The Natural Gas Revolution and the World's Largest Economies

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Abstract: In the last decade, three interacting technological developments have revolutionized the production of natural gas resulting in a much expanded supply and much lower price. These technologies are hydraulic fracturing, directional drilling, and the worldwide build-out of liquefied natural gas (LNG) import and export facilities. Hydraulic fracturing and directional drilling are mainly responsible for the improvement in supply, while the richer LNG infrastructure is facilitating the worldwide transportation of gas and starting to knit the once fractured gas market into a truly world market. The consequences of these processes has dramatically different effects around the world, creating true winners and losers. This article assesses the impact of these natural gas developments on the world's ten largest economies. It concludes that the United States is the largest beneficiary of these developments, followed by China, with Russia being the largest loser in the new world of natural gas.

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I. Introduction

In the span of just a few years, the production of fossil fuel resources, most notably natural gas, has accelerated so quickly that is reshaping the world's energy future. In its 2011 assessment, the International Energy Agency posits that the world is entering a "golden age of natural gas" and other notable commentators such as Martin Wolf and Daniel Yergin have reinforced this analysis.[1] Sounding a similarly optimistic note, Amy Myers Jaffe asserts that shale gas will rock the world and that the Americas will supplant the Middle East as the world capital of energy.[2] Others have likened North Dakota to Saudi Arabia[3], while a sizable chorus of analysts predicts that the United States will soon be energy independent, while even those not firmly convinced now see U.S. energy independence as a serious hypothesis.[4]

This suddenly bright future stands in marked contrast to the natural gas supply and demand forecasts of just a few years ago. Circa 2005, the United States was expected to need to import very large quantities of natural gas. For example, the February 2005 "Annual Energy Outlook," published by the U.S. Energy Information Administration forecasted that the United States would be importing more than 170 billion cubic meters (BCM) of natural gas annually by 2025.[5] Even as recently as the end of 2009, Exxon forecasted that the United States would need to import growing amounts of natural gas reaching a forecasted import need about 143 million cubic feet *per day* in 2030. While many deny that the U.S. will be energy independent in the near future, virtually all serious analysts concur that the United States will almost certainly produce enough natural gas for its own needs. Thus, the terms of debate over fossil-based energy have changed entirely. While circa 2005 the United States was building and planning to build many LNG import terminals, today there is not a single one on the drawing board. The last one being built was Cheniere Energy's Sabine Pass plant on the Louisiana-Texas border, which the firm is now converting to an LNG *export* terminal. So today the debate over natural gas imports and exports concerns whether U.S. energy companies should be allowed to export natural gas, as many are anxious to do, or whether U.S. natural gas should be retained for domestic use.[6]

This striking reversal of the natural gas supply and demand situation for the United States is due to three related technological developments and their mutually reinforcing interaction which are revolutionizing the world's energy future. These are hydraulic fracturing, horizontal drilling, and the build-out of the world's liquid natural gas (LNG) infrastructure. This process constitutes what this article calls the "natural gas revolution." Section II, "Elements of the Natural Gas Revolution," briefly reviews the technological breakthroughs driving vast improvement in the world's energy prospects, as well as the associated ecological challenges. The United States has essentially created the natural gas revolution and is the first and perhaps largest beneficiary. However, this revolution will also have enormous implications for many other nations. Section III, "Natural Gas and the World's Largest Economies," focuses on the ten nations with the world's largest GDP: the United States, China, Japan, Germany, France, Brazil, the United Kingdom, Italy, the Russian Federation, and India. These ten countries produce two-thirds of the world's GDP. Beyond these ten countries, there are three additional countries that have a critical stake in the natural gas revolution because they hold such a high proportion of the world's natural gas reserves. They are Iran, Qatar, and Turkmenistan. So while the focus of this article is on the ten largest nations by GDP, their interaction with Iran, Qatar, and Turkmenistan also forms a minor theme of Section III. Section IV concludes.

II. Elements of the Natural Gas Revolution

In conventional gas deposits, a large and unified pool of gas collects far beneath the earth's surface and is held in place by surrounding rock formations. To acquire the gas, an exploration company sinks a well into the pool and pumps. This simple process left much of the gas in place, especially the gas that was infused into and trapped by the surround geological formation. To capture a greater portion of the gas, drillers long ago began to use the technique of hydraulic fracturing or "fracking."[7] In hydraulic fracturing a gas well is drilled with strong cement and steel containment around the well bore. The driller then pumps a mixture of water, sand, and chemicals into the well, and uses the pressure of this introduced fluid to fracture the rock that surrounds the gas deposit, allowing additional gas to flow into the well and to be pumped to the surface. So long as this technique was applied to a single pool of gas, the additional increments of production remained modest. However, the development of hydraulic fracturing became more valuable when combined with a second innovation of horizontal drilling.

In horizontal drilling the driller sinks a vertical shaft from the surface to a suspected gas deposit far below and then turns the drill to a more nearly horizontal angle and continues drilling to reach additional deposits. Shale deposits often contain considerable natural gas, with the gas being diffused through the rock rather than residing in a single pool. As the technique has advanced, drillers have been able to use a single vertical shaft to access an increasing number of horizontal drill paths, which has several advantages. First, the driller can reach much more gas from a single site on the earth's surface. Second, because the driller reaches a wider area from a single pad, the drilling process has a reduced "footprint" at the surface.

By using the techniques of hydraulic fracturing and horizontal drilling in tandem, drillers have been able to achieve very large gains in gas production. The energy industry has known of gas (and oil) trapped in shale formations for some decades, but until the advent of horizontal drilling, there was no effective or economic way to capture this more widely diffused gas. Among rocks, shale is quite friable, so it is especially amenable to hydraulic fracturing. These gas recovery processes have been created and developed almost exclusively in the United States, so to mid-2012, only the United States has seen any increased production from these techniques. Of course, many other countries are now racing to exploit the same technology.

Figure 1 shows natural gas proved reserves and gas production for the United States from 1980-2011. Proved reserves are 52 percent larger now than they were in 1980, and the figure also shows the remarkable surge in production that began in 2006, with 2011 production being 27 percent larger than that of 2005. From 2000 to 2010, U.S. natural gas production increased from 0.39 to 4.87 trillion cubic feet per year, surging by more than a factor of twelve.[8] Beyond proved reserves, a report commissioned by the U.S. Energy Information Administration estimated that the United States has 750 trillion cubic feet of technically recoverable natural gas.[9] (Note: "Proved reserves" are defined as "that portion of recoverable resources that is demonstrated by actual production or conclusive formation tests to be technically, economically, and legally producible under existing economic and operating conditions." Technically recoverable resources are "the total amount of resource, discovered and undiscovered, that is thought to be recoverable with available technology, regardless of economics."[10])

While the twinned technologies of hydraulic fracturing and horizontal drilling create a bonanza of production in well-endowed localities, there is still a need to get the new bounty of gas to market. In many cases that can be accomplished by transporting the gas via pipeline. However, there are large potential customers, most notably Japan, that are beyond the reach of pipelines. The presence of such customers makes liquefied natural gas (LNG) a critical element of the natural gas revolution.

Natural gas becomes a liquid if it is cooled to -162 degrees Fahrenheit. It can then be pumped into special containers capable of maintaining the necessary temperature and then shipped by rail, or more importantly, by ship. Upon reaching its destination, the carrier offloads the LNG to a regasification terminal, which then pumps the newly gasified energy into a land-based pipeline network and on to the ultimate consumer. The liquefaction process is an old one having been developed in the 19th century. The first significant commercial transport of LNG by ship occurred in 1964 when Algeria shipped LNG to the United Kingdom.[11] In the ensuing years, the world's LNG infrastructure developed only slowly, but it has now reached a fairly high degree of completion and sophistication. In 2011, LNG shipments accounted for 32 percent of the global gas trade.[12] As of June 2012, there were 31 operating liquefaction plants in the world, 10 more were being built, and an additional 15 under planning. On the regasification side, 89 plants were operating, 18 under construction, and 26 being planned.[13]

All forms of energy acquisition have ecological costs, whether oil or gas is drilled, dams are built, wind turbines are constructed, or solar panels are put in place. Not surprisingly, natural gas acquisition through hydraulic fracturing and horizontal drilling have their particular ecological risks and environmental challenges.

Much of the potential environmental damage stems from the "slickwater" hydraulic fracturing fluid. While drillers have jealously guarded their exact formulas for creating their proprietary fluids, the basic outlines are clear. More than 95 percent, perhaps up to 99 percent, of the mix consists simply of water. The second key ingredient is often sand, which serves as a proppant. After the fluid is forced into the shale formation and creates cracks, those cracks must be kept open for some time to allow the gas to flow into the well, and that is accomplished by the proppant. (Ground up guar beans are also used as a proppant.[14] Beyond water, sand, and beans, the fracking fluid often contains some very nasty chemicals such as benzene, tolulene, xylene, ethylbenzene. Hydrochloric acid is sometimes included to initiate fissures in the rocks, while gluteraldehyde 2 and 2-dibromo3-nitrilophopionamide, two biocides, are often added to the mix, and ammonium persulfate, potassium, and sodium peroxydisulfate help to reduce viscosity.[15] However, these more exotic chemicals constitute significantly less than one percent of the 2-4 million gallons of fracturing fluid require to frack the typical well. Further, the shale strata being fractured typically lie thousands of feet below aquifers. Nonetheless, the well pierces the aquifer en route to the gas and shale below, and the fear is that defective well casings could allow fracking fluids to enter the aquifer directly, or that fracking fluid pumped into the shale strata could percolate up and into the aquifer.

In the worst case scenario, the damage to an aquifer could be very serious. For example, the Barnett Shale underlies the Dallas-Fort Worth metroplex. One can only imagine the human and economic cost of seriously damaging the water resource for such a large population. Everything about this issue remains quite controversial. The U.S. Environmental Protection Agency has leveled charges of water contamination from fracking a number of times, but has generally had to rescind those claims.[16] Nonetheless, the fear of aquifer contamination is probably the most significant and emotional environmental concern surrounding the natural gas revolution.

As noted above, the process of hydraulic fracturing requires about 2-4 million gallons of water per well. That water must be acquired from some source, so hydraulic fracturing puts additional demands on the water supply. Further, about 70 percent of the hydraulic fracturing fluid injected into a well returns to the surface through the well and must face disposal. While water usage may be a significant concern in some areas with very limited water supplies, the water demand is generally not of primary concern. Four million gallons may seem like a tremendous quantity of water, but it is a relatively fairly small amount in most locales. For example, in the dry country of south Texas, irrigating 640 acres of corn requires 400 million gallons of water and yields a crop worth only about $200,000. The same amount of water could frack about 100 gas wells.[17]

Disposal of the more than one million gallons of fracturing fluid returned to the surface from each well is a more serious problem than acquiring the water, especially as the entire amount is tainted with the chemicals added to the mix. Further, the returned fracturing fluid also often contains small levels of radioactivity that is picked up from the fluid's contact with radioactive rocks beneath the surface. This tainted water is often stored in open, plastic-lined pits. There it can poison birds and other wildlife and runs the risk of entering streams, especially if heavy rains occur. Some of this tainted water has been injected into local treatment plants that are not equipped to handle the particular chemicals in the fracking fluid mix. To remediate this problem, the gas industry has been developing ways to re-use the returned water to fracture additional wells, thereby reducing the disposal problem per well. Also, the water can be given an initial treatment to make it acceptable as an input to municipal treatment systems. Following a longstanding practice in the energy industry, the water can be injected into cavities deep in the ground as well. As discussed below, this injection disposal method has its own environmental difficulties.

The process of hydraulic fracturing and the pumping of fluids into underground caverns has also been statistically associated with a greater frequency of earthquakes and has apparently caused at least one earthquake.[18] In its study of this problem, the National Research Council concluded the following: "Three major findings emerged from the study: (1) the process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events; (2) injection for disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation; and (3) CCS [carbon capture and storage], due to the large net volumes of injected fluids, may have potential for inducing larger seismic events."[19] In the United States, the quakes that have been blamed on the energy industry were very small in magnitude, causing no injuries or property damage.[20] The clearest evidence that underground disposal of liquid might cause earthquakes derived from events near Blackpool, England in 2011. There some minor quakes were most likely caused by the injection of wastewater from hydraulic fracturing causing the drilling firm shut down operations. However, in 2012, the U.K.'s environmental agency once again gave the green light to the production of natural gas by hydraulic fracturing.[21]

In the entire cycle of natural gas production and use, some natural gas escapes into the environment. This fugitive gas occurs at the wellhead and farther on in the distribution system. This methane is a powerful contributor to global warming, estimated as being twenty times as powerful as carbon dioxide. One of the presumed advantages of natural gas over coal for electricity production has been that it is less harmful to the environment. One well-known 2002 study placed various forms of electricity production on a common scale of carbon dioxide equivalents and concluded that a coal-powered plant produced 80 percent more greenhouse gases than a natural gas-powered plant of the same scale.[22] Thus, natural gas appeared to be an attractive bridge fuel for electricity production until a more environmental friendly method of electrical generation could reach scale.

This view has been challenged recently by new studies that estimate much higher levels of fugitive methane than previously thought. Under this analysis, electricity generation fueled by natural gas could actually be worse than coal for greenhouse gas emissions. (This still leaves the particulate emissions of coal plants as an additional problem.) This highly critical view of natural gas was immediately challenged and has given rise to a vigorous debate. The controversy centers on how much fugitive methane is actually emitted and also on whether controls can be increased to reduce those emissions. The scientific evidence on this issue remains extremely mixed and highly controversial, and has led to a spirited public debate as well.[23] While the question remains unsettled, most parties to the debate agree that controlling methane emissions is a critical part of the battle against climate change.

In addition to the ecological challenges just discussed, there are a number of environmental issues associated with the natural gas revolution, especially hydraulic fracturing. Much of the gas being exploited lies in rural areas that have been able to maintain their bucolic characteristics until now. Setting up a drilling pad is quite invasive to the immediate area, including heightened truck traffic, the establishment of the drilling pad itself, the creation of a pit for wastewater containment or storage, and the noise of the drilling. Of course, when the drilling occurs on private land, it is by agreement with the drilling company and compensation to the landowner. In addition, the sudden influx of the gas industry and its workers has also created social change and even dislocation in some areas. For example, Williston, North Dakota is now experiencing very rapid growth, soaring housing prices, crowded schools and some increase in crime.[24] Perhaps one of the best accounts of some of the effects of gas drilling is *The End of Country*, by Seamus McGraw who tells of the experience at his parents' home in the Marcellus shale region of rural Pennsylvania.[25] On the positive side of the ledger, many areas have experienced new wealth, plentiful jobs and high wages, increased general economic growth, and surging tax revenues paid by drillers. And the relatively sudden burgeoning energy supply has already had and promises continuing very substantial benefits for the energy hungry United States.

III. Natural Gas and the World's Largest Economies

This section turns to the effects of the natural gas revolution on the world's largest economies. In doing so, it assumes that the ecological problems discussed in Section II can be managed well enough to allow full natural gas production to proceed without additional regulatory impediment.

The natural gas revolution turns first and foremost on the remarkable increase in world production potential stemming from hydraulic fracturing and horizontal drilling, and these innovations are truly "made in America" phenomena.[26] Without these technologies there would be no natural gas revolution at all. But technology alone is insufficient—there must also be a resource base to which the new technology can be applied. The United States has tremendous shale gas resources. Table 1 presents basic information on gas resources, production, and consumption for the ten largest economies that are the focus of this study. The natural gas data of Table 1 are drawn from the "Statistical Review of World Energy" published by BP in 2012. The United States has 8,500 BCM of natural gas proved reserves, which ranks it second to Russia among these ten economies, but Russian proved reserves are more than five times as large as those of the United States.

While U.S. proved reserves are large, yet modest in comparison with Russia's, this relative scarcity in the United States casts into doubt the basis for the enthusiasm over the future of natural gas in the United States. However, Table 2 presents further information on some of the world's shale gas reserves drawing on estimates from the U.S. Energy Information Administration and comparing their estimates to those of BP. As Table 2 shows, the two estimates of proved reserves are highly consistent, but the estimates of shale resources has particular interest. In 2011 the U.S. Energy Information Administration (hereafter EIA) made an initial assessment of some of the world's shale gas resources, focusing on those that are technically recoverable. (Proved reserves are essentially those that are recoverable using current technology in the current economic environment, while technically recoverable reserves are those that can be recovered with current technology, but without reference to economic viability.) As Table 2 shows, for countries with estimates of both proved and technically recoverable shale gas resources, the shale gas resources are almost six times as large as proved reserves. These estimates of shale resources are preliminary and will no doubt be revised over time. However, it does seem clear that shale resources dwarf proved reserves in most regions. Optimism over shale resources is based largely on these estimates as well as the proven viability of shale production in the United States. Further, past estimates of hydrocarbon reserves have a long history of upward revision.

United States. The United States now leads the world in the production and consumption of natural gas, accounting for almost 20 percent of the world's total,[27] with more than half of U.S. production coming from shale. As the world leader in gas production and gas technology, the United States is beginning to reap six important benefits.

The first major benefit of increased gas production is a remarkable fall in prices starting from 2008. Figure 1 shows how natural gas prices fell from approximately \$13.00 per 1,000 cubic feet to the neighborhood of \$2.00 in 2012 before recovering to about \$3.00. (One thousand cubic feet of natural gas supplies the typical U.S. home for four days.) (Ironically, the very recent short-term rise in gas prices is due to the very success of the natural gas revolution—the surge in supply has driven prices below the recovery cost in a number of areas driving some drillers from the scene.) The larger and longer term price drop of more than 75 percent has ramifications in a number of areas of the economy. In the United States, about one-third of natural gas consumption is industrial, while residential and commercial uses together account for about another third; electrical power generation uses 31 percent, and transportation accounts for less than 3 percent.[28] The quantity used for manufacturing, electrical power generation, and transportation are all set to expand. From 2004 to 2008, employment in this sector (the mining, oil and gas field machinery industries) increased from about 50,000 to more than 80,000, before falling back to 70,000 during the financial crisis, but then returning to exceed 80,000 in 2011.[29]

Perhaps most surprisingly, the sudden increase in gas supply and the rapid drop in prices has not only expanded employment in the U.S. energy industry, but it already proved an important stimulus to the beleaguered U.S. manufacturing sector. Within the manufacturing sector, the largest user is the chemical industry, accounting for about 30 percent, with the petroleum and coal products industry itself using about 14 percent and primary metals and mineral production consuming just less than 20 percent.[30]

The chemical industry stands to benefit as much or more than any other from the sudden economic availability of natural gas. For example, Dow Chemical is building a natural-gas-to-plastics plant in Freeport, Texas, while Royal Dutch Shell is building a similar plant in Pennsylvania. At least four other such plants are also planned or underway. Significantly, some of these new plants will represent inward foreign direct investment from Taiwan and the Netherlands.[31] This trend is driven by hard economic calculation based on the enlarged supply and reduced cost of U.S. natural gas. The *Financial Times* notes that: "…this advantage gives manufacturing plants in the U.S. a 60 percent, 70 percent, or even 80 percent cost advantage over those operating in China, Japan, South Korea or European countries."[32]

Given its suddenly enlarged supplies of natural gas attainable at very low prices, the United States has the opportunity to become a significant exporter of LNG. Historically, the United States has been a net importer of natural gas, and even in 2011, it remained a net importer, with consumption outstripping production by six percent. That six percent must come from either net imports or reductions in previously stored natural gas. In 2011, the United States both imported gas from and exported gas to Canada via pipeline, importing more than it exported. The United States also exported gas via pipeline to Mexico and imported gas from Trinidad and Tobago as LNG. Now the Sabine Pass export terminal has been permitted, and applications for seven other export terminals are before regulators. Together, all eight plants could export 20 percent of future U.S. production.[33]

Powerful forces are arrayed against these potential exports. First, manufacturing interests are anxious to prohibit or minimize U.S. exports, as they wish to have a continuing supply of cheap natural gas to fuel their production and to help them maintain a competitive advantage against other countries. Second, environmental groups are generally opposed to any expansion of hydrocarbon production, and export would clearly require increased drilling in the United States.[34]

The facilitation of LNG exports by the United States and other nations could have two powerfully beneficial consequences beyond the purely economic gains to the United States. The first is a geopolitical impact on importing nations. Currently, nations that rely strongly on LNG imports, particularly Japan and others in east Asia, have only a few suppliers, making them potential geopolitical hostages. The United States as a reliable supplier would ease those concerns. Consistent with that point, Alaska holds the only LNG export facility currently operating in the United States and the state of Alaska emphasizes the geopolitical reliability of U.S. supplies to Asia.[35]

A second benefit of U.S. LNG exports would be the encouragement of a global gas market. As discussed in more detail below, Japan, in particular, and Asian nations generally, pay especially high prices for their LNG imports, due largely to a limited range of suppliers. As a result, prices in geographically separated gas markets differ very markedly. In recent months, LNG gas imports in Asia have cost four times as much as pipeline gas prices in the United States. If the United States and other nations, such as Australia, become significant exporters, there is a good chance that a truly world market for natural gas will emerge. This is an advantage for the United States as it generally supports market-based approaches to commodities and would create a truly fungible world supply of gas.[36] U.S. exports alone will be insufficient to create a world market for natural gas. But with growing pipeline exports and anticipated LNG exports from Australia and Russia, there is a genuine potential for a unified world market in natural gas.

With less than three percent of natural gas produced in the United States being used in the transportation sector, very few vehicles are powered by natural gas, and at present the number of vehicles in the U.S. powered by natural gas is on the same scale as electrically powered vehicles. Even at this small scale, CNG (compressed natural gas) powers approximately twice as many U.S. vehicles as does electricity (about 120 to 60 thousand).[37] Currently, the subsidies for electric vehicles are much larger than those available for those powered by CNG. Nonetheless, CNG power appears to be more popular than electric vehicles. A number of large fleet operators are already converting their vehicles to CNG, such as Frito-Lay and UPS. Nonetheless, this movement will be hampered by the paucity of fueling points, currently fewer than 2,000 in the entire country.[38]

At present, it remains unclear whether CNG or electric vehicles will be ultimately more popular. No matter which comes to dominate, natural gas will play an important role, because so much of the electricity generated in the United States is fueled by natural gas, and that proportion is expected to increase. Coal has long been the major energy source for the generation of electricity in the United States, and continues to account for 45 percent of all electric production. However, the role of natural gas has become much larger, from being negligible in 1950, to being a major force in recent years. Figure 2 shows the amounts of electricity generated by coal and natural gas in the United States from 2002-2012. Clearly the gap is narrowing rapidly, with some predicting that gas will predominate within a few months.[39] Further, in its "Annual Energy Outlook," the U.S. Energy Information Administration forecasts future electricity energy generation sources under alternative scenarios. In virtually all scenarios imagined by the EIA, the proportion of electricity generated by coal falls and the share of gas increases.[40] In its analysis, ExxonMobil forecasts that electricity generation will increase by 80 percent from 2010 to 2040, and that the share of electricity generated by coal will fall while that generated by gas will rise relative to coal.[41]

Fueling electricity generation with natural gas rather than coal reduces environmentally harmful emissions. Current low prices for natural gas suggest that natural gas could be a beneficial "bridge fuel" to carry our economy from one that is too reliant on hydrocarbon-based energy to one that mainly uses renewable energy sources. Part of this opportunity has been created by the introduction of more efficient combined cycle gas turbines that generate electricity more efficiently than previous technologies, and the replacement of older plants with this new technology continues with substantial environmental improvements relative to coal electricity generation.[42] But part of the attractiveness of gas as an alternative to coal in electric power generation is the currently low price of natural gas, which it self largely a product of the increased supply due to hydraulic fracturing and horizontal drilling.

A number of environmentalists have raised concerns about the environmental impact of acquiring natural gas, which is a different issue that the relative emissions of burning gas and coal once they have been acquired. At least one stream of studies argues that using shale gas is actually worse for greenhouse gases (GHG) than coal, although this claim is quite controversial.[43] Compared to carbon dioxide, methane is approximately twenty times more powerful in contributing to global warming. So if the production of shale gas releases enough methane into the environment, then the GHG impact of shale gas could be worse than that of coal. Further, it is argued that shale gas production techniques result in more emitted methane—or "fugitive methane"—than conventional gas drilling.

Much of this debate turns on two issues: What percentage of natural gas is vented into the atmosphere in shale gas production and distribution, and what time scale is the relevant one for considering the impact of emissions? Estimates of the loss rate from shale gas production are themselves controversial. But it does seem clear that drillers are able to take measures to reduce the level of fugitive emissions. The time scale over which the GHG impact is measured also plays an important role. While methane is clearly a more potent factor in GHG production than carbon dioxide, it breaks down much more rapidly, so the impact of methane is much shorter-lived than the lingering effects of carbon dioxide. Thus, if one considers one or two decades, the relative impact of methane is heightened compared to a longer time horizon of a century, for instance. Time scale is potentially critical however. The fear that the climate might reach a tipping point in the near term gives a reason to focus on a shorter period for evaluating the overall climate benefit or detriment of natural gas and shale gas production. Without doubt, reducing emissions will not only help to conserve a non-renewable resource, but it will also reduce the overall impact of natural gas production on the environment. Assuming that the emissions of shale gas production can be controlled—some have suggested that constraining loss to a one percent level is an achievable goal—then generating electricity with natural gas dominates coal-based electricity from an environmental perspective. Even so, some environmentalists oppose natural gas production, as it may delay the attainment of a world that uses only renewable energy resources: They clearly favor the perfect as the enemy of the good.[44]

China. In the United States, some favor an "all of the above" strategy for energy production, but the U.S follows no such policy. By contrast, China clearly follows pursues all sources of energy, and natural gas is an important part of China's energy acquisition strategy. In 2009, China's consumption of hydrocarbon energy (oil, gas, and coal) surpassed that of the United States for the first time, and exceeded that of the United States by 23 percent for 2011, all measured in tons of oil equivalents. Table 3 shows the distribution of hydrocarbon resource consumption for China and the United States in 2011, and they differ radically. For China, more than 75 percent of hydrocarbon energy comes from coal, and less than 5 percent from natural gas. By contrast, the United States has balanced consumption across oil, gas, and coal—43, 32, and 26 percent. As a result, the United States uses more than five times as much natural gas as China.

As is well known, China's energy consumption is accelerating rapidly, and one of the major challenges facing China is the acquisition of energy and the management of the country's notorious air pollution stemming in large part from such a heavy reliance on coal. (From 2001 to 2011, China's annual growth rate of hydrocarbon consumption exceeded 17 percent, compared with a U.S. growth rate of less than one percent.) As a result, China is not only struggling to increase its acquisition of hydrocarbon energy, but needs to change its mix, substituting away from coal and toward natural gas.

As Table 1 shows, China produces relatively little natural gas compared to its resource base. While the United States produced about 7 percent of its proved resources in 2011, China produced less than 3 percent. Also, the United States imported more natural gas than did China, but only eight percent of consumption, while China imported 24 percent of the gas it consumed in 2011. As Table 2 shows, China possesses more natural gas than does the United States, even though a relatively high percentage of Chinese gas resources await discovery. Further exploration in China will almost certainly increase its proved reserves enormously.

Given China's problem in acquiring sufficient energy and its excessive reliance on coal, it is not surprising to see how aggressively it is moving to acquire gas from abroad and to develop its own resources. China began to acquire natural gas from Turkmenistan in December 2009, importing 14.3 BCM in 2011. Soon Turkmenistan should be delivering 60 BCM. While China now receives pipeline gas only from Turkmenistan, it has ambitious plans to also receive pipeline gas from Kazakhstan, Uzbekistan, Russia, and Myanmar, with all of these pipelines delivering by 2015.[45] China also receives natural gas in the form of LNG, mainly from Russia, Australia, Qatar, and Iran, importing 16.6 BCM in 2011. By the end of 2012, China should be operating at least nine LNG import terminals with a capacity to receive 27.2 million tons of LNG or 38 BCM of natural gas.[46]

With 2011 consumption of 130.7 BCM, China is importing 24 percent of its natural gas, compared to the United States, which imports only 8 percent. This natural gas dependence, coupled with China's high reliance on oil imports from the Persian Gulf leaves it in a highly dependent and potentially very vulnerable geopolitical position. While pipeline imports might be relatively reliable, China's dependence on a country with Turkmenistan's problems is not comforting, especially as these supplies transit Uzbekistan and Tajikistan.[47] China's most important geopolitical energy vulnerability stems from its heavy reliance on seaborne energy sources, especially its long sea route lifeline from the Persian Gulf to the South China Sea. This is especially important for China's oil imports, but is also critical for natural gas. Partially because of this vulnerability, China has been investing heavily to build a "blue water" navy that could be capable of affording some protection. In addition, some believe it is developing a "string of pearls" strategy to the same end, with the "pearls" being a network of naval support facilities and potential bases along the littoral of the Indian Ocean from the Persian Gulf on to the Straits of Malacca and into the South China Sea.[48] (Of course, many observers believe that China's naval plans go far beyond it's the need to protect its energy supplies and match much more elevated geopolitical aspirations.[49])

China's great domestic energy resources provide a potential counter to these geopolitical vulnerabilities. China's proved reserves of natural gas are bound to increase with further exploration, and China surely possesses unparalleled shale gas deposits. To date, China has not accessed even one cubic meter of unconventional shale gas, but it is moving with its customary speed and vigor to do so. Tapping those reserves depends on the acquisition of technology and equipment. To that end, China is pursuing an aggressive multi-prong strategy of buying firms from abroad with the technology, partnering with firms that have the necessary expertise, and actively developing its own internal development capacity.[50]

In sum, China's spectacular economic growth and energy consumption coupled with initially poor ability to develop its own resources have placed it in quite a vulnerable position. However, China stands to be one of the greatest beneficiaries of the natural gas revolution. First, a greater diversity of supply around the world helps China to diversify its own imports through multiplying pipeline partners and LNG suppliers. Second, and even more importantly, China's vast domestic energy resources and their quick development will help reduce its geopolitical vulnerability in the energy arena. Third, the development of domestic natural gas will speed a substitution of natural gas for coal in electricity generation, thereby reducing its currently horrible air pollution. Fourth, there is a potential spillover benefit to other nations. If China can reduce its geopolitical energy vulnerability by developing its own resources, it will have one less reason to speed its military development. Whether this reduction in need will affect China's actual military plans remains to be seen.

Japan. Of all the major economies considered in this article, Japan has the poorest domestic hydrocarbon endowment. It has essentially no domestic oil, gas, or coal resources, leaving it entirely dependent on imports. The Fukushima nuclear disaster in 2011 has imperiled its nuclear power plans. After idling all of its nuclear plants in the wake of the disaster, its recent decision to restart two plants not only shows its almost desperate need for this energy source, but it has also reenergized domestic opposition to the entire nuclear energy industry. Currently, Japan imports all of its natural gas via LNG—no natural gas pipeline reaches Japan at all, and none is likely to in the near or intermediate term. In spite of this situation, Japan stands to be a significant winner from the natural gas revolution, and its benefits fall in two major arenas—price and security of supply.

Prices for LNG gas in the Asian market have been and currently are extremely high relative to prices in other areas. For example, in summer 2012, the price of pipeline natural gas in the United States was under \$3.00 per million btus, while Japan was paying about \$15.00 for LNG imports of the same quantity. Part, but only part of this differential is due to the costs of transportation, liquefaction, and regasification. However, the main cause of the differential is the pricing system for LNG which links gas prices to crude oil prices. While gas prices were quite low in summer 2012, crude oil was trading near \$100 per barrel. One promise of the natural gas revolution is the development of a truly world market for natural gas with many suppliers of LNG. The development of such a system would result in gas being priced based on its own supply and demand factors and having a spot price tied to current supply and demand rather than being tied to decades-long contracts linked to oil prices. In short, a worldwide abundance of supply would create a natural gas market with many competing suppliers and would give Japan an opportunity to pay the world price of pipeline gas plus an LNG differential consisting of only transportation, liquefaction, and regasification costs.[51]

Japan is the world's largest importer of LNG. In 2011 it imported 107 BCM of LNG from 19 different countries. Its five largest suppliers in rank order were Malaysia, Australia, Qatar, Indonesia, and Russia, together accounting for 72 percent of its imports.[52] Clearly Japan has a diversity of suppliers, but some of these sources are geopolitical rivals and some are themselves dependent on long sea lanes through potentially hostile waters. In the light of the natural gas revolution, Japan stands to secure supplies from a still greater variety of suppliers, some of whom are more reliable allies. For example, the recent decision to allow at least some LNG exports from the United States can only increase Japan's security of supply. In a world of controlled geopolitical tensions, this increased security of supply has limited benefit, but could become extremely important in less pleasant circumstances. Heightened potential from sources like Australia and the United States can only enhance Japan's security of supply, and Japan will gain this increased security even without actually importing LNG from these friendly nations, but merely because it will have the potential to receive LNG supplies from the nation with the world's strongest navy.[53]

The Eurozone Economies—Germany, France, and Italy. Germany, France, and Italy are the largest economies in the Eurozone and are among the world's ten largest economies. Their general prospects in the natural gas revolution hold for many of the other countries in the Eurozone, but each country has circumstances that are substantially different in some important respects.

Western Europe has had a continuing reliance on the Soviet Union and now the Russian Federation for much of its supply of natural gas. In the Soviet era, supplies came from Russia and from its republics in central Asia, most notably Turkmenistan. The Soviets routed their pipelines into Russia and then through the Ukraine and on to markets in western Europe. The breakup of the Soviet Union left this legacy pipeline network in place, but under the control of a variety of fractious independent nations, resulting in disputes of supply and transport. For example, all pipelines from the newly independent nation of Turkmenistan went only north to Russia leaving Turkmenistan with its very rich natural gas resources as a price hostage Russia. Not surprisingly, Turkmenistan has struggled to develop other markets for its gas, including the recently opened pipeline to China.[54] As a transport issue, the main pipelines to the west ran from Russia through Ukraine. In the last five years, disputes between Russia and Ukraine resulted in Russia's shutting off supplies at least three times.[55] As a result, the Eurozone has a problem with security of supply, while Russia has a vulnerability in its capacity to delivery gas to its market in western Europe. In response to this situation, countries of the Eurozone are trying to diversify their suppliers, while Russia aims to find alternative delivery routes to keep western Europe tethered to its supplies.

Focusing on the Eurozone, the situation differs for individual nations. For example, in 2011 Germany imported 42 percent of its natural gas consumption from Russia via pipeline, but France and Italy only about 20 percent in this way. A large part of this difference depends on geographical proximity to Russia, but France has also had an historical focus on nuclear energy, and Italy acquires gas from Mediterranean nations. Nonetheless, Germany, France, and Italy remain highly reliant on Russian pipeline gas for critical supplies, and the same is true of the Eurozone as a whole.

European countries differ quite widely in possession of their own natural gas and their willingness to drill for it. Germany and Italy each have about 100 BCM of proved reserves, and their consumption is high relative to those reserves with both Germany and Italy consuming about 70 BCM per year, per Table 1. In France, little is really known of their indigenous natural gas resources. France consumes about 40 BCM, and there is a marked reluctance to find and develop whatever resources the country does possess.

In terms of willingness to use shale gas technologies to address their energy needs, the three countries behave somewhat similarly. France has banned even the search for shale gas; Italy's resources remain unknown, and Germany's shale reserves are modest at best compared to its annual consumption. In western and central Europe, only Poland and Ukraine seem both to have substantial shale gas resources coupled with a willingness to secure it. There are at least three main reasons for the reluctance of Germany, France, and Italy to adopt shale gas technology. First, the population is quite dense in most areas, making it difficult to drill without adverse impacts on occupied areas. Second, the opposition of environmental groups is quite vociferous, especially in France. Third, in contrast to the United States the property rights to natural gas generally do not run with ownership of the land's surface, but are held by the state. While many property owners in the United States have embraced shale gas drilling for clearly pecuniary reasons, the European landowner has little clear ability to capture proceeds from the gas under his land. Of course, this raises resistance to the prospect of allowing drilling.

Despite a general hostility or inability to participating directly in the natural gas revolution, Europe stands to be a substantial beneficiary of the movement. As we have seen, the natural gas revolution has brought a very substantial price reduction. With Germany, France, and Italy collectively importing 200 BCM per year, this cheaper gas is worth a great deal. Second, the emerging world market in natural gas coupled with a more mature LNG infrastructure enhances the security of supply for all three countries. Germany, for example, imports no LNG, but gets roughly a third of its imported pipeline gas from each of the Netherlands, Norway, and Russia, with a somewhat greater proportion coming from Russia. While one might expect the supplies delivered from the Netherlands and Norway to be fairly secure, Germany still relies most heavily on Russian pipeline gas for over 40 percent of its annual consumption. A richer LNG infrastructure gives Germany an important alternative to Russian gas in the event of supply problems. In essence, the Eurozone as a whole is something of a free rider in the natural gas revolution—it receives substantial benefits without active development of its own resources.

Russian Federation. Russia and Europe are intimately connected as supplier and recipient of natural gas deliveries. As western Europe depends on Russian supplies, Russia is highly dependent on exporting hydrocarbon, as Matthew Hulbert notes: "Russia still depends on hydrocarbons for two-thirds of its exports, half its federal budget and 20% of its GDP..."[56]

In light of its disputes with Ukraine over transit, Russia has very aggressively developed pipeline routes to its major markets that do not rely on transiting other countries. Recently, Russia and Germany developed the Nord Stream pipelines to connect Russia and Germany directly across the Baltic Sea. Similarly, the Blue Stream pipeline connects Russia to Turkey directly across the Black Sea.[57]

Western Europe, fearing a dangerous dependency on Russian gas, has been working to diversity its sourcing of pipeline gas, especially through what is known as the Southern Corridor.[58] Various plans have been bruited for bringing gas from central Asia into southern Europe, thus circumventing Russian dependency. These efforts have largely come to naught, due in no small measure to Russian efforts to forestall them. Russia has used a combination of diplomacy, economic and geopolitical pressure, and specious protestations about environmental risks to frustrate this European sourcing of central Asian gas.

Perhaps Russia and Japan are the two large economies with the most critical stake in natural gas, Russia because its necessity of disposing of its huge supply, Japan because of its total dependency on imports. For Russia, the question of energy is not merely one of economics, but capturing revenue from its energy resources plays an absolutely critical role in helping Putin's Russia to maintain a significant world geopolitical role.

For Russia to meet its aims, it must complete its land-based delivery routes to western Europe while keeping them free of transiting other countries such as Ukraine. In this, it is doing a quite effective job. Second, Russia needs to develop other markets it can serve while also avoiding dependency on other nations. Accordingly, Russia is aggressively pursuing the expansion of its deliveries of pipeline gas to China.[59] Third, Russia aims to become a major participant in the world LNG market, having completed a liquefaction plant on its Pacific coast in 2009. According to Gazprom, this plant will be tasked with "…providing for the LNG supply to Japan, South Korea and North America."[60]

We have seen that the increase in the world's accessible natural gas supply has expanded greatly in recent years, due to hydraulic fracturing and horizontal drilling, and that this richness of supply has a very wide geographical distribution. Given Russia's dependency on exporting energy, these developments hurt Russia in several critical ways. First, the natural gas revolution is reducing the dependency of almost all countries on its previous specific sources of supply, first by the prospect of developing its own shale gas resources, and secondly by having a diversity of suppliers through a burgeoning LNG market. Second, the fall in the price of natural gas already reduces, and almost certainly will continue to reduce, the revenue stream on which Russia depends to keep its economy afloat. While some of this gas will continue to capture the higher prices prevailing for LNG in Asia, this will likely be short-lived if a more robust international market in gas truly develops. Further, it seems clear that North America will not be a long-term customer for Russian LNG. As such, Russia is almost certainly the biggest loser in the natural gas revolution among the world's top ten economies.

United Kingdom. The U.K. has modest natural gas proved reserves that it produces and consumes at a prodigious rate. From Table 1, the U.K. has proved natural gas reserves of 200 BCM, but it produces 45.2 BCM from this reserve and consumes a total of 80.2 BCM. These high ratios of production to reserves and of consumption to reserves leaves the country in a somewhat delicate supply and demand balance, making its natural gas acquisition critical. In 2011, the U.K. has net natural gas imports via pipeline of 11.8 BCM and via LNG of 25.3 BCM.

Initially the U.K. appeared eager to exploit its shale resources. However, it appears that two small earthquakes near Blackpool resulted from hydraulic fracturing operations in 2011, leading to a nationwide suspension. By summer of 2012, the U.K. regulators were preparing to allow operations to resume.[61] Given its relatively modest unconventional gas resources, shale operations in the U.K. are unlikely to be a major factor in changing the energy prospects of Great Britain, as the country's shale resources are only about seven times annual consumption. New discoveries could improve this outlook, but even in this case the industry would have to contend with the U.K.'s high population density which makes drilling operations difficult. Therefore, the U.K. will likely need to rely on natural gas imports going forward.

In many respects, the U.K. enjoys an advantageous import situation. Via pipeline, the U.K. receives gas from the Netherlands and Norway, but exports pipeline gas to Ireland and Belgium. Both the Netherlands and Norway have quite ample reserves relative to their consumption. The Netherlands consumption to proved reserves is about one percent, while Norway consumes only a miniscule proportion of its proved reserves, leaving ample supplies for export. As a result, the U.K. is blessed with reliable pipeline partners. Further, given the U.K.'s geographical position as an island on Europe's periphery, it is ideally placed to benefit from LNG deliveries in the emerging world market in natural gas.

Brazil. Brazil's stake in natural gas is relatively small and its supply and demand situation relatively simple. Focusing on hydrocarbon energy resources, Brazil derives only 16 percent of its energy from natural gas and an almost negligible amount from coal. Of its 26.7 BCM of consumption in 2011, it produced 16.7 BCM and imported the balance from Bolivia via pipeline. While it has quite significant shale gas resources, Brazil has very ample supplies of oil and these are receiving the focus of its development efforts. In essence, Brazil is presently a bystander to the natural gas revolution, but will continue to have significant and valuable supplies in the ground as a future resource.

India. Even with its huge population being in the same league as China's, India consumes slightly less than half as much natural gas and must import a fourth of its annual consumption. In 2011, per Table 1, India consumed 61 BCM, while producing 46 BCM, and importing 17 BCM as LNG. India has no pipeline imports. Each year, India consumes about 4 percent of its proved reserve and holds technologically recoverable shale reserves estimated at 1,784 BCM, or about 29 years of current consumption. India has been slow to determine its own additional shale reserves. The first actual discovery of Indian shale gas occurred only in the summer of 2011.[62]

India's economy has been growing at 7-8 percent in recent years, and it has great ambitions to continue its rapid development, seeing itself as being in the same league as China. However, India's energy infrastructure is radically inadequate to its aspirations. In the summer of 2011, a general failure of India's power grid left an area of India with almost 700 million people without power for days. To meet its development goals, India needs to enhance its general energy infrastructure included the natural gas component.

Perhaps surprisingly for a major nation with a very large geographical area, India currently imports no natural gas via pipeline. On the north, India has a border with a phalanx of small mountainous nations, the Himalayas, and China, with its own energy deficits. On the west, Pakistan is consuming its entire production and is unlikely to provide a stable energy partner for India in any event. To the east, Bangladesh also consumes its entire small production, and even Burma beyond has minimal resources. For any hope of securing natural gas pipeline imports, India must look farther to the west to Turkmenistan and Iran with their huge reserves, and there is much talk of pipelines coming to India from these distant lands.

Every week, there is further news about plans to develop the Turkmenistan-Afghanistan-Pakistan-India, or TAPI, pipeline. To run from the Dauletabad fields in eastern Turkmenistan into India, the pipeline would have to traverse 1,000 miles and run through what can only reasonably be described as a gauntlet. In Afghanistan, the line would pass near Heart, Helmand, and Kandahar, all of which have been in war news much more than energy news. In Pakistan, the pipeline would go through tribal areas which are hardly under full governmental control. As John Foster notes, "When construction will start is uncertain because security in Afghanistan and the tribal areas of Pakistan remains a problem."[63] Beyond the technological challenges and the uncertain operating conditions prevailing in Afghanistan and Pakistan, the project would require a very bold consortium of investors. At best, it will be quite a few years before any gas arrives in India from the TAPI line, if it every occurs.

A second possible pipeline route would run from Iran, through Pakistan, to India, (the IPI pipeline) thereby at least circumventing Afghanistan. Planned at least since 1993, this pipeline would originate in Iran's South Pars field and run 1,700 miles through Pakistan and into India. It would be capable of delivering 60 million cubic meters to Pakistan each day and 90 million to India. Like the TAPI line, IPI is in no danger of being started immediately, and the United States would certainly be a major obstruction to the delivery of Iranian gas to either Pakistan or India.[64] Confronted with these obstacles, technical, political, financial, and geopolitical, not to mention outright sabotage and war, India will be compelled to rely on its internal resources and LNG deliveries. Nonetheless, the development of a worldwide gas market with higher levels of LNG deliveries available should reduce India's difficulties with securing sufficient natural gas and should also help India secure natural gas at a world market price.

Qatar; Turkmenistan; Iran. As we have seen, among the ten largest economies there are sharp differences in demand and supply situations, with Russia being a huge exporter and Japan being entirely dependent on imports, while the United States is in a transition from being a deficit to a surplus nation. Nonetheless, taken together the ten largest economies are collectively in a deficit position, importing more than 250 BCM per year, with about 30 percent arriving by pipeline and 70 percent being accepted as LNG.

These large economies must make up their deficit somewhere, and Qatar, Turkmenistan, and Iran each hold more than 5 percent of the worlds proved natural gas reserves, as Table 4 shows. Collectively these countries are consuming only one-fifth of one percent of their proved reserves. For its part, Iran is almost completely isolated from the world market. Qatar has succeeded in becoming a world LNG supplier over the last two decades, exporting 103 BCM of LNG in 2011, and there is every indication that Qatar will continue to be a major supplier to world markets. However, the development of indigenous resources in many countries is bound to impede the growth of Qatar's export market. In addition, the build-out of the world's LNG infrastructure can only help reduce the world price of natural gas and reduce the rents that Qatar presently reaps by its deliveries to Asia. Turkmenistan has quite large proved reserves and is anxious to export, but it is geographically and geopolitically constrained as discussed above. We can expect Turkmenistan to struggle in the coming years to bring its reserves to the world market.[65]

IV. Conclusion

We have seen that the natural gas revolution brings enormous energy advantages to the world, although the environmental impacts of a continuing reliance on hydrocarbons in any form remains extremely controversial. Among the world's largest economies, there are clear winners and losers. The United States is already reaping very significant advantages as it moves from a seriously deficit nation to being a potential supplier to the world. China's large population and rapid economic growth pose major energy problems. The natural gas revolution, especially with China' huge shale gas resources, will be a tremendous benefit to China, although it is unlikely to become an international supplier.

By contrast with the United States and China, Russia stands to lose the most, as it relies so heavily on revenues from its exports. Also, Russia's ability to sell its gas at a high price will be hampered by the development of indigenous resources by some of its customers and the development of a world gas market. Japan, bereft of its own hydrocarbons, will continue to import virtually all of its natural gas, but it will still be a major beneficiary. The natural gas revolution brings to Japan two major benefits, a security of supply stemming from a new diversity of suppliers, many of whom might be counted as allies. In addition, as the world market for natural gas matures, Japan should capture a major price advantage as the higher prices that prevail for Asian LNG deliveries move toward the world price. India too will reap similar benefits, although of a magnitude somewhat less substantial than those Japan stands to capture.

For some of the other major economies, much depends on their own behavior. The Eurozone appears to hold substantial resources. Whether Europe can move to exploiting those resources depends on their environmental lobbies, problems with the ownership structure of mineral rights, and overcoming the disadvantages of their population densities. The United Kingdom will reap modest benefits for the price it will pay for the portion of its imports that come as LNG. Finally, Brazil will be the one nation among the ten that seems to be the least affected—it is essentially a bystander to the natural gas revolution, although it will enjoy the security of large reserves that will remain in the ground available for future development.

Table 1
The World's Largest Economies in 2011:
GDP and Natural Gas Data
Natural Gas
(Billion Cubic Meters)

GDP Rank	Country	2011GDP $ Trillions	Proved Reserves	Production	Consumption	Reserves/ Production	Net International Flows	
							Pipeline	LNG
1	United States	15.1	8,500	651.3	690.1	13.1	47.4	8.0
2	China	7.3	3,100	102.5	130.7	30.2	14.3	16.6
3	Japan	5.9	N/A	N/A	28.5	N/A	0	107.0
4	Germany	3.6	100	10.0	72.5	10.0	84	0.0
5	France	2.8	N/A	N/A	40.3	N/A	32.3	14.6
6	Brazil	2.5	500	16.7	26.7	29.9	3.6	0.0
7	United Kingdom	2.4	200	45.2	80.2	4.4	11.8	25.3
8	Italy	2.2	100	7.7	71.3	13.0	60.8	8.7
9	Russian Federation	1.9	44,600	607.0	424.6	73.5	-176.9	-14.4
10	India	1.9	1,200	46.1	61.1	26.0	0	17.1
	Total	**45.6**	**58,300**	**1486.5**	**1599.5**	**39.2**	**77.3**	**182.9**
	World	70.0	208,400	3,276.2	3,222.9	26.0		
	Large Economies /World	65.1	28.0	45.4	49.6			

Sources: GDP:Worldbank.org; Accessed July 27, 2012. Gas Data: BP Statistical Review of World Energy, June 2012.
Note: World flows (billion cubic meters): Pipeline: 694.6; LNG: 320.8. "N/A": Not available or negligible.

Table 2
Estimates of Proved and Technically Recoverable Gas Resources
(Billions of Cubic Meters)

Country	**BP**	**U.S. Energy Information Administration**	
	Proved Reserves	**Proved Reserves**	**Technically Recoverable Shale Gas Resources**
United States	8,500	7,716	24,409
China	3,100	3,030	36,104
Japan	N/A	N/R	N/R
Germany	100	176	227
France	N/A	6	5,097
Brazil	500	365	6,400
United Kingdom	200	255	566
Italy	100	N/R	N/R
Russian Federation	44,600	N/R	N/R
India	1,200	1,073	1,784
Total	58,300	12,621	74,587
Total (Excluding Russia)	**13,700**	**12,621**	**74,587**

Sources: BP Statistical Review of World Energy, June 2012, and U.S. Energy Information Administration, "World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States," April 2011, p. 4. “N/A”: Not available or negligible. “N/R”: Not reported by U.S. EIA as not covered in study.

Table 3
2011 Hydrocarbon Consumption by China and the United States

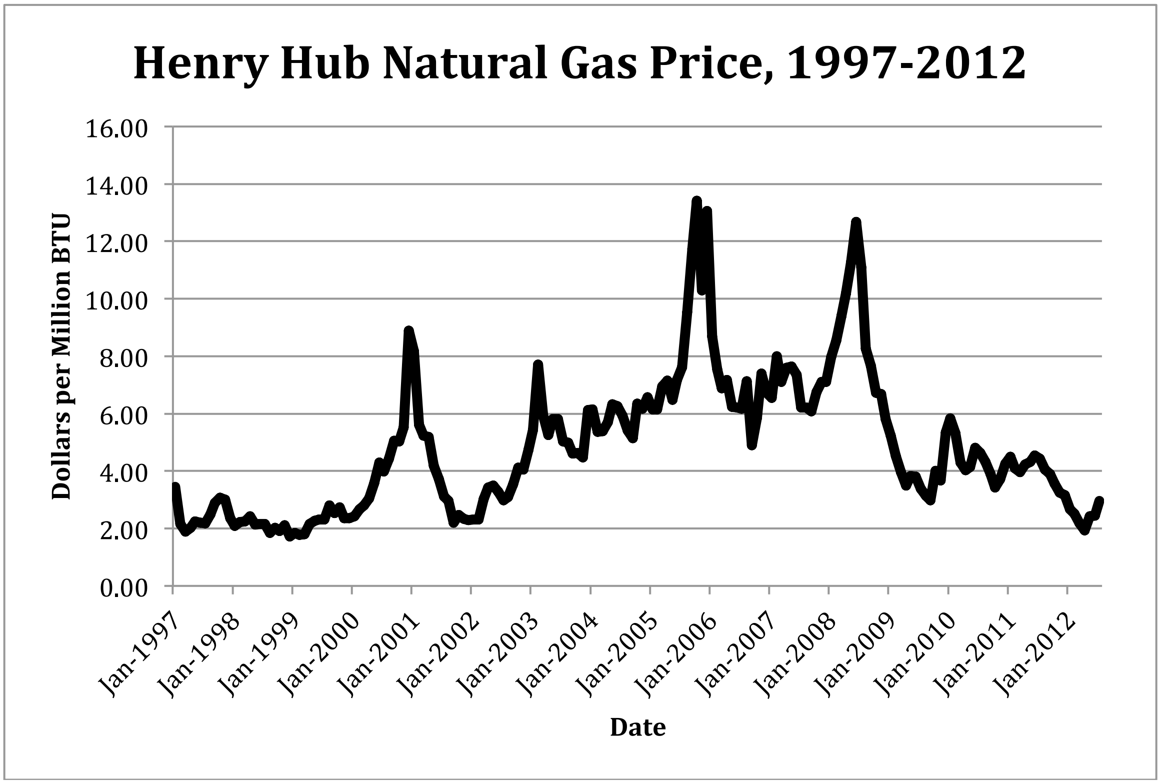
	China		United States	
	Consumption	**Percentage**	**Consumption**	**Percentage**
Oil	462	19.10	834	42.51
Gas	118	4.88	626	31.91
Coal	1839	76.02	502	25.59
	2,419		1,962	

Source: BP, "Statistical Review of World Energy," June 2012. Note: Consumption is measured in million tons of oil equivalents.

Table 4
Other Nations with More than 5% of World's Natural Gas Reserves:
Natural Gas Data

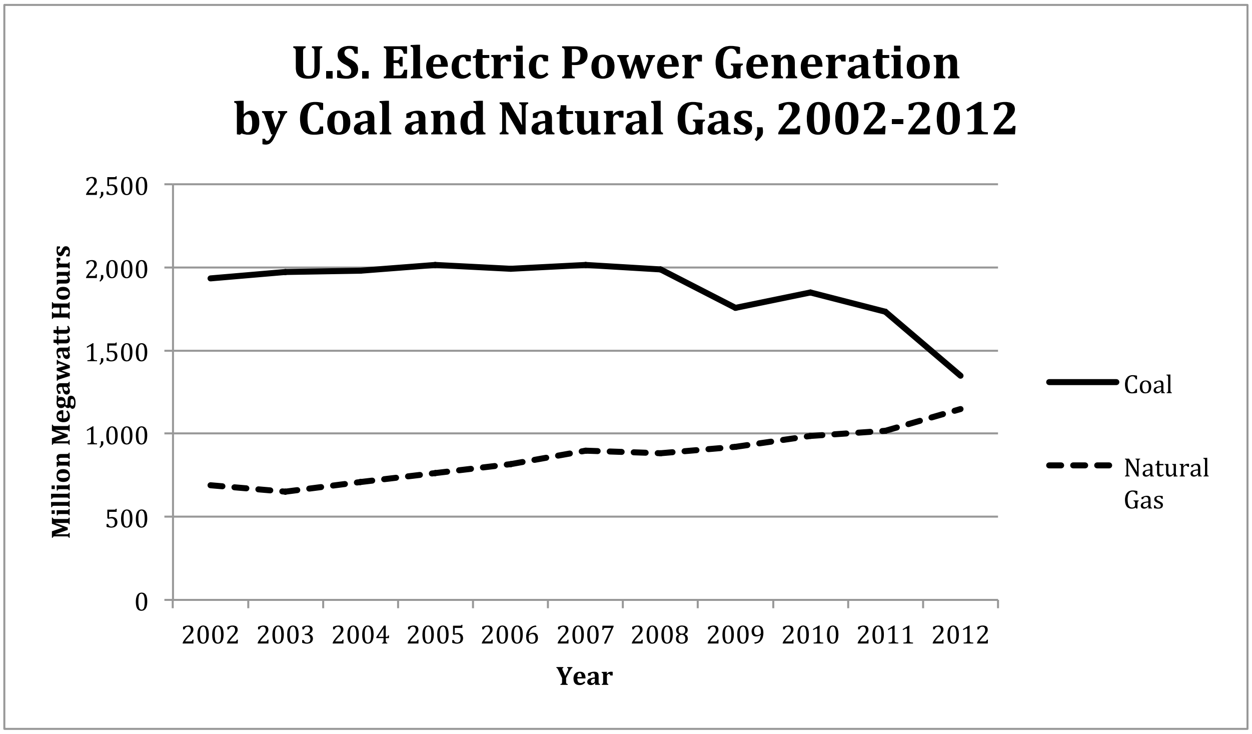
	Natural Gas (Billion Cubic Meters)				Net International Flows	
Country	**Proved Reserves**	**Production**	**Consumption**	**Reserves/ Production**	**Pipeline**	**LNG**
Iran	33,100	151.8	153.3	218.1	1.5	N/A
Qatar	25,000	146.8	23.8	170.3	-19.2	-102.6
Turkmenistan	24,300	59.5	25.0	408.4	-34.6	N/A
Total	**82,400**	**358.1**	**202.1**	**230.1**	**-52.3**	**-102.6**
Three Nations /World	39.5	10.9	6.3			

Figure 1



Source: United States Energy Information Administration:
http://www.eia.gov/naturalgas/data.cfm#prices.

Figure 2



Source: U.S. Energy Information Administration, "Electric Power Monthly," Table 1.01, July 2012. 2012 generation is shown at an annual rate based on data for January-May 2012.

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