Photos courtesy of EQT Corp.

Demand Outlook: A Golden Age of Natural Gas

William Liss
Gas Technology Institute

The shale gas boom in the U.S. is transforming the energy marketplace and a wide range of manufacturing industries that rely on natural gas.

The International Energy Agency issued a report last year titled *Are We Entering a Golden Age of Gas? (1)*. In the U.S., the answer is an emphatic "yes" — in large part due to the confluence of shale gas resources, hydraulic fracturing, and directional drilling techniques.

The current situation represents an impressive turnaround in the U.S. gas supply outlook. During the last decade, U.S. reliance on natural gas imports was increasing — along with prices — and liquefied natural gas (LNG) import terminals was a hot topic. Today, the U.S. is on a path toward the elimination of natural gas imports and is now starting to construct LNG export facilities — a remarkable 180-deg. U-turn.

For the chemical and petrochemical industries, the period from 1997 to the recession of 2009 was an era of intense demand destruction, due in part to high natural gas prices and international competition (offshoring). More than 2.3 trillion cubic feet (Tcf) in annual U.S. industrial natural gas demand was eliminated (a 28% decrease).

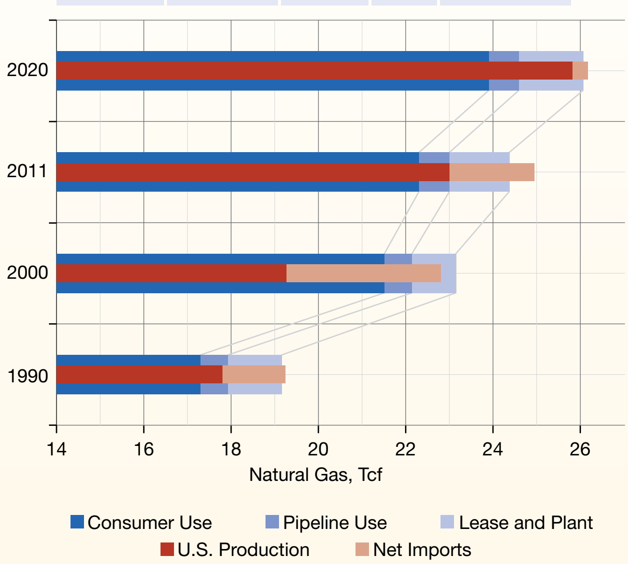
New shale gas resources have completely transformed the U.S. natural gas supply and demand outlook. Even with a warm winter, 2011 set an all-time record for U.S. natural gas demand, with end users consuming about 22.3 Tcf.

Figure 1 summarizes U.S. natural gas consumption and production trends. The dark blue bars indicate the amount of gas purchased for consumer use in the residential, commercial, industrial, power generation, and transportation sectors. The lighter blue bars represent natural gas used as fuel in well, field, and lease operations, for example to operate drilling equipment, heaters, dehydrators, and field compressors (lease and plant), and in pipeline operations (*e.g.,* to power compressors).

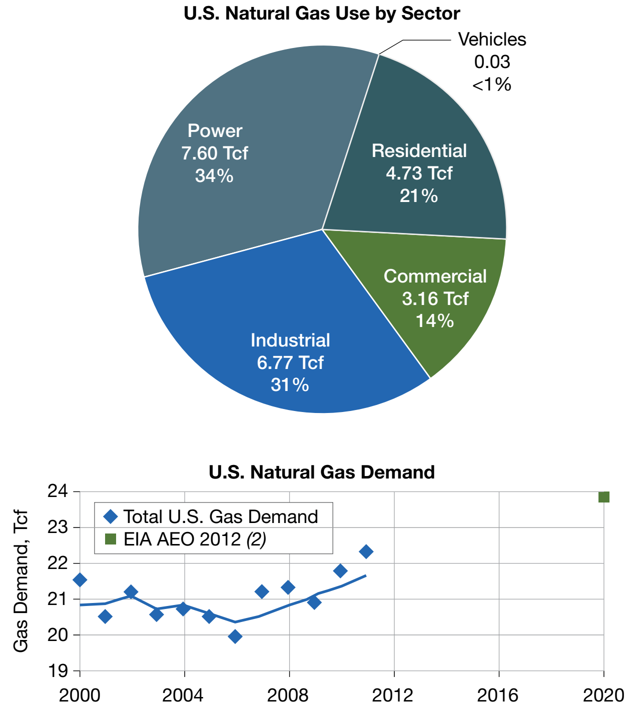
In 1990, domestic production (17.8 Tcf) exceeded consumer use (17.3 Tcf), and imports accounted for only 8% of total natural gas consumption. By 2000, consumer use (21.5 Tcf) outstripped domestic production (19.3 Tcf), and reliance on imports doubled to 16%. Although the consumer use of natural gas surged over the last decade (to 22.3 Tcf in 2011), domestic production ramped up to 23 Tcf — reducing reliance on imports to 9%. The U.S. Dept. of Energy's Energy

Projected Incremental Growth from 2010 to 2020, billion ft³

Residential	Commercial	Industrial	Power	Transportation
163	378	893	673	53



▲ **Figure 1.** Natural gas supply and demand outlook. Domestic production will continue to exceed growing consumer use. Source: *(2, 3).*



▲ **Figure 2a.** U.S. natural gas use trends. The power generation and industrial sectors account for roughly two-thirds of the total U.S. natural gas consumption. Source: *(3).*

Information Administration (DOE-EIA) expects demand to increase to 24 Tcf by 2020 *(2),* although this could prove to be a conservative prediction. Growth is anticipated in all markets, led by the industrial, power generation, and transportation sectors. Import reliance is expected to be negligible in 2020 (less than 1.5% of consumer use).

Figures 2a–2e illustrate natural gas consumption trends by end use sector *(3).* Recent gas demand has been shaped by power generation growth, industrial decline, and, of course, weather. The past two years have seen record demand levels, led by a strong industrial demand rebound and inexorable power generation expansion. Natural gas vehicles (NGVs) are experiencing high growth rates, albeit on a small base, driven by large fuel price differentials compared with diesel and gasoline.

Demand vectors and value creation

It certainly appears to be a golden age for natural gas in the U.S. But a vital question remains: For whom? Many are staking claims and making plans to capitalize on bountiful natural gas supplies. New resources could be channeled along many demand vectors — traditional and nontraditional, large and small. Many options provide a compelling value proposition, with several hinging on multi-billion-dollar capital investments — new industrial manufacturing (*e.g.,* chemical/petrochemical) plants, gas-to-liquids (GTL) (*e.g.,* gasoline or diesel substitutes) plants, power generation facilities, NGV fueling infrastructure, natural gas liquefaction plants, and others.

Natural gas consumers are realizing significant savings (Table 1). Prices for large-volume industrial and power generation users have dropped precipitously. Compared with 2008 prices, current natural gas prices are saving consumers nearly $90 billion per year. For the industrial sector, this frees up working capital for other investments. An added bonus for the U.S. economy is that natural gas imports are down by more than 1.8 Tcf since 2007, which has positively impacted both the balance of trade and employment.

Time will tell how the competitive marketplace will adapt to natural gas supplies and — just as important — how further value creation from natural gas will be realized. This article explores some of the market factors that may influence natural gas use and industrial output, and the role of chemical engineering and chemistry in this transformation.

Industrial demand for natural gas

Natural gas is expected to be a significant game changer in the industrial sector, where it is used extensively by manufacturers for power and steam production, process heating, and as a chemical feedstock. The value proposition associated with expanding industrial natural gas use revolves around growth in manufacturing output, gross domestic product (GDP), and employment. For example, a facility that displaces foreign-made goods has a leveraged positive impact on GDP and job creation. Studies point to the phenomenon known as onshoring, which may increase value-added U.S. manufacturing over the coming decade. The confluence of low-cost natural gas and onshoring may turbocharge U.S. manufacturing over the next 10 to 20 years *(4).*

New U.S. natural gas supplies are playing a key role in this anticipated industrial renaissance, particularly for the chemical and petrochemical segments *(5).* Expansion is projected in the manufacture of products that depend on natural gas or methane, such as ammonia, urea, hydrogen, and

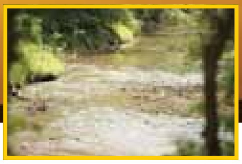
Table 1. The production of shale gas has increased natural gas supplies and driven down prices, resulting in significant savings in all sectors.

Prices, $/MMBtu*	Industrial	Power Generation	Commercial	Residential
2008 Prices	9.65	9.26	12.23	13.89
2011 Prices	5.02	4.87	8.86	10.80
Change	–48.0%	–47.4%	–27.6%	–22.2%
Sector Savings, $ billion	$31.3	$33.4	$10.7	$14.7

* per million Btu

Source: GTI analysis of DOE-EIA data.





methanol, as well as ethylene made from ethane (which is a component of natural gas and natural gas liquids [NGLs]).

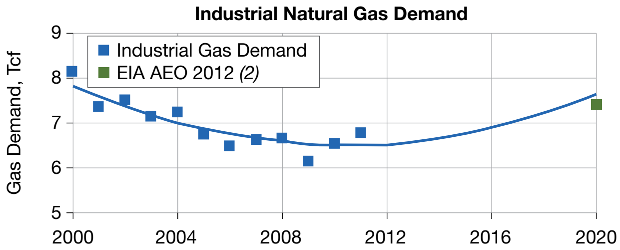
Methane is a chemical precursor not just for the chemical and petrochemical industries. The iron and steel industry can use methane as a reducing agent in iron ore conversion. For example, Nucor Corp. is constructing a major new direct-reduced iron (DRI) plant that will use natural gas for iron ore processing. Integrated steel producers may also look to supplemental natural gas use in blast furnaces to offset coking coal.

Low U.S. natural gas prices help producers compete internationally. In ammonia production, for instance, low gas prices provide U.S. producers with a competitive advantage over foreign producers in a tight commodity market (particularly producers using higher-cost naphtha feedstock). Agriculture is a primary market for ammonia and other nitrogen-based fertilizers. High grain commodity prices (partially tied to ethanol production) and growing international grain demand are acting to increase domestic ammonia demand and prices, making U.S.-based ammonia production from natural gas more profitable. This helps boost GDP and job creation in multiple segments (*e.g.,* agriculture, chemicals, natural gas production) and demonstrates the ripple effect that natural gas supplies and prices can have.

An increasingly robust supply of NGLs being produced as a co-product of natural gas extraction is creating large domestic supplies of ethane. Like methane, ethane is a simple molecule with an outsized impact and value as a chemical precursor. The transformation of ethane to ethylene in ethane steam cracking furnaces has an extensive cascading effect on the production of value-added chemicals and products: low- and high-density polyethylene (trash bags, bottles, food containers, pipe), ethylene oxide (ethylene glycol for antifreeze, and polyester resins and fibers for carpeting and clothing), ethylene chloride (polyvinyl chloride [PVC] for pipe), ethylbenzene (styrene, styrene butadiene rubber), and many other industrial chemicals and products.

These strong NGL and ethane supplies are positioning the U.S. as a top-tier, low-cost ethylene producer — particularly when juxtaposed against countries where ethylene is produced from naphtha. This is inspiring new investments in ethane recovery (*e.g.,* NGL extraction and fractionation plants) and pipeline systems to move ethane from new gas-production regions to existing ethane steam cracking facilities in the South Central U.S. and Ontario, Canada. In addition, several companies are evaluating major investment in new ethane steam cracking plants in Pennsylvania, West Virginia, Ohio, and others states.

The American Chemistry Council (ACC) reports that a 25% increase in U.S. ethane supplies could generate over 400,000 new jobs, nearly $33 billion in new chemical production, and a total GDP impact in excess of $132 billion *(6).*



▲ **Figure 2b.** Industrial demand for natural gas is projected to increase as new domestic sources of shale gas come online. Source: *(3).*

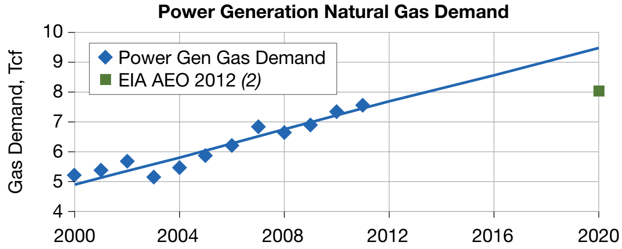
The manufacture of transportation fuels (*e.g.,* diesel, gasoline, and biofuels such as ethanol) is a major part of the chemical process industries. Natural gas works behind the scenes in refineries and ethanol plants to provide the power, steam, heat, and chemistry needed to make transportation fuels. For example, hydrogen from steam reforming of natural gas is used in the hydrodesulfurization of liquid fuels, and natural gas-fueled combined heat and power (CHP) systems provide onsite power and steam at refineries and ethanol plants. Approximately 1.3 Tcf/yr of natural gas is used to produce liquid transportation fuels (including about 0.5 Tcf/yr for ethanol).

From this perspective, natural gas has a larger footprint in the transportation fuels market than is generally recognized. Incremental gas use in the production of transportation fuels could result from refinery capacity expansions and new ethanol plants, although ethanol growth is somewhat contingent on the maturation of cellulosic ethanol production. Bioengineering and chemical engineering could help bring about important breakthroughs in this area.

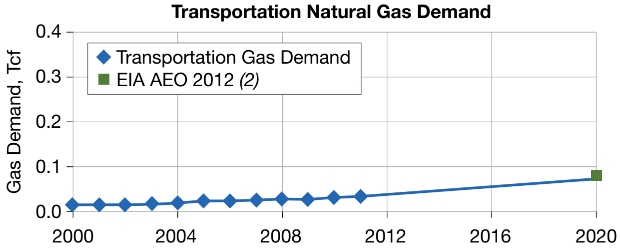
Other vectors by which natural gas could impact the liquid transportation fuels space include gas-to-liquids (GTL) transformation to produce substitute gasoline or diesel fuels (*e.g.,* via the Fischer-Tropsch, Shell Middle Distillates Synthesis [SMDS], ExxonMobil methanol-to-gasoline [MTG], Topsoe Integrated Gasoline Synthesis [TIGAS], and other processes), and methanol production from natural gas. Methanol, which is generally made from methane rather than biomass feedstocks, is considered an alternative or complement to ethanol for vehicles *(7).*

GTL and methanol processes typically have, at their core, synthesis gas production. Synthesis gas (syngas) consists of hydrogen and carbon monoxide, which act as molecular building blocks in the production of methanol and longer hydrocarbons that are compatible with gasoline or diesel. Syngas can be made by various routes, including steam reforming, autothermal reforming, and partial oxidation of natural gas, as well as gasification of solid fuels such as coal or biomass.

Key issues impacting GTL plants are capital cost, access to low-cost gas resources, and conversion efficiency. Conversion (or well-to-wheels) efficiencies in the range of



▲ **Figure 2c.** Consumption of natural gas for power generation will continue to soar. Source: *(3).*



▲ **Figure 2d.** Demand for natural gas in the transportation sector, though growing, is much lower than in other segments of the economy. Source: *(3).*

60–65% have been reported for GTL plants. The chemical engineering challenge is twofold: raise GTL plant conversion efficiency and reduce capital intensity.

Breakeven conditions for GTL plant economics hinge upon high crude oil prices and low natural gas costs. The Pearl complex in Qatar, which produces 140,000 barrels per day (bpd) of liquid fuels and other products using the SMDS process, had a construction cost of over $20 billion, but a reported payback time of less than 3 yr at current oil prices.

Sasol Ltd. recently announced plans to construct an $8–10-billion GTL complex in Louisiana. This facility could consume up to 1 billion cubic feet (Bcf) of natural gas per day and have an output of 96,000 bpd of liquid fuels and other products. Shell is also reportedly considering the construction of a plant of similar scale in the U.S. Gulf Coast area.

Natural gas conversion to liquid fuels includes natural gas liquefaction, a cryogenic refrigeration process that produces LNG at temperatures of –150°C to –160°C. Several companies are considering constructing large-scale, capital-intensive LNG plants and exporting the output to Europe or Asia, which raises concerns about the potential impact of natural gas exports on domestic gas prices. For natural gas producers, the increased demand for natural gas in LNG plants will open a new market option while also boosting NGL output that could be used by chemical and petrochemical producers. There are also potential applications for complementary domestic LNG use in heavy-duty trucks, rail, and marine markets (*e.g.,* ferries, barges).

Natural gas in power generation

Over the past 15 yr, natural gas use for power generation has grown by 85%, with 3.5 Tcf/yr in new demand bringing the total consumption by this sector to 7.6 Tcf/yr. This has occurred even though coal, which has accounted for about 45% of U.S. power production, is less expensive on a per-Btu basis. The value of natural gas in power generation stems from the low capital cost and high efficiency of combined cycle power plants and the efficiency of CHP facilities. Value also arises from operating flexibility — *i.e.,* the ability of gas-fired plants to stop and start and to ramp up and down quickly. Operating flexibility is becoming increasingly important as more intermittent power sources (*e.g.,* solar, wind) populate the electric grid.

In 2011, natural-gas-fired power generation output totaled nearly 988 GWh — a 64% increase since 2000 and nearly 24% of U.S. electricity production. Natural gas CHP systems generated 208 GWh of electricity — much of this tightly integrated with industrial manufacturing operations that benefit from the waste heat and steam co-produced by CHP systems. DOE-EIA's 2012 Annual Energy Outlook *(2)* anticipates natural gas use in power generation growing to 8 Tcf/yr by 2020. If recent market trends (*e.g.,* coal plant retirements) and low natural gas prices continue, natural gas use in power generation may be closer to 9 Tcf/yr by 2020.

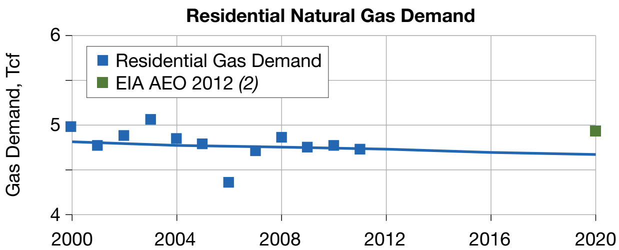
Natural gas demand in the transportation sector

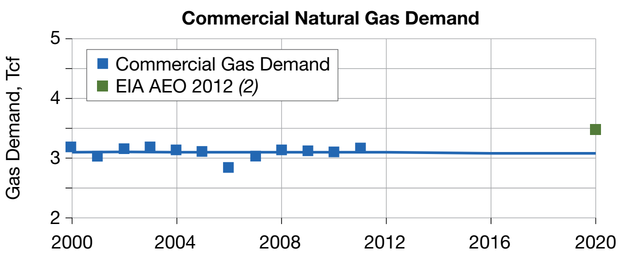
Unlike other sectors, the U.S. transportation market is highly dependent on one energy source — crude oil and its derivative products (*e.g.,* gasoline, diesel). This has impacts on the balance of trade, and creates a long-recognized energy security risk.

As already noted, natural gas plays an indirect role in the production of transportation fuels such as gasoline, diesel, and ethanol. There is significant potential, however, for greater direct use in natural gas vehicles.

The U.S. and the rest of the world now have several decades of experience with compressed natural gas (CNG) and LNG vehicles. Today, an estimated 15 million NGVs are in use worldwide, with about 120,000 of those in the U.S. The NGV industry started in the U.S. around 1990 with the introduction of high-performance, low-emission NGV engines, advanced lightweight composite high-pressure cylinders, and an expanding NGV fueling infrastructure.

NGVs are now poised for a new wave of growth, particularly with high-fuel-use fleet vehicles such as heavy-duty buses and trucks. Significant progress has already been made with transit bus and, more recently, with refuse fleets. Freight trucks, both regional and interstate, represent the next growth segment. These heavy-duty fleet vehicles can use 10,000–20,000 gal/yr of diesel fuel. According to the U.S. DOE January 2012 price survey, diesel prices were $3.86/gal and CNG prices were $2.38 per diesel gallon





▲ **Figure 2e.** Natural gas demand in the residential (top) and commercial (bottom) sectors remains relatively flat. Source: *(3).*

equivalent *(8)*. Such price differentials equate to annual fuel-cost savings in the range of $15,000–$30,000 per heavy-duty vehicle and provide the opportunity for a 2–4-yr payback on the initial NGV cost premium.

The use of 1 Tcf of natural gas in NGVs — less than 5% of current consumer natural gas demand — could displace nearly 8 billion gal of diesel fuel, saving fleet operators more than $12 billion/yr in fuel costs while diversifying transportation fuel use and enhancing energy security.

Research on adsorbed natural gas storage as an alternative low-pressure storage option for NGVs is also underway. This includes high-performance carbons and metal organic framework (MOF) materials, both of which might be used in other chemical and petrochemical applications for separation and processing of gases and liquids.

Residential and commercial natural gas demand

Today's residential and commercial (res/com) markets are dominated by natural gas and electricity, which together meet 85–90% of the energy needs of U.S. homes and commercial businesses. In 2011, res/com gas demand totaled 7.9 Tcf (35% of total gas demand). The demand trend in these two sectors is flat, and this trajectory is expected to continue into 2020. Increases in total housing stock and commercial building space are largely offset by improvements in appliance efficiency and tighter building envelopes (*e.g.,* through better insulation and windows). In 2011, U.S. natural gas utilities invested — on behalf of their customers — $1.2 billion in energy efficiency programs (62% of which was for residential users), and similar investments are expected in coming years.

New value creation opportunities (*e.g.,* consumer energy cost savings) for residences and commercial consumers include displacing inefficient electrical uses (*i.e.,* inefficient on a source-energy basis) and expensive fuel oil.

Source-energy efficiency is an important concept in understanding energy use and losses. It is also referred to as total fuel cycle energy use, and is similar to the chemical engineering practice of drawing a box around a system of process flows. As shown in Figure 3, substantial losses occur in the electricity value chain — significantly more than in the use of natural gas.

For instance, about 68% of the energy contained in coal is lost before the electricity is delivered to the customer:

• extraction of coal and delivery, typically by railroad, to the power plant — a 5% loss

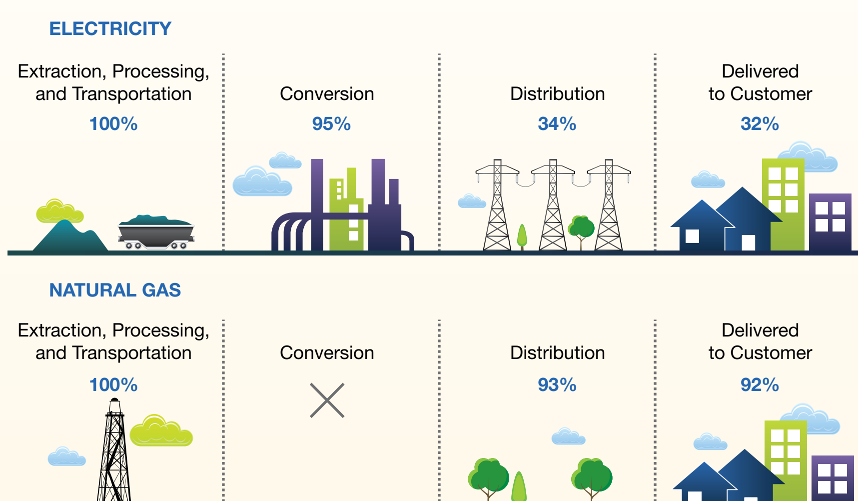
• conversion to power — a 61% loss, the most significant source of inefficiency

• power transmission and distribution to users — a 2% loss.

In contrast, natural gas losses are about 8%.

DOE-EIA data indicate that res/com sites consume 9.49 quadrillion Btu (quads) of electricity, and an additional 20 quads of energy is lost before the electricity reaches the consumer. Thus, the total res/com electric energy requirement is nearly 29.5 quads. For comparison, the res/com natural gas source energy requirement is about 8.5 quads, which includes markedly lower energy losses of less than 0.7 quads.

Direct use of natural gas for water heating, for example,



▲ **Figure 3.** Source-energy losses are much larger for electricity delivered to the consumer (68%) than for delivered natural gas (8%). Source: *(9).*

is generally twice as efficient as electric water heating on a source-energy basis. Beyond substantial total energy savings, however, consumers can also save money. Efficient natural gas water heating can save consumers $275/yr over electric water heating and $320/yr over heating water with fuel oil. For each 5 million consumers, this adds up to $1.4 billion/yr in energy savings compared with electricity and $1.6 billion/yr compared with fuel oil.

Touchpoints and future needs: Natural gas, chemistry, and chemical engineering

Natural gas has widespread influences in our daily lives. This stems from the myriad ways it is used as an energy source and as a raw material in making a spectrum of products — not only in the chemical and petrochemical industries, but also in the food processing, iron and steel, aluminum, glass, and other manufacturing sectors.

Chemical engineers will play a leading role in transforming the energy marketplace and U.S. manufacturing. Examples of possible chemical engineering contributions include:

- better methane and ethane conversion routes that improve energy efficiency and reduce capital intensity
- more-efficient processes for making ethanol (including cellulosic routes) and methanol for use as chemical feedstocks and transportation fuels
- high-performance materials that reduce building energy losses and ensure efficient use of natural gas in homes and businesses
- advanced working fluids and system solutions for high-efficiency natural gas heat-pump systems used for space heating and cooling
- advanced natural gas fuel processing and electrochemistry solutions for ultra-clean fuel cell power generation and CHP
- methods for cost-effective carbon dioxide capture and use
- high-performance materials (*e.g.,* polymers, epoxy, carbon fibers) for use in NGV fuel storage containers
- advanced materials and adsorbents (*e.g.,* MOF materials) that can be used for gas processing, natural gas storage, and other novel applications
- high-temperature heat-transfer fluids for hybrid solar thermal and natural gas power systems and for heating and cooling applications.

Closing thoughts

Over the past five years, the U.S. shale gas revolution has been a truly remarkable transformation — the full implications of which are still unfolding in the marketplace. This will certainly influence U.S. natural gas demand and have worldwide implications in other regional energy markets. The consequences of shale gas and advanced natural gas production methods are profound.

In the coming decade, we will more fully realize the implication of this sea change in U.S. natural gas end use sectors. There are many ways that natural gas can create value and improve the daily lives of many — from basics such as more efficient and cost-effective water heating, to substantial growth in industrial production and employment, cleaner and more-efficient electricity production, and cost-effective and clean transportation options.

The potential implications in the industrial sector are substantial, particularly for the chemical and petrochemical segments. Continued advancements in science and technology — including chemistry and chemical engineering — can enhance the value-creating potential that is possible with new natural gas supplies. CEP

Literature Cited

1. **International Energy Agency,** “World Energy Outlook 2011 Special Report: Are We Entering a Golden Age of Gas?,” IEA, www.iea.org/weo/golden_age_gas.asp (June 2011).
2. **U.S. Dept. of Energy, Energy Information Administration,** “Annual Energy Outlook 2012, Early Release Overview,” DOE-EIA, www.eia.gov/forecasts/aeo/er/executive_summary.cfm (Jan. 23, 2012).
3. **U.S. Dept. of Energy, Energy Information Administration,** “Natural Gas,” www.eia.gov/naturalgas/data.cfm (accessed Apr. 2012).
4. **Sirkin, H. L., *et al.*,** “Made in America, Again: Why Manufacturing Will Return to the U.S.,” www.bcg.com/expertise_impact/publications/publicationdetails.aspx?id=tcm:12-84591, Boston Consulting Group, Boston, MA (Aug. 2011).
5. **Swift, T. K.,** “Looking for Growth in the Chemicals Industry,” *Chem. Eng. Progress,* **108** (1), pp. 12–15 (Jan. 2012).
6. **American Chemistry Council,** “Shale Gas and New Petrochemicals Investment: Benefits for the Economy, Jobs, and U.S. Manufacturing,” www.americanchemistry.com/Policy/Energy/Shale-Gas, ACC, Washington, DC (Mar. 2011).
7. **Leppin, D.,** “Technology Options and Economics for Unconventional Shale Gas and Gas Liquids Monetization,” presented at the World Gas Conference, Kuala Lumpur, Malaysia (June 2012).
8. **U.S. Dept. of Energy,** “Clean Cities Alternative Fuel Price Report,” DOE Alternative Fuel Data Center, www.afdc.energy.gov/afdc/price_report.html (Jan. 2012).
9. **Meyer, R.,** “Squeezing Every BTU,” *American Gas,* pp. 28–31 (Apr. 2012).

WILLIAM LISS is Managing Director, End Use Solutions, at Gas Technology Institute (1700 S. Mount Prospect Rd., Des Plaines, IL 60018; Phone: (847) 768-0753; Email: bill.liss@gastechnology.org; Website: www.gastechnology.org), where he manages a multifaceted research, development, and demonstration (RD&D) team focused on new energy technology development, with an emphasis on natural gas. He has a BS in chemical engineering from the Univ. of Illinois at Chicago and an MBA from Keller Graduate School of Management of DeVry Univ. He is a long-standing member of AIChE, the American Society of Mechanical Engineers, and the Society of Automotive Engineers.