LNG to Distributed Power. Source: GE Gas to Power estimates. Notes DP: Distributed Power includes Aeroderivative or gas engine options. GSA: Gas sales agreement. PPA: Power purchase agreement. Assumes domestic gas at $5.00 per MMBtu. Indicative cost estimate for discussion purposes. Project specific and actual cost structures may vary depending on multiple factors.



smaller producers joining with developers and government entities to create fully integrated GTP projects.[14] The power project is the anchor customer for the gas development, but additional sources of demand, like industrial users, around the project site become critical. As the gas infrastructure needs and costs get larger, including drilling wells or constructing pipelines, the role for government entities typically increases. However, selected midstream investments in processing or compression might be integrated into the GTP project structure. Reducing the scale of the GTP project in a more distributed power approach is another option.

Distributed power fed by a "virtual" pipeline is a smaller scale option with interesting potential. "Virtual" pipelines distribute gas via land or sea transportation and are a substitute for physical pipelines. Virtual pipelines replicate the continuous flow of energy in a pipeline or electric transmission line, with discrete "cargos" of energy based on storage and transportation logistics. One of these systems can effectively replicate the continuity and flexibility of a pipeline and can meet changing load profiles without permanently committing to a fixed, point-to-point conduit.

This approach is particularly suitable to areas with power shortages where domestic gas resources exist but delivery is hampered by a lack of pipeline infrastructure. Historically, end-users tended to turn to oil for emergency power because of its high energy density and lower cost transportation logistics. Today, oil prices are disconnecting from gas prices, and even propane prices, in many regions. Now it is often less expensive to transport gas where it is needed, versus oil. Virtual pipelines are typically not substitutes for gas pipelines, but rather are a compelling option when supply and demand centers are large and pipeline development is not possible in the short term. Longer term, pipelines remain the most cost effective way to move large quantities of natural gas, but virtual pipelines can fill the gap in connecting smaller supply sources to

Key takeaways

GTP solutions that deliver power at 10 to 15 cents per KWh are often 30 to 50 percent below the cost of oil-fired power.

[14] Examples include Banda in Mauritania, Kribi in Cameron, or Kudu in Namibia.

LM2500 gas turbine

emerging or remote demand centers. Virtual pipelines have become a viable, cost-effective, and mobile alternative means to deliver fuel.

GE offers the following conceptual case study to illustrate how virtual pipeline and distributed power systems might work together. The project entails a 90 MW natural gas-fired combined cycle power plant to run in baseload operations. The power plant will be supplied by a small-scale LNG facility and trucking and storage tanks to create a “virtual pipeline” for an inland isolated end-user, such as an industrial facility. This example assumes that an existing regional gas pipeline is the supply source for the project, but the pipeline does not reach the industrial site and the load potential is not large enough to justify a pipeline expansion. We assume the gas is dry and clean, needing only minor pre-treatment before entering the LNG system, and the gas is supplied at $5.00 per MMBtu. For this design, we are using a 240,000 LNG gallon per day plant that needs approximately 21 MMcf per day of feed gas. The plant is assumed to produce about 900 cubic meters (CM) of liquid LNG per day.

Given a 200 km one-way voyage to the power generation site, travel time is assumed to be about 4 hours with 3 hours for delivery time. The project would need between 15-20 trailers each with about 10,000 LNG gallon capacities. Each truck unloads the cargo into a second LNG storage site with regasification and a short pipeline to the power generation site. The trucks arrive on schedule to keep the storage on site topped up ready in cases of a disruption. As shown in Figure 6, the total cost of the virtual pipeline infrastructure including conversion and trucking translates to about $4.50 per MMBtu. The total cost of gas supply is $9.50 per MMBtu or fuel charge of about $0.10 per KWh. The power plant capital and operating costs when amortized over a 15-year period total about $0.046 per KWh. Total cost of power in this example is about $0.15 per KWh. This often compares very favorably against the costs of diesel power, which can range from $0.20 to $0.30 per KWh.

These are indicative cost estimates for discussion purposes. It should be recognized that project-specific and actual cost structures may vary depending on multiple factors. A variety of virtual pipeline concepts can be explored utilizing barges, rail cars, or small regional feeder vessels. There are also a number of fuel options including propane and compressed natural gas (CNG) along with LNG. The variety of modes and fuel options creates optionality for remote and fast power applications that can be competitive with diesel-fired power. In this case, the cost of the gas transport system is slightly lower than the cost of supply. As in the large scale example, the cost of fuel is about 70 percent of the cost of electricity. It is clearly critical to manage fuel options, along with many other variables, in order to execute successful GTP development. The advantage of this approach is that the capital cost of this type of project are in the range of $200 to $300 million dollars, much lower than centralized power, and typically they can be online in two to three years, or less, depending on gas availability.

Project development for new gas economies and growth regions

GTP projects require strong stakeholder commitment to regulatory and industry best practices, underpinned by coordination at each project stage. It is important to understand the high level aspects of the development process, to identify the key projects stakeholders and to determine what is needed in each component – including technology selection and execution (or "activation") requirements, to deliver a successful project. Figure 7 outlines elements of the "technology" and "activation" models required for a GTP project. The technology aspect focuses on country-specific considerations such as scale, application, and need, all of which combine to determine which technology options make the most sense. The activation model underscores the various stakeholder and institutional factors in a country that can create an attractive environment for GTP projects. This includes credible regulatory structures, viable power purchase agreements (PPA), and availability of credit support. Specific roles for project stakeholders as shown in Figure 8 are discussed below.

Figure 7: Project structuring dimensions. Source: GE Global Gas to Power

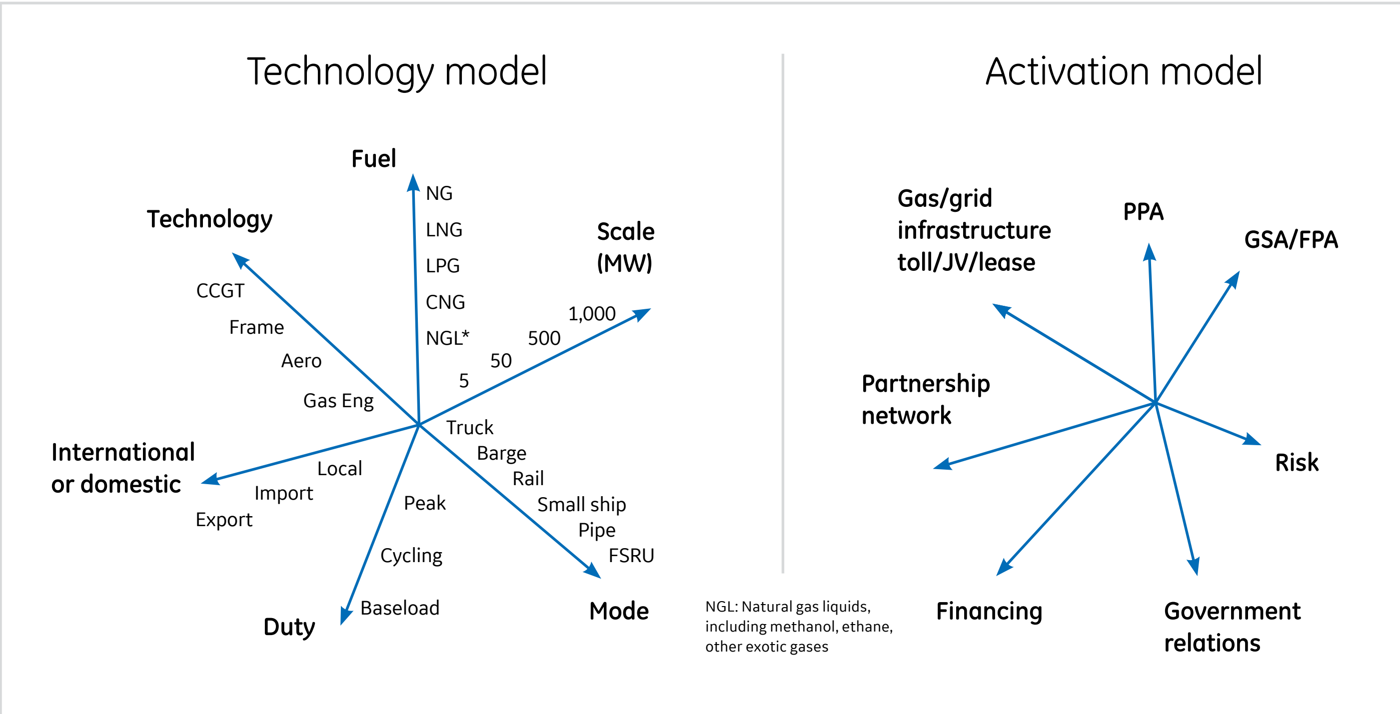
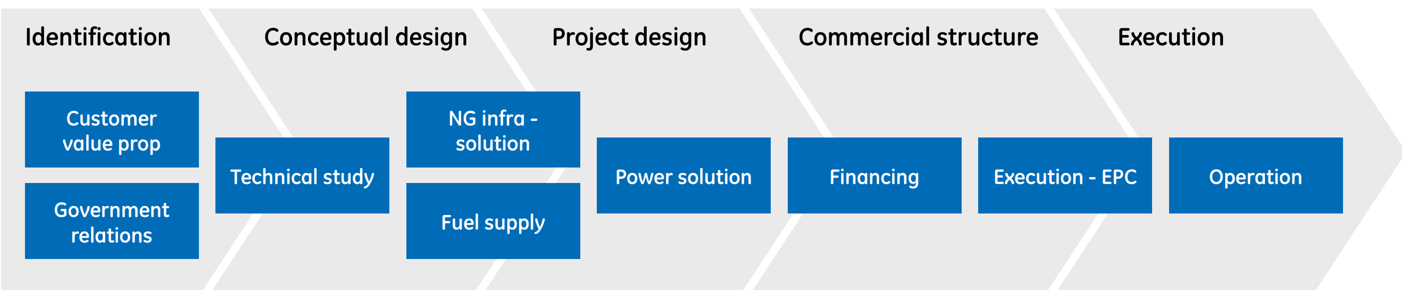


Figure 8: Project Development Components. Source: GE Global Gas to Power



Policy framework – International, national, and local regulatory requirements must be transparent, reasonable, and responsive to the pace of business. Policymakers must have political will to implement reforms and confront legacy interests where needed. Tariff schemes for the sector must ensure that governments and companies share the risks and rewards of the activity and that the private sector can recover the cost and rely upon a reasonable rate of return for investments.

Gas development and transportation – The fuel source, whether domestically sourced or imported, must be cost competitive and sustainable for the life of the project. Supply contracts must be flexible to address local needs.

Power generator (seller) – Private sector or state-owned enterprises must be committed to industry best practices, and a world class Power Purchase Agreement (PPA) must be negotiated between the power seller and off-taker. (A PPA is a contract between two parties, one who produces or generates power for sale and one who seeks to purchase that power over a long time horizon. The quality of the PPA can determine whether or not power projects are financeable and viable for the long-term, and hence are among the key ingredients of a successful GTP project.)

Distribution company (off-taker) and customers/end-users – Private sector or state-owned enterprises must be committed to industry best practices. The regulatory landscape must be sufficiently stable to forecast revenue streams over the life of the project. The utility must have the ability to minimize losses from theft and inefficiency. There must be sufficient demand by end-users who are willing to pay market costs for electricity over the life of the project.

Regulator – Depending on market structure, electricity tariffs should be maintained under the authority of an independent regulator to judge the prudency of new investments, maintain a balance between the interests of power plant owners/operators and consumers, and to de-politicize the ratemaking process.

Project finance – Stakeholders must have access to competitive private sector or development bank financing, reflecting construction risk, sovereign risk, and currency risk. Host governments may need to provide sovereign guarantees, tax exemptions, and other credit enhancements to attract financing.

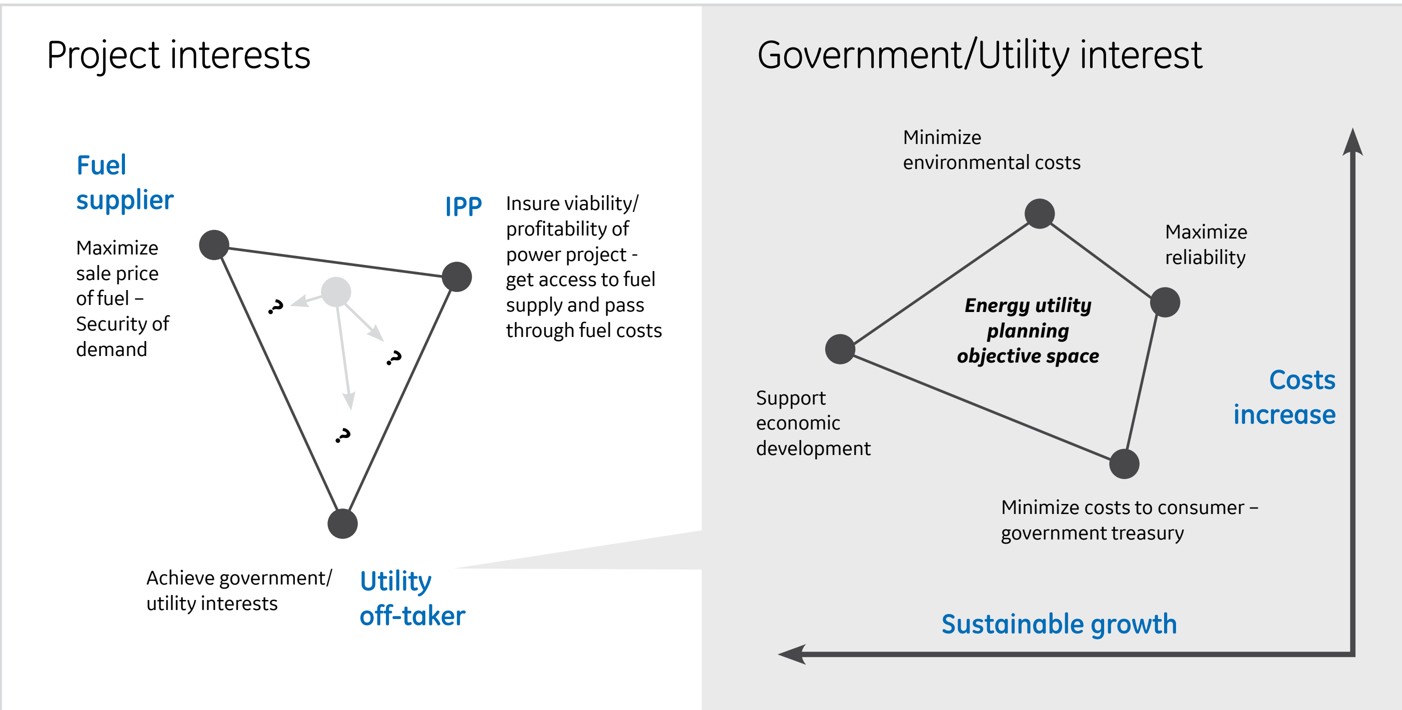
Construction – Engineering, procurement, and construction (EPC) firms must be experienced in working in the local and regional markets and have the ability to operationalize new (greenfield) projects or update older plants (brownfield projects).

The key challenge is to align the potentially divergent interests of all of the stakeholders. Fuel suppliers want the highest price for their gas. Generators want tariff assurances, security of fuel supply, and secure offtake agreements. Harmonization between public and private interests is also required. Figure 9 maps out natural positions of private stakeholders and the challenges governments face to navigate multiple competing interests. Once all parties are generally aligned, market and political forces can force re-alignment. The fundamentals and mutual advantages must be strong enough for a project to move to financial close and implementation, and to withstand unexpected changes in the market.

Key takeaways

Stakeholders in a GTP project will often have competing interests. Creating alignment among various parties is critical for success.

Figure 9: Navigating Interests. Source: GE Global Gas to Power



Policy considerations

International companies are often willing to take on significant financial and operational risks to develop resources, build infrastructure, and link markets, provided governments can create a stable environment for investment and ensure a reasonable and sustainable return on investment. This is even more important for gas supply projects with 20- to 30-year investment horizons. Some of the common policy challenges – and potential recommendations - for GTP projects are summarized below.

Holistic decision making – Fuel and technology choices made now and 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 turnover of major energy systems. Policymakers and industry experts should take a holistic approach to long-term decision making to include diversification of supply, non-subsidized fuel price comparisons, future trends, environmental targets, and regulatory structures.

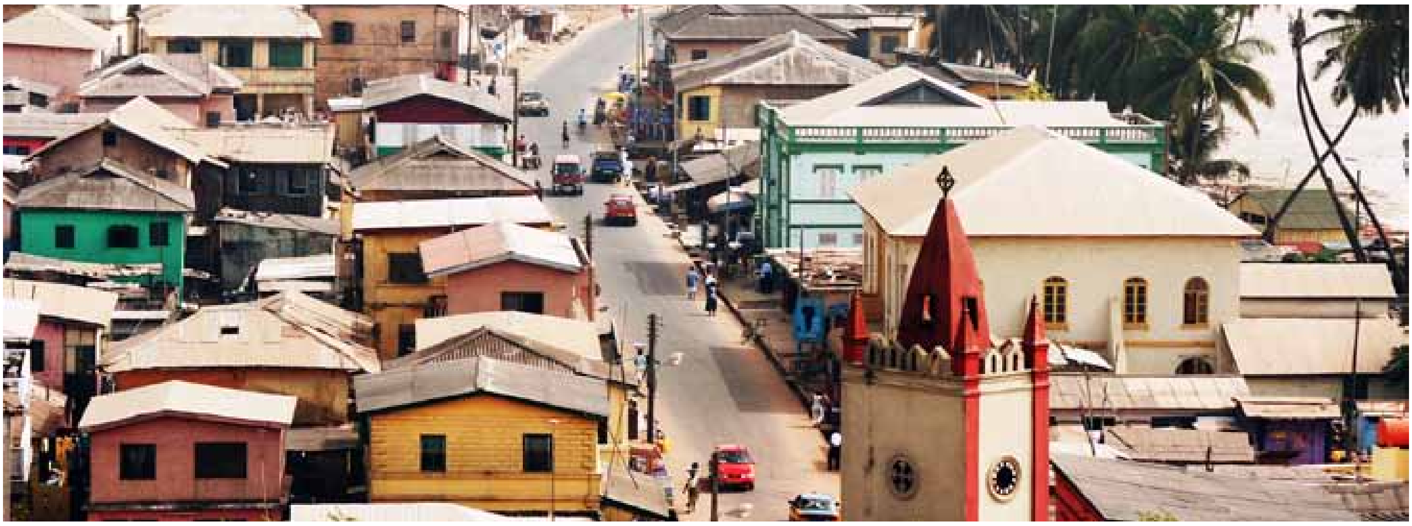
Developing fuel and infrastructure – Where the resources exist, policymakers can stimulate investment in gas development by structuring income distribution schemes for the sector whereby governments and investors share the risks and rewards of the venture. Regulations need to promote a transparent and inclusive transfer of benefits to local communities so that they benefit from and support new investments. Consultative institutions and clear legal regimes that insulate firms from volatile political leadership changes and the consistent enforcement of labor and environmental rules increase private sector confidence to develop long-term gas projects.

Legacy sector interests – Every new project must take into consideration operators already in the market. In many cases, these private companies or state-owned enterprises will become new, integral partners to the project’s success. In some markets, however, where significant structural reform is needed or legacy operators will face new competition, policymakers must have the political will and power to ensure new initiatives can succeed through new regulation and implementation.

Electricity pricing – Electricity prices can be a highly politically-charged issue. Cost-reflective prices for customers guarantee the stability and sustainability of any new power project as tariffs are normally the only income stream to pay off the investment. Many utilities in emerging markets still do not charge cost-reflective prices for electricity and new power projects are derailed because suppliers do not see a way to recover the costs of new investments. Many developing countries with state-owned electricity systems do not have the financial wherewithal to invest in significant volumes of new power generation and increasingly seek private sector investment through an Independent Power Producer (IPP) model. This can relieve the burden on government to make the up-front investment. At the same time, the IPP must be able to recoup and make a return on its investment over the life of the project, and have security that revenue will be sustained in order to attract financing. This can be achieved through the employment of a strong power purchase agreement that enables cost recovery and that protects the investor against political interference in the ratemaking process. This in turn argues for a strong, independent regulator to oversee prices to consumers and balance the interests of all parties while guaranteeing a reasonable rate of return for prudent investments.

Financing – Many countries are undertaking reforms to stimulate private participation. When new or reformed market entrants are establishing themselves during this transition, stakeholders need certain guarantees to facilitate bankable projects. Policymakers can stimulate infrastructure project financing using funds from donor governments and development financial institutions (DFIs) to address project development and feasibility studies in addition to construction risk, sovereign risk and currency risk in emerging markets. There is a growing need for credit enhancements, partial risk guarantees, and sovereign risk guarantees to make this happen. As private finance becomes more sophisticated and willing to seek out these opportunities, DFIs can leverage relatively small investments with their own funds to mobilize substantial private capital. While many DFIs and bilateral donors are already doing this, more can be done to coordinate resources. At the country level, policymakers should ensure their regulations include consent mechanisms to attract DFI and donor support.

Regional cooperation – 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, sellers, regulators and other stakeholders will be pivotal in mobilizing new mega-project investments. Regional economic partnerships and trade blocs could elevate energy cooperation by forming technical working groups to help standardize related regulation.



Case study

Ghana 1000 – Regulatory change and regional supply makes large GTP project feasible

Since 2012, Ghana has faced power shortages caused by inadequate and unreliable gas supplies to run power plants. Electricity demand growth has been constrained by lack of power. Industries have been forced to curtail energy use as well, for example, VALCO's large aluminum plant in Tema operated at 20 percent utilization in 2013. In addition, hydro-generation has been variable driving significant use of oil-fired generation. In response, GE is working with a set of partners to develop Ghana 1000, a 1,300 MW combined cycle power plant and Sub-Saharan Africa's largest integrated gas to power (GTP) project. While the project is still in the development stage, it shows tremendous promise to solve Ghana's long-standing energy challenges. By shifting generation from light crude oil to cleaner natural gas, the project will ensure reliable electricity supply while significantly reducing emissions and delivering associated health and environmental benefits.

Consortium partners General Electric, Endeavor Energy, Sage Petroleum, and Eranove have entered into a Joint Development Agreement (JDA) to develop Ghana 1000 near Takoradi in the Western Region of Ghana. Ghana 1000 features GE's state-of-the-art multi-fuel gas turbine technology, purpose-built LNG import infrastructure, and a floating storage and regasification unit ("FSRU") provided by Excelerate Energy. In addition, the consortium has entered into exclusive supply negotiations with Shell Trading regarding a long-term supply agreement for LNG. The consortium is structuring the gas agreements so that the plant can utilize a portion of the domestic gas from ENI's and Vitol's Sankofa gas development when available. The combination of domestic and international sources creates supply diversity and flexibility to withstand supply disruptions and to follow variation in demand from hydro availability. The project will be built in two phases:

- Phase 1: 750 MW of power from two power blocks, each producing 375 MW from two gas turbines and a steam turbine
- Phase 2: 550 MW of power from 3 gas turbines and one steam turbine

LNG can potentially lower the cost of power in Ghana by up to 35 percent, as the cost of LNG is expected to be lower than oil by 2018 and combined cycle gas is more efficient than simple cycle oil generation.

Switching thermal generation from oil to gas on roughly 3,000 MW of capacity can reduce energy costs by $1 billion annually.[15] A LNG solution combined with increasing availability of domestic gas will dramatically increase supply options, allow faster development and create a hedge against upstream delays or disruptions. In addition, many of Ghana's regional neighbors beyond Nigeria will be exporting LNG in the next few years, creating multiple opportunities to access nearby supply. The gas contracts are structured with flexibility so that Ghana can end the contracts when it starts producing sufficient gas supply from domestic production.

Regulatory changes in Ghana around electricity tariffs and government resolve to work toward a private solution has been key to unlocking this project's potential. When it is complete, the Ghana 1000 project will be a signature accomplishment of the Power Africa Initiative. However, a variety of US and international institutions including the World Bank, IFC, USAID, OPIC, Ex-Im, and the MCC are helping to ensure the success of the project. Efforts at this scale require a whole-of-government approach. If ultimately successful, Ghanaians will have affordable, reliable electricity and the project will even benefit Ghana's neighbors though power exports to surrounding countries. Furthermore, Ghana 1000 has the potential to be a model for other nations with similar challenges.

[15] This calculation is indicative of the savings potential based on 750 MW of simple cycle oil generation priced at roughly $80 per bbl or $14 per MMBtu versus 750 MW of combined cycle generation priced at $12 per MMBtu including FSRU costs. The resulting annual savings is $250 million per year. The annual savings in 2018 on 3,000 MW of thermal capacity, a target for Ghana, is roughly $1.0 billion dollars.

Small-scale LNG plant

Conclusions

The "Age of Gas" is a game changer for the power industry. While large baseload generation such as hydro, coal, and oil will continue to have a large part to play in power generation in the future, the gas market evolution coupled with traditional power market challenges is creating ever increasing GTP opportunities.

In many places, gas to power has key advantages, including; the speed of development, access to new and diverse gas supply options, lower capital intensity, flexibility to support the expansion of renewables in the power mix, and increasing price competitiveness.

Rapid access to energy is needed across much of the developing world. Yet traditional development models have struggled to deliver in many of these regions as large-scale developments often get delayed from a myriad of technical, political, environmental, and financial hurdles. The speed and flexibility of GTP projects holds tremendous promise for communities, countries, and regions willing to take a fresh look at how gas can play a larger role in their energy mix.

The complexity of these projects, although less than traditional models, still present challenges that will require more concerted efforts by stakeholders to build strategic alliances to bring these projects on-stream faster.

Key takeaways

GTP has strong advantages in many regions, and the modularity and flexibility of the concept allows for its application to the full range of energy needs, from mega-projects to micro-grids.

GTP projects require strong stakeholder commitment to regulatory and industry best practices, underpinned by coordination at each project stage.

About Us

GE works on the things that matter in the oil and gas industry. In collaboration with our customers, we push the boundaries of technology to bring energy to the world. From extraction to transportation to end use, we address today's toughest challenges in order to fuel the future

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Note on gas conversions

Conversions between natural gas and LNG are based on standard measures in the International Gas Union (IGU) natural gas conversion pocket book at

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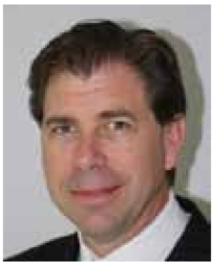

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