**Natural Gas: The Global Energy Arbitrage**

The idea of natural gas as a “game changer” has become especially topical since this past winter, due to very low natural gas prices in the United States and Canada. This price signal has led an array of media, politicians and investors to conclude that the structure of the U.S. economy and the drivers of our energy sector could change dramatically due to a plentiful and inexpensive supply of this commodity. In our view, current price extremes are likely a temporary phenomenon, but even with some firming over the next couple of years, we believe natural gas is likely to remain moderately priced and should be a benefit for certain industrial sectors, job creation and overall growth. That being said, our research reveals structural limits on the extent to which the U.S. can “tilt” its economy toward natural gas—thus causing the impact to be less transformative than some believe. Most basically, we believe that wider adoption of natural gas will prove beneficial to industrial users and consumers alike. In the pages that follow, we present our findings on supply and demand dynamics, including markets that we believe are well positioned for an increase in natural gas use.

**KEY POINTS:**

- The price ratio of oil to natural gas has reached record highs
- New drilling and completion techniques have created a revolution in accessing the North American natural gas and oil resource base
- Mild weather, lease-driven drilling and other temporary factors have contributed to recent natural gas price weakness
- Natural gas prices could soon rise to a normalized $4 – $5, but stay at levels that encourage consumption
- Transportation, chemical production and, to some degree, exports could drive an increase in natural gas demand
- Natural gas is unlikely to prove “transformative,” but could support a U.S. industrial renaissance triggered by other factors
A number of factors—some structural, some temporary—have combined to boost the supply/demand imbalance of natural gas significantly over the last six months. They include:

- The discovery of new shale gas reservoirs, which have allowed the oil and gas industry to bring on new production at significantly lower risk than doing so from conventional wells.\(^1\)

- The use of more efficient “unconventional” drilling and completion techniques (horizontal drilling and hydraulic fracturing), which has transformed oil and gas production into more of a manufacturing process than traditional (“hit or miss”) methods.

- A land leasing boom that began in 2007–2008, when natural gas and oil prices were at record highs. Common lease terms have required oil and gas companies to drill wells within 3–5 years in order to continue to hold the lease, encouraging the build-up of more supply than needed in the near term.

The opening of the shale gas reservoirs represents an important change that we view as positive for both the oil and gas industry and consumers. The same goes for the oil service industry’s impressive advances in drilling unconventional wells over the past five to 10 years. Rigs have extended their reach by drilling horizontally along the shale as opposed to traditional vertical drilling, providing access to greater amounts of gas and lowering the number of individual wells needed for production. Perhaps the most significant contribution has come from high-performance rigs that are designed to drill multiple wells from a single location. In some areas, drillers have put rigs on wheels, enabling them to be moved to new drilling pads without taking them apart. These innovative tactics have accelerated drilling efficiency and, consequently, have produced more gas supply at a lower cost per unit.

Still, we believe the surge in natural gas production is to some degree temporary as it was prompted by the high commodity prices of 2007–2008 and the need for companies to drill simply to hold onto their leases—a trend that we believe is fading. While well productivity has greatly improved, we believe the most significant advances have already occurred—such that efficiency gains are likely to slow from here. Given low natural gas prices and what we consider unsustainable growth in supply due to temporary factors, we think there will be a meaningful reduction in dry natural gas production over the next two years, both in Canada and in the U.S. Combine that with a return to normal weather patterns and spot natural gas prices should move meaningfully higher than the current $2/mmBtu (one million Btu), roughly equal to $2/Mcf (dollars per thousand cubic feet) and the three-year strip price, recently at $3.85/mmBtu.

**The ‘Core’ of the Supply Issue**

Looking beyond these phenomena, a more structural issue is likely to send prices higher: underappreciated reservoir productivity declines. In assessing the economics of an unconventional gas well, we believe it is helpful to think of the shale natural gas deposits as you would an archery target. The “bull’s eye” represents the core—the most valuable resource, while the outer rings correspond to increasingly less prolific and therefore less valuable deposits. Since the cost to drill and complete a given well remains the

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\(^1\) Dry hole costs are a significant and underappreciated expense when exploring and developing conventional oil and gas reservoirs. With unconventional resources, dry hole costs are minimal.
same regardless of which ring of a particular shale play is being drilled, the economics of a given well are determined by how much gas or oil can be produced initially (as defined by the initial production rate or IP rate), and then by the absolute amount of gas or oil produced over the life of the well. In the “core” or “bull’s eye” sections of many shale reservoirs where IP rates are the highest, we believe wells are profitable even at $4/Mcf. Many conventional natural gas wells would require a price closer to $7/Mcf to be profitable. However, once the core has been fully drilled out, which we believe will be the case for many North American shales over the next 2–3 years, the outer rings cannot be drilled with the same well economics. Our study indicates that, for many dry natural gas shales (those not producing hydrocarbon liquids), the next ring requires a price closer to $5/Mcf, and the third ring, $6/Mcf.

![FIGURE 1: NATURAL GAS AND THE BULL’S EYE PHENOMENON](image)

Index of initial production intensity

Source: Sanford Bernstein report, “Sweet Spot and Infills—Why the Resources Plays Don’t Run Forever.” This geological map of a Barnett Shale natural gas reservoir is color-coded as a “heat map” indicating the initial production rate of the wells drilled in those areas. Clearly seen are three “cores” represented by the white centers. Just like a bull’s eye ring, as the drill bit moves away from the cores, IP rates decline, changing the economic profile of the well.

Natural resource producers tend to develop their best assets first. The industry refers to this as “high grading,” which was rampant in the gold industry of the late 1990s.

During that period of low gold prices, companies elected to mine from the best and lowest cost resources first, which they then sold forward in the futures market. The key driver of this approach for publicly traded producers was to demonstrate positive production growth to Wall Street investors—a key metric by which their stock was valued. In the end, however, it was a misguided strategy. As we can now see, once that low cost gold was extracted the price of gold quickly began to rise. Companies that chose to leave gold in the ground would later benefit from higher gold prices—what would become a huge profit opportunity. We believe the same dynamic is at work in the North American gas industry and a similar outcome is possible in the natural gas industry within the next five years.

Natural Gas Liquids Drilling and Its Threat to Dry Gas Prices

When discussing single-well economics, we think it is important to distinguish “dry” from “wet” natural gas wells. Both conventional and unconventional oil and gas wells often produce a mixture of hydrocarbon products. An oil well may produce some natural...
gas while many natural gas wells also produce “liquids” (propane, ethane, butane, etc.). These “liquids” are usually assigned a higher value and, in some cases (as we are seeing today), the overall economics of a well can sometimes depend entirely on the sale of those “liquids.” In such situations, the “dry” gas that comes out of the well is merely a byproduct as producers are specifically targeting the liquids.

Many unconventional wells in North America are currently being drilled for the value of these “liquids” alone. Our study indicates that the most optimistic development of the oil and natural gas liquids shales could bring on 1.0 Bcf – 1.5 Bcf/day (billion cubic feet) of additional dry “by-product” gas each year over the next five years. In the context of current natural gas demand of ~65 Bcf/d, this production would account for ~2% growth in supply. It is important to remember that “dry” gas represents 80% of gas supply in the U.S., and is the primary determinant of the supply, and, hence, the price of natural gas.

Our main concern is the current explosion in drilling for “liquids rich” natural gas, which could potentially lead to a supply glut of ethane (one of the primary liquid natural gas products) and ultimately end up in the dry gas market. Assuming few buyers emerge for excess ethane in the U.S., it would likely be blended into the dry natural gas stream. In our view, this could depress the dry natural gas price for an additional 2–3 years and would postpone the natural gas price recovery we are anticipating. Our team is carefully monitoring the drilling activity in the liquids-rich production as well as the construction of new chemical facilities in the U.S. which would be positioned to absorb and benefit from the increased ethane supply.

NEW NORMAL’ PRICING AND PROSPECTS FOR DEMAND

Clearly, natural gas pricing will play both a crucial role in determining the profits of natural gas producers and the role of natural gas as a catalyst for U.S. industrial growth. In our view, the future price of natural gas will be determined by a simple economic principle—supply and demand. The “new normal” natural gas price will be determined by the marginal cost of supply but also the marginal increase in demand. If one were to draw a simplified picture of our view of the marginal supply curve for natural gas, it would look something like Figure 2.

FIGURE 2: IF PRICES RISE, SO SHOULD SUPPLY—HYPOTHETICAL ILLUSTRATION

For illustrative purposes only. Current gas demand around 66Bcf/d (in bold) could be met by supply at a price of $4/Mcf. Should 100% of the country’s transportation sector shift to natural gas, ~132Bcf/d would be needed and push the price to $6/Mcf.
In order to effectively gauge future natural gas prices, however, we also need to construct a marginal demand curve. Over the last decade, U.S. natural gas demand has followed a predictable pattern of increased industrial demand when natural gas prices are around $4/Mcf, and demand destruction starting at around $6/Mcf. When the U.S. has seen large spikes in the price of natural gas (i.e., above $8/Mcf) demand has turned substantially negative. The key question now is whether the new, unconventional natural gas supply will be abundant and cheap enough to encourage significant demand growth, while at the same time command high enough prices to encourage further supply development.

For context, one barrel of oil contains six times as much energy as 1 Mcf of natural gas, as measured by British Thermal Units (Btu). Extrapolating from this ratio, and referring to prices as of the time of this writing, one Btu of oil costs 9.2 times as much as one Btu of natural gas—an impressive price difference for an identical good. Put another way, U.S. natural gas, at $2/mmBtu, costs the equivalent of $20 for one barrel of oil, which is far below the current trading price of $103 for West Texas Intermediate crude. With such a price disparity, and assuming that users are economically motivated, those in the U.S. that are capable of switching from oil to natural gas are incentivized to do so. In fact, the spread between natural gas and oil prices is now near historic highs.

We believe that several sources of incremental U.S. natural gas demand are currently emerging, underpinned by three key themes: energy affordability, energy security and de-carbonization.

Recent numbers suggest that people are catching on. Over the past decade, U.S. natural gas consumption has grown an average of 1.1% per annum but, in the last two years, demand has grown 3.7% annually, coinciding with persistently falling natural gas prices. Nearly all of the long-term growth in demand has been driven by electric utilities, as they have reduced their use of coal. Over the last decade, electric utilities have accounted for nearly one-third of all the natural gas consumed in the U.S. Industrial users, which include chemical producers like Dow and DuPont, account for 28% of consumption. Meanwhile, residential and commercial users consume 20% and 13% of the total natural gas demand, respectively. The gas extraction process itself consumes 8.5% and the transportation industry accounts for a mere 0.5%.

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de-carbonization. Recent announcements of new petrochemical facilities, incremental coal-to-gas switching at electric utilities, approval for LNG (liquefied natural gas) exports, and the potential for an unprecedented adoption of natural gas as a transportation fuel all point to an acceleration in demand growth. Next, we will address the specific sectors that could have the most significant impact on natural gas consumption.

U.S. TRANSPORTATION FUEL: THE REAL ‘GAME CHANGER’

Natural gas use as a transportation fuel in the U.S. is rare today. Although it is becoming clear that America may have an abundant natural gas resource, its share of the world’s compressed natural gas (CNG) vehicles is less than 1%. This is precisely why we now see an opportunity. Assuming a long-term natural gas price of $5/Mcf and oil above $100/bbl, shifting the U.S. car and light truck fleet to CNG makes economic sense.

Natural gas as a transportation fuel comes in either CNG or LNG form. The difference lies in the amount of energy content, or Btus\(^2\) that can be jammed into a given space. One Btu of LNG requires less space than one Btu of CNG—the reason LNG vehicles achieve greater range from a same sized tank. However, the liquefaction process is energy intensive to produce and store, making it more costly than CNG. As a result, LNG is largely considered for heavy-duty applications like long-haul trucks, ships and locomotives where the value of the haul is also much greater. For light-duty vehicles, however, the relatively short distances traveled make CNG a more attractive solution.

The Mechanics of CNG

Inside any traditional internal combustion engine, CNG is burned the same way that gasoline is, where one Btu of CNG delivers the same power output as one Btu of gasoline. This explains why the CNG version of a given gasoline-powered car will achieve an equal miles-per-gallon rating. We believe CNG represents an additional fuel source for existing vehicles on the road, not a replacement fuel. By adding the necessary components, drivers will have the ability to toggle between gasoline and CNG at the flip of a switch, allowing them to select the cheaper and/or most convenient fuel. CNG-powered and “flex fuel” vehicles (which burn gasoline and natural gas interchangeably) are already popular in several countries, including Australia, Brazil, Italy and Argentina.

CNG vehicle technology dates from the 1960s and gained greater popularity among commercial fleets during the oil crisis of the 1970s and early 1980s. CNG is a particularly compelling fuel source because, unlike electric hybrids or hydrogen vehicles, CNG requires little technology to implement. In fact, all that is needed is a CNG storage tank, fuel line and fuel regulator. Together, these components can cost as little as $2,500. At today’s commercial pump prices, CNG costs approximately one-third less than conventional gasoline and, depending on the vehicle and average range driven, the payback period (covering the additional equipment expense) falls between two and four years.

We have calculated the consumer "point of indifference" between gasoline and CNG at a gasoline price of $4/gallon, all else equal. Based on these calculations, the price of natural gas at the Henry Hub (the benchmark price for natural gas) would have to approach $24/mmBtu to make consumers indifferent between CNG and gasoline. Put another way, if natural gas prices remain at $2/Mcf, the price of gasoline would have to fall to $1.25/gallon in order for consumers to be indifferent.\(^3\) Assuming a sustainable natural gas price of $14/Mcf ($6/Mcf at the Henry Hub + $8/Mcf average distribution cost and

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\(^2\) Energy content as measured by British thermal units.

\(^3\) Assuming natural gas is delivered at current utility prices.
taxes), the equivalent price of gasoline would be $1.75/gallon. This wide price disparity offers a sizable buffer in which the price of gasoline and/or natural gas can vary before eliminating the positive benefit of CNG relative to oil.

Despite the favorable economics of CNG, we recognize the hurdles preventing mass adoption are numerous, such as an absence of refueling stations, lack of familiarity among consumers, insurers, police and firefighters, a dearth of CNG vehicle availability by major OEMs, ambiguous warranty clauses for CNG conversions on current gasoline cars, and a perceived reduction in range, safety and horsepower, among other issues.

**Most Viable Solution: A Hybrid of Gasoline and CNG**

With respect to refueling and range, we believe that CNG will only work if introduced as a hybrid solution, to be used in conjunction with gasoline. This would enable drivers to continue enjoying the convenience of America’s extensive gasoline station infrastructure, and spare them the worry of ever running out of fuel. CNG tanks require approximately 3.4 times as much physical space for the same range as needed for gasoline. CNG tanks also account for the bulk of the cost of the equipment needed to enable a vehicle for CNG. For these reasons, tanks tend to be relatively small. We believe the optimal CNG tank will be large enough to cover the vast majority of the average driver’s annual distance. Our chart in the Appendix entitled “2012 Toyota Camry with CNG Tank” outlines the size of the CNG tank that would be needed to cover 60 miles of range, or double the national daily average.\(^4\) We determined that a 2,500 cubic inch CNG tank would suffice. Assuming the tank is added to a standard 2012 Camry, 10% of the Camry’s trunk space would be sacrificed for the CNG tank—a small loss considering the significant savings offered by natural gas over gasoline.

The lack of refueling stations is another pressing obstacle preventing significant adoption of CNG. We believe two initiatives could help provide greater access. First, traditional gasoline stations are planning to introduce separate CNG pumps much like the introduction of diesel pumps during the 1980s. The second initiative is home refueling. According to the Energy Information Administration (EIA), of the roughly 110 million or so homes in America in 2010, 65.5 million were connected to a natural gas main, or around 60%. Conveniently, the gas that is delivered through the utility network into a home for use in a stove or furnace could readily be used as vehicle fuel. For example, Honda Motor Company USA has already offered a home refueling unit for its natural gas powered Civic GX. The garbage bin-sized unit costs between $2,000 and $3,000 and is available through a payment program. Since it draws gas from the local utility provider, the cost per cubic foot of gas is significantly lower than what is offered at a commercial pump. Other independent companies offering home refueling stations have also emerged and we believe that, with greater CNG models coming to market, a vibrant home refueling industry could quickly follow.

Safety is a common concern about high-pressure CNG tanks. Think of a CNG tank as a typical scuba diving tank containing natural gas instead of nitrogen mixed with oxygen. Both store gas at roughly 3,600psi (pounds per square inch). Of course, natural gas is flammable, while nitrogen and oxygen are not. However, natural gas is much lighter than air and dissipates very quickly when released. This characteristic makes it far less volatile than gasoline. In fact, it can be argued that, from a purely explosive standpoint,

\(^4\) National Household Travel Survey, 2001 – 2002.
gasoline—a fuel we are all quite comfortable to ride around with in our cars—is more dangerous than CNG.

As for the lack of CNG vehicles available today, GM, Ford and Chrysler recently announced new gasoline/CNG hybrid models on a wide range of pickup trucks due to hit the U.S. market by 2013. We view this as a powerful signal of the functionality and viability of CNG as a fuel as well as the sustainability of cheap (relative to oil) and abundant natural gas. The Honda Civic GX is a dedicated CNG model and is the most widely available consumer CNG vehicle available in the U.S. today.

How Much Is Enough?

So, how much gas would be needed to fuel all of America’s cars? We estimate that number to be approximately 50 Bcf/d—in contrast to the 66.8 Bcf/d consumed in 2011 for utilities, industrial, commercial and residential purposes. If we consider the natural gas needed to power the nation’s heavy- and medium-duty vehicles, for which conversion efforts are more advanced, we would need another 15 Bcf/d—or roughly the same as that consumed by the entire residential segment in 2011. Effectively, switching both light and heavy duty all at once would double the country’s demand for natural gas from 66.8 Bcf/d in 2011 to 131 Bcf/d. This would result in a dramatic displacement of crude oil, likely causing a significant reduction in the oil price, which in turn would challenge the economic merits of natural gas. In addition, ramping up the natural gas service industry and infrastructure to supply an additional 65 Bcf/d demand would take several years. However, we see two reasons why natural gas has staying power as a transportation fuel. First, by moving to a “flex fuel” option, drivers will have the ability to consume the cheaper of the two fuels on a daily basis. Second, we believe that in the time needed to bring significant CNG vehicles to market, China’s demand for oil will only continue to rise, effectively absorbing what the U.S. no longer consumes. This could serve to keep the price of oil near $100 and the economics of CNG favorable.

In addition to light- and heavy-duty vehicles, other applications exist, such as marine and rail. In many cases, rising environmental standards are acting as catalysts for LNG and CNG adoption. The International Maritime Organization (IMO)\(^5\) is pushing for LNG to replace marine fuel oil (or bunker fuel) since sulfur and NOx (nitrogen dioxide) emissions from LNG are significantly lower. The fact that the price of LNG is now roughly equal to low-sulfur bunker fuel makes this change impossible to ignore. By January 2015, the 1% sulfur content limit in the North Sea, Baltic Sea and the English Channel will be cut to 0.1%. In certain countries like Norway, LNG enables vessel owners to qualify for lower NOx emission taxes.

In summary, the factors we have described lead us to believe that natural gas will increasingly be adapted as a transportation fuel. Of course, this will be gradual and most likely take place within the context of a replacement cycle for retiring vehicles. As it relates to our demand curve for natural gas, we think the propensity for switching to CNG will accelerate the longer the price disparity remains elevated.

Coal to Gas: Transition Accelerates

During the last three years, an activist U.S. Environmental Protection Agency (EPA) and cheap natural gas prices have driven a substantial shift away from coal-fired power generation in favor of natural gas. Several political mandates over the last 10 years have

\(^5\) UN-backed global shipping regulator.
 intensified the economic burden of burning coal for electricity. Although most utilities in operation today have already invested significant capital in “scrubbers” to filter coal emissions and capture toxic matter, new initiatives, such as the Cross State Air Pollution Rule (CSAPR) issued by the EPA in 2011 and the proposed Mercury and Air Toxics Standards (MATS) rule, have made coal even more expensive to burn. This has and will continue to spur greater demand for coal substitutes when cheaper alternatives like natural gas are available, since natural gas carbon emissions are 50% lower than those from a coal-fired power plant. Judging from our research and conversations with utility companies, at the very low natural gas prices currently on the existing power generation base, most coal-to-gas switching has already occurred. As such, natural gas power generation appears to be running at practical capacity levels.

New Combined Cycle Gas Turbine (CCGT) power plants, which burn natural gas, are up to 50% more efficient than old coal fired plants when measured on the electricity output for each unit of energy input. However, many new coal plants are competitive with natural gas CCGTs, and to the extent that utilities can switch between the two fuels, we foresee that natural gas and coal prices in the U.S. will be tightly linked going forward. Importantly, reserve margins, or the available generation capacity, are high at most of the Independent Systems Operators (organizations that coordinate the electrical power grid in the United States), so there does not appear to be a pressing need for new power generation capacity. Barring a significant increase in the country’s industrial activity, we think it is unlikely there will be large scale construction of CCGT plants unless required by regulation. While the price of natural gas is low, it does not appear low enough to warrant building new CCGT capacity to displace perfectly functional coal-fired power capacity—even with the environmental costs of burning coal. However, if coal plants to be retired over the next three years are replaced with new CCGT generation, this could add to natural gas demand. If no new CCGT plants are built, a coal/gas arbitrage could be the norm and the fuel choice for electrical power generation would likely be determined by the marginal cost of the lowest cost fuel.

**INDUSTRIAL USAGE: SUPPORTING A ‘RENAISSANCE’?**

China’s labor cost advantage has been gradually eroding—something that we believe is likely to encourage a boost in U.S. industrial production, which in turn should draw on excess natural gas supply. Energy-intensive processes like metal smelting and fabrication, pulp and paper processing, and chemical production continually seek low-cost and sustainable energy. In particular, the chemical industry, the second-largest component of U.S. manufacturing, depends heavily on natural gas both as a feedstock and as a power source. The U.S. chemical industry is currently using natural gas liquids from shale drilling as a low-cost feedstock, making its production more competitive globally.

To the extent that confidence grows regarding the sustainability of America’s low-cost natural gas, we expect to see increased activity in chemicals and other industrial sectors. For example, Dow Chemical announced last year that it would like to build an advanced ethylene facility in Freeport, Texas. The pace of new ethylene plant construction will be a key driver for absorption of the natural gas liquids supply and a key determinant in the near-term economics for natural gas companies focused on wells that produce liquids.

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6 60% eff compared to 40% for a coal plant, energy converted into electricity.
OVERSEAS DEMAND

It’s interesting to note that America’s LNG terminals were all built to accommodate natural gas imports at a time when the country consumed more gas than it produced. With the current natural gas production boom, the situation has completely reversed. In fact, several companies have applied for licenses to export LNG as a way to profit from the price disparity between domestic natural gas prices and the high international LNG price, which is indexed to oil. Gas-to-liquids (GTL) technology, which converts natural gas to diesel fuel, provides another potential outlet for exports. Sasol’s ORYX and Shell’s Pearl projects in Qatar are examples of major GTL projects. The significant capital and processing costs for GTL have kept adoption low, which is why it has historically only been used in very low cost natural gas markets like Qatar, where the production cost for natural gas is around $0.50/Mcf. The fact that GTL produces diesel is advantageous because of the fuel’s wide use and extensive supporting infrastructure; a key drawback is the energy loss in the GTL production process.

The global LNG market is currently in a supply shortage which is likely to get worse. Following the Fukushima disaster of 2011, several nations opted to freeze nuclear reactor development or decommission existing facilities. Japan has decommissioned all of its nuclear reactors, which once supplied a third of the country’s electricity. Germany also plans to terminate its nuclear fleet by 2014. These countries alone will put significant pressure on global natural gas prices. Germany’s initiative towards increased dependence on renewable energy will require a complementary base load fuel source to provide power when the wind and sun are unavailable—and those fuels will likely be natural gas and coal. If other countries choose to displace nuclear power generation, global demand for LNG could increase. Already the seaborne LNG market is price-indexed to oil using a mechanism known as the “Japanese Crude Cocktail” which sets the price for LNG exports to Asia. Japanese LNG spot import prices over the last six months have hovered around $16/mmBtu, an oil-equivalent price of nearly $120/barrel. Our research suggests that, at such prices, the price of natural gas from the Henry Hub would need to reach around $6.50/mmBtu to wipe out the benefit of shipping LNG from the U.S. (Louisiana) to Japan. In our view, this leaves a price cushion large enough to commit initial shipments of LNG from the U.S. Gulf Coast.

China’s share of the global LNG seaborne market is only 3%, or 9mt (million tons) per year, and natural gas accounts for just 4% of China’s primary energy mix, compared to 25% in the U.S. For perspective, if that percentage increased to 5%, China would require an additional 20mt of LNG.

Two North American LNG export terminals are under permitting or construction today, which could supply the global LNG market with an additional 4–6 Bcf/d of LNG, or a little more than 5% of global LNG consumption. Ultimately, we believe the demand for LNG will depend on the relative price of oil and coal. Just like the natural gas and coal dynamic in the U.S., global coal, oil and LNG prices will likely be arbitraged and we think most countries will opt to have a mix of power generation so that they have fuel choices based on supply and price. If oil prices remain at current levels, this would likely pull both LNG and global coal prices higher. Also, China has repeatedly demonstrated a pragmatic approach to commodity consumption. We believe that any switch to imported
natural gas (whether pipeline from Russia or seaborne LNG) for power generation will take place in the context of arbitraging the seaborne coal price and, secondly, diversifying China’s energy mix.

CONCLUSION
In thinking about the marginal supply and demand curves for natural gas based on the analysis set forth in this paper, we anticipate the normalized natural gas price over the next decade will be close to $5/Mcf and eventually trending to $6/Mcf. We would expect this price to go to $6/Mcf sooner if transportation demand accelerates faster than we anticipate. At $6+/Mcf, we believe there would be ample supply to meet the increased demand. With this in mind, we foresee natural gas prices ultimately rising to the marginal cost of supply, yet safely within the “demand creation” range (anything below $6/Mcf).

In order for consumers and industry players to commit significant capital to create additional natural gas demand in America, there must be confidence in the long-term future supply of cheap natural gas. Unfortunately, uncertainty persists regarding the environmental impact of hydraulic fracturing or “fracking,” despite recent studies showing little risk of water contamination. With the many benefits that cheap, abundant natural gas could potentially bring to the U.S. economy, the government has a real incentive to institute clear regulation of the fracking process in order to signal an effective outcome for both the environment and the economy.

At the start of this paper, we considered the question of whether natural gas use could prove transformative, to which our answer is “both yes and no.” There will certainly be a lot of economic activity around developing these resources, which is a benefit for job creation and a step towards energy independence. The auto industry could also be helped by an acceleration of scrapping aged vehicles and trucks for CNG and LNG powered replacements. However, we believe a broader manufacturing renaissance in the U.S. is more likely to be driven by other factors such as its global comparative cost.
There are many exploration and production companies now targeting oil shales in the U.S. using the same unconventional drilling and completion techniques as in the gas shales.

and productivity of labor, regulatory reform and tax policy. Low-cost energy would represent a benefit on the margin, and could represent a savings for the average American household, but in itself, would not be the game-changer that some suggest to bring significant manufacturing back to the United States.

A final point on the shale revolution is that the current U.S. trade deficit is largely due to the crude oil imported for transportation. There are many exploration and production companies now targeting oil shales in the U.S. using the same unconventional drilling and completion techniques as in the gas shales. Some optimistic estimates suggest these shales could increase oil production by 500,000 to 1mm bbls per day per year.7 Currently, the U.S. consumes ~18.2mm bbls per day of oil, 62% of which is imported. In addition to boosting domestic oil production, if there were a meaningful shift to CNG over the next decade by the passenger and light truck fleet, which account for roughly a third of oil consumption, there would be a substantial positive effect on the U.S. balance of payments. This would also strengthen the dollar. Although this shift would not address the size of the large U.S. budget deficit, it could substantially reduce dependence on foreign capital to finance the country’s balance of payments deficit. This would be truly transformational from a global geopolitical perspective.

7 4mm to 6mm bbls per day increase spread over the next five to 10 years.
The natural gas equivalent of one gallon of gasoline is one “gallon of gasoline equivalent,” or GGE. Both contain roughly 114,000 Btu of energy. At 900Btu/cf, one GGE contains ~127cf of gas. Today’s average pump price for gasoline is $4/gallon; the average CNG station GGE price is $2.69, or roughly one-third less.

Assuming 15,000 average miles driven per year, an average 20 MPG consumption rate and $4 gasoline, the average driver will spend roughly $3,000 a year on gasoline. By switching to CNG, the same driver would save ~$1,000 per year. Since the estimated price premium for a CNG car is $2,000, the payback period is two years.

The savings can be increased if drivers use home refueling units that draw gas from a household gas main at utility prices. The average cost of natural gas delivered to households across America provides a reasonable proxy of the true cost of natural gas to the consumer. This utility price includes (minimal) processing, infrastructure and taxes. Through December 2011, the average price for natural gas supplied by a utility to a U.S. household was $9.69/Mcf. This translates into $1.23 for 127cf (what is needed to make one GGE), which is $2.77, or 70%, cheaper per gallon than gasoline.

Determining the Breakeven Price

In order to understand the potential of natural gas as a major vehicle fuel source, it helps to know the breakeven price of CNG versus gasoline, which we assume to be $4 gallon for our analysis.

Holding all else equal, the point at which a driver becomes indifferent between CNG and gasoline occurs when he or she must pay $4 for one GGE of natural gas. At that price, the implied price for one Mcf at Henry Hub pricing is $31.50/Mcf, explained by the following equation: $4 gallon gasoline/127cf of natural gas (what is needed to make 1 GGE) x 1000 (because we want the price in Mcf) = $31.50. Of course, one must take into account distribution, processing and taxes. Therefore, we use a five-year average delivery cost of natural gas of $7.89/Mcf, which equates to $23.60/Mcf at the Henry Hub, or roughly 11.6 times the current price. Put another way, the price of gasoline would have to fall to $1.25/gallon before it would reach parity with natural gas delivered through the utility network. Until this happens (a very unlikely proposition), running a CNG car with gas from a home refueling unit will save money.

Tank size and trunk space are often cited as major concerns about CNG. Our calculations indicate that CNG requires 3.4 times more physical space per mile than gasoline. While this sounds like a large number, one should not assume that CNG cars would come with fuel tanks 3.4 times larger than those of gasoline-fueled cars; CNG/gasoline flex fuel cars could likely get by with a CNG tank large enough to cover 90% of the average daily miles driven, which in the U.S. is 30 miles.

We conducted an analysis, based on our own research and calculations, of the space needed to install a CNG tank in a 2012 Toyota Camry (the most popular car in America). Our results, shown in Figure 6, indicate that the driver of a 2012 Toyota Camry who wants to retain the Camry’s original 425-mile total range but wishes to accomplish 60 miles of that through the use of CNG, will only need to forego around 6.7% of the original

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8 EIA, “U.S. Price of Natural Gas Delivered to Residential Consumers.”
9 5-year average of the difference between annual average delivery cost of gas and HH (2011-2007) EIA.
10 The price of CNG delivered through the utility network should be $2 + $7.89 = $9.89/Mcf, or $0.00989/cf x 127cf = $1.25/ gallon gasoline.
trunk space to accommodate the appropriate CNG tank. Note that the 60-mile range is twice the national average daily miles driven per car, as noted above; so, this driver would theoretically have more than enough CNG capacity to cover the vast majority of annual driving needs.

Also, the 6.7% reduction in trunk space assumes that Toyota decreases the gasoline tank’s size by 14.12% to make room for the CNG tank while maintaining its original range of 425 miles. Assuming the driver chooses to purchase a regular Camry and buy the CNG tank separately, 10% of the trunk space would be lost. In this scenario, the vehicle’s total range would include the 425 miles offered by the original gasoline tank as well as an additional 60 miles provided by the CNG tank.

We view the loss of space as very manageable given the significant cost savings associated with CNG over gasoline.

<table>
<thead>
<tr>
<th>TABLE 1: 2012 TOYOTA CAMRY WITH CNG TANK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPG (city)</strong></td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td><strong>Fuel (gallon)</strong></td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td><strong>Range (city miles)</strong></td>
</tr>
<tr>
<td>425</td>
</tr>
<tr>
<td><strong>Tank size (cubic inches)</strong></td>
</tr>
<tr>
<td>5,350</td>
</tr>
<tr>
<td><strong>Trunk space (cubic inches)</strong></td>
</tr>
<tr>
<td>26,611</td>
</tr>
<tr>
<td><strong>GGE for most common CNG tank</strong></td>
</tr>
<tr>
<td>4.7</td>
</tr>
<tr>
<td><strong>Tank size (cubic inches)</strong></td>
</tr>
<tr>
<td>5,000</td>
</tr>
<tr>
<td><strong>Range (miles)</strong></td>
</tr>
<tr>
<td>117.5</td>
</tr>
<tr>
<td><strong>Desired CNG range (miles)</strong></td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td><strong>GGE required</strong></td>
</tr>
<tr>
<td>2.4</td>
</tr>
<tr>
<td><strong>Required tank size (cubic inches)</strong></td>
</tr>
<tr>
<td>2,553</td>
</tr>
<tr>
<td><strong>Desired total range (city miles)</strong></td>
</tr>
<tr>
<td>425</td>
</tr>
<tr>
<td><strong>Total tank space (cubic inches)</strong></td>
</tr>
<tr>
<td>7,148</td>
</tr>
<tr>
<td><strong>Forgone trunk space:</strong></td>
</tr>
<tr>
<td>-6.76%</td>
</tr>
</tbody>
</table>

Information reflects the physical size of a CNG tank that would be needed to provide enough fuel for 60 mi of distance. At the Camry’s average 25 mpg, 2.4GGE of natural gas would be required. Since a common 4.7GGE capacity tank takes up 5,000 cubic inches, a 2.4GGE tank should require roughly half that amount, or 2,553 cubic inches. When placed in the Camry’s trunk area, the 2.4GGE tank would take up 9.59% of the Camry’s available 26,611 cubic inches of trunk space. This would give the Camry an additional 60 mi of range above its standard 425 mi for a total of 485 mi. Assuming that the CNG tank displaces the original gasoline tank, while maintaining the Camry’s standard 425 mi of range, only 6.76% of the trunk space would be lost to make room for the CNG tank.
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