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natural gas for generation

a solution or a problem?

NATURAL GAS IS AN ESSENTIAL energy source in this country that has many applications, including heating homes and businesses, powering industrial and agricultural production, and, most recently, generating a substantial amount of electricity needs. Thus, natural gas plays a vital role in achieving the nation's economic and environmental goals.

In 2004, we saw price spikes and high volatility in the crude oil and natural gas markets. The crude oil price peaked at US$55/barrel during mid-October. Figure 1 shows the spot price for natural gas at Henry Hub from 1 December 2003 to 31 December 2004. The natural gas price was well above US$5/MBtu (million Btu) in most of 2004, peaked close to $8/MBtu, averaged $6/MBtu, and was extremely volatile in the last quarter of the year. Figure 2 shows the National Petroleum Council's natural gas price forecast ranges for alternate scenarios over the next 20 years: US$5/MBtu on the average and higher than US$7/MBtu in the worst case. Current high gas prices are the result of a fundamental shift in the supply and demand balance. On the one hand, gas production from traditional U.S. and Canadian basins has plateaued, new gas exploration has not been encouraging, and liquefied natural gas (LNG) import is just at the start. On the other hand, economic recovery has pushed up demand for natural gas. Although its balance of supply and demand does not need to be instantaneous as it does for electricity, natural gas supplies still cannot quickly adjust to demand changes, leading to periodic supply and demand imbalances, thus high price volatility.

The high price and high volatility of natural gas has been a great concern for


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those expecting to profit from gas-fired generation units in the competitive electricity markets. Since the late 1990s, restructuring in electric power systems has resulted in a huge addition of gas-fired generation capacity, with over 200,000 MW of new gas-fired capacity built at a cost of more than US$100 billion. Among the reasons for the emergence of gas-fired generation capacity are the high efficiency and environmental friendliness of gas-fired units and presumed low gas prices.

The total energy conversion efficiency of combined cycle plants can reach 60%, which is a 20–30% improvement over that of traditional thermal plants. In addition, the electric industry, in its efforts to function in competitive markets, has designed a market that promotes natural gas generation because of its fast ramping capabilities. This allows natural gas units to respond in many more markets (for example, reserve markets) than coal-fired units or nuclear units, which are most efficient in supplying base load.

A typical combined-cycle plant would produce carbon dioxide (CO_2) at about 0.8 lb/kWh as compared to that of a new coal-fired power plant at about 2 lb/kWh. Tightening environmental standards will continue to improve the competitiveness of gas relative to coal. Other types of environmentally hazardous exhaust gas from a gas-fired combined cycle plant, such as nitrogen oxides (NOx), carbon monoxide (CO), and sulfur dioxide (SO_2), are much less than those from other types of thermal plants. Gas is considered the one petroleum-based product the environmentalists would accept.

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Many state electric utility restructuring programs were adopted at a time when it was assumed near-universally that natural gas prices would remain well below US$3/MBtu. When restructuring started in California, for instance, the price of gas was an average of about US$2/MBtu, ranging from about US$1.6–2.2/MBtu. But, unfortunately, the price of gas rose dramatically to a level where US$5–6/MBtu is not uncommon.

As the low gas price era is over, the rationales for building gas-fired units have met serious challenges. Since fuel is the largest contributor to the cost of electricity generated by gas-fired units, the natural gas price's increase above $US5/MBtu has made the plants uneconomical to run in a competitive environment. So, although natural gas generation has been and remains the environmental favorite, the high natural gas price has jeopardized the economics of gas-fired generation.

Let's take a broader look at the relationship between gas-fired generation and natural gas markets. On the one hand, the large quantity of gas-fired generation addition has fundamentally changed the demand pattern for natural gas. For decades, most natural gas was used for industrial production. Many petrochemical and plastics companies designed plants to run on cheap natural gas which was used both as a raw material and as a fuel source. But higher prices in the last several years have cut industrial demand quite severely.

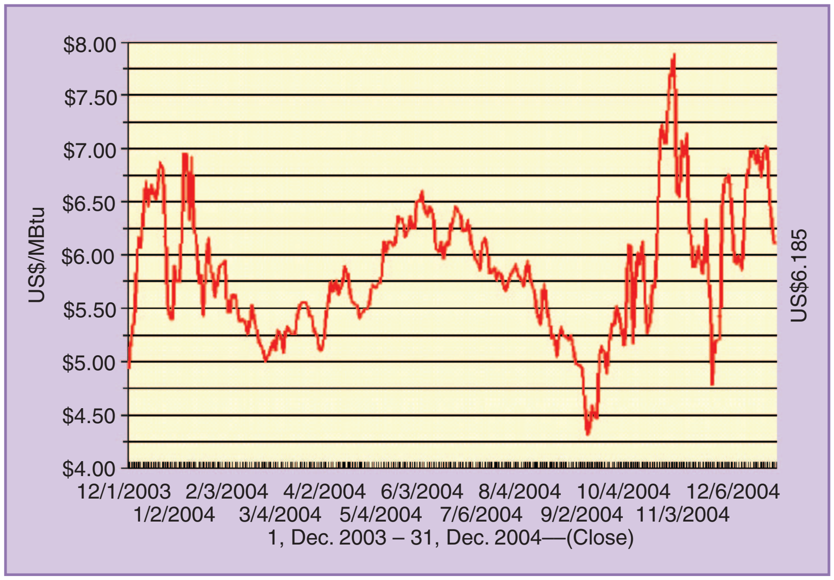
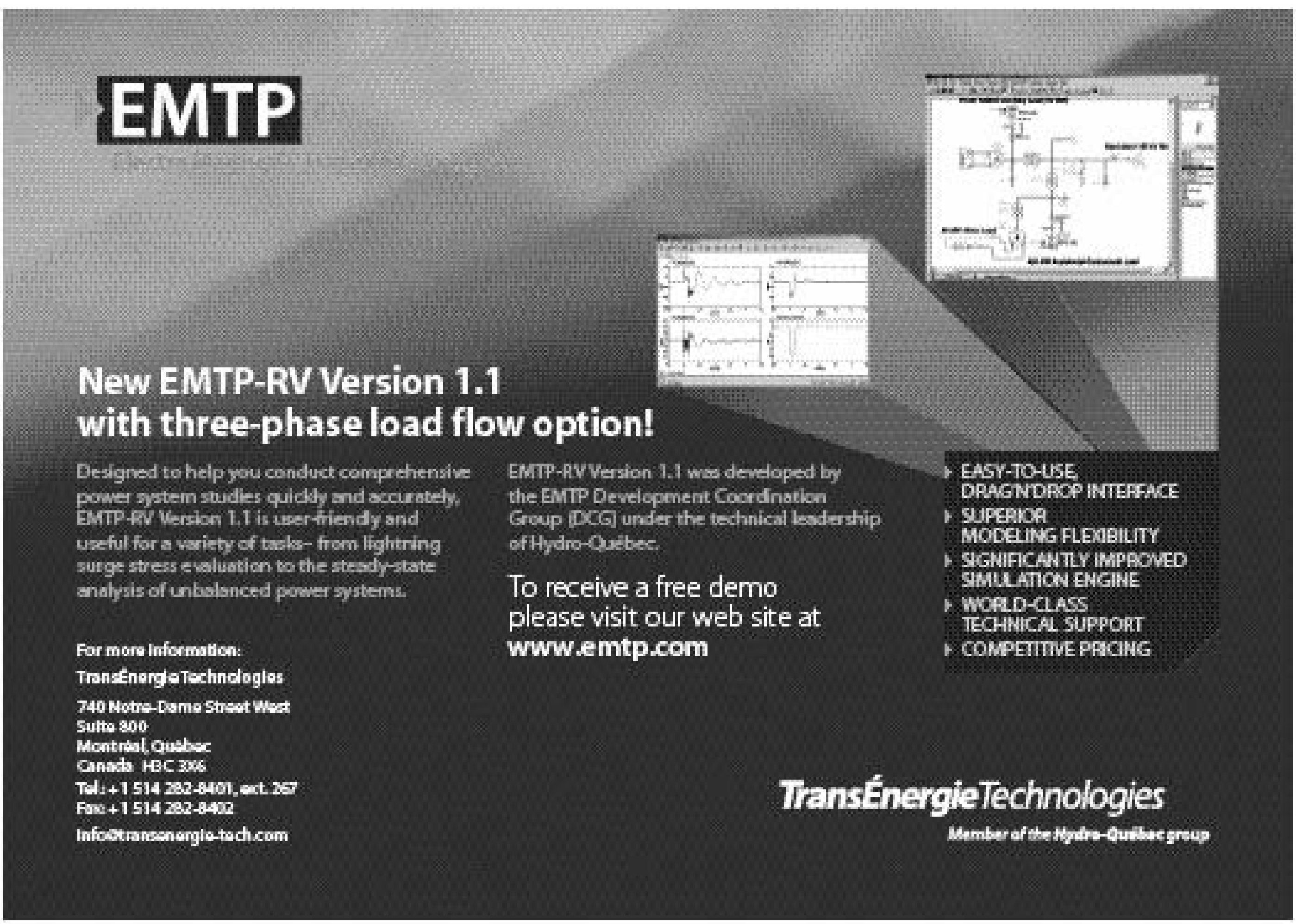


figure 1. Natural gas spot price at Henry Hub (courtesy of www.wtrg.com).



According to the Energy Information Administration (EIA), demand in the industrial sector has declined over 10% in the last few years. The phenomenon in which demand declines because of high price is called *demand destruction*. Essentially, if prices go high enough, a significant portion of the industrial usage (the most price-sensitive class) will be driven out of the market. The smelter industry in the Pacific Northwest, for example, almost shut down completely long ago and is unlikely ever to start back up. At least a dozen fertilizer plants have declared bankruptcy. Ethylene production has been cut back significantly. Some other chemical operations have been shifted overseas.

The situation with the electricity industry is quite another story. In the 1980s the U.S. power grid's generation capacity was 30% greater than needed. This margin dropped in half as the demand for electricity in the U.S. increased about 2% annually on average. Much of the increase in demand was met with existing coal or nuclear power plants. However, no major nuclear units have been built in the past 20 to 30 years, and coal units have become more and more unpopular as environmental constraints get stricter. The restructuring of the electricity industry has given the development of gas-fired units historic opportunities.

Natural gas-fueled power plants are much cleaner burning, and the capital expenditures for such plants are lower than for coal or nuclear-fired plants. As a result of the clean burning nature of the fuel, 98% of the electric power plants that have been built in the last five years in this country are fueled by natural gas. As a result, electric power companies' usage of natural gas jumped by an incredible 25% in the same period. Currently, power generation accounts for 23% of total gas demand. More importantly, 95% of announced power capacity additions are gas-fired, accounting for about 80% of the cumulative growth in gas demand through 2010. According to EIA's projection, the demand for natural gas in the electric generation sector will grow at an annual rate of 4.5%, and by 2020 the demand will rise to 10.3 trillion ft^3 (10.3 TCF) per year, accounting for 30% of the natural gas used annually in this country. If EIA's projections for gas-fired electricity are realized, this sector will likely have a significant effect on future natural gas prices.

Natural gas demand for electric generation may now be more elastic than before, but according to industry experts, it is becoming more inelastic. Previously, many generation facilities could use either natural gas or an alternate fuel, such as oil, depending on which energy source was less expensive. However, natural gas prices were low throughout the 1990s, so many electric generation facilities decided to use natural gas as their only source of energy, thus increasing their dependency on natural gas.

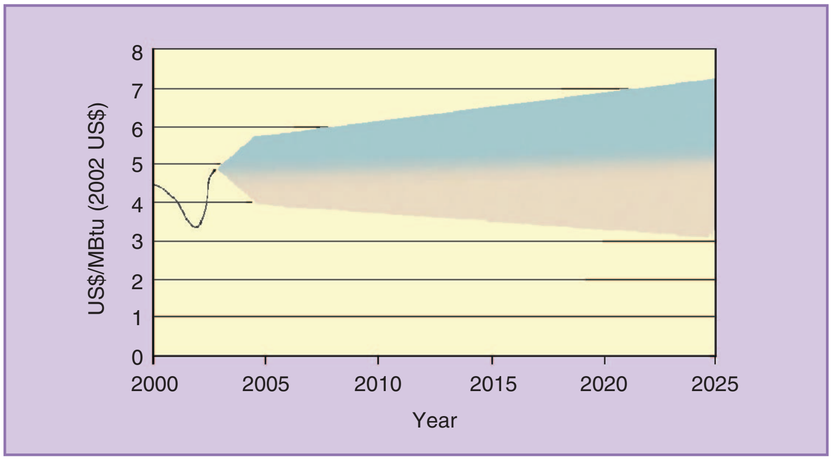


figure 2. Annual average Henry Hub prices (courtesy of National Petroleum Council).

In addition, the volatile gas demand pattern of power generation throughout seasons, days, and even hours makes it difficult for generators to commit to long-term, large-volume contracts. So, in addition to higher peak demand, gas demand could continue to experience higher volatility. The real effect will be seen when all the new gas units kick in for intermediate and peaking applications.

On the other hand, the emergence of large quantities of gas-fired units increases the dependence of electricity markets on gas markets, and high natural gas prices have a negative impact on gas-fired generation. Specifically, the profitability of gas-fired units has been dramatically discounted. In the simplest fashion, the profitability of a gas-fired unit is measured by spark spread, which is the electricity price minus the product of gas price and heat rate. Apparently, a higher natural gas price means smaller spark spread and less profitability.

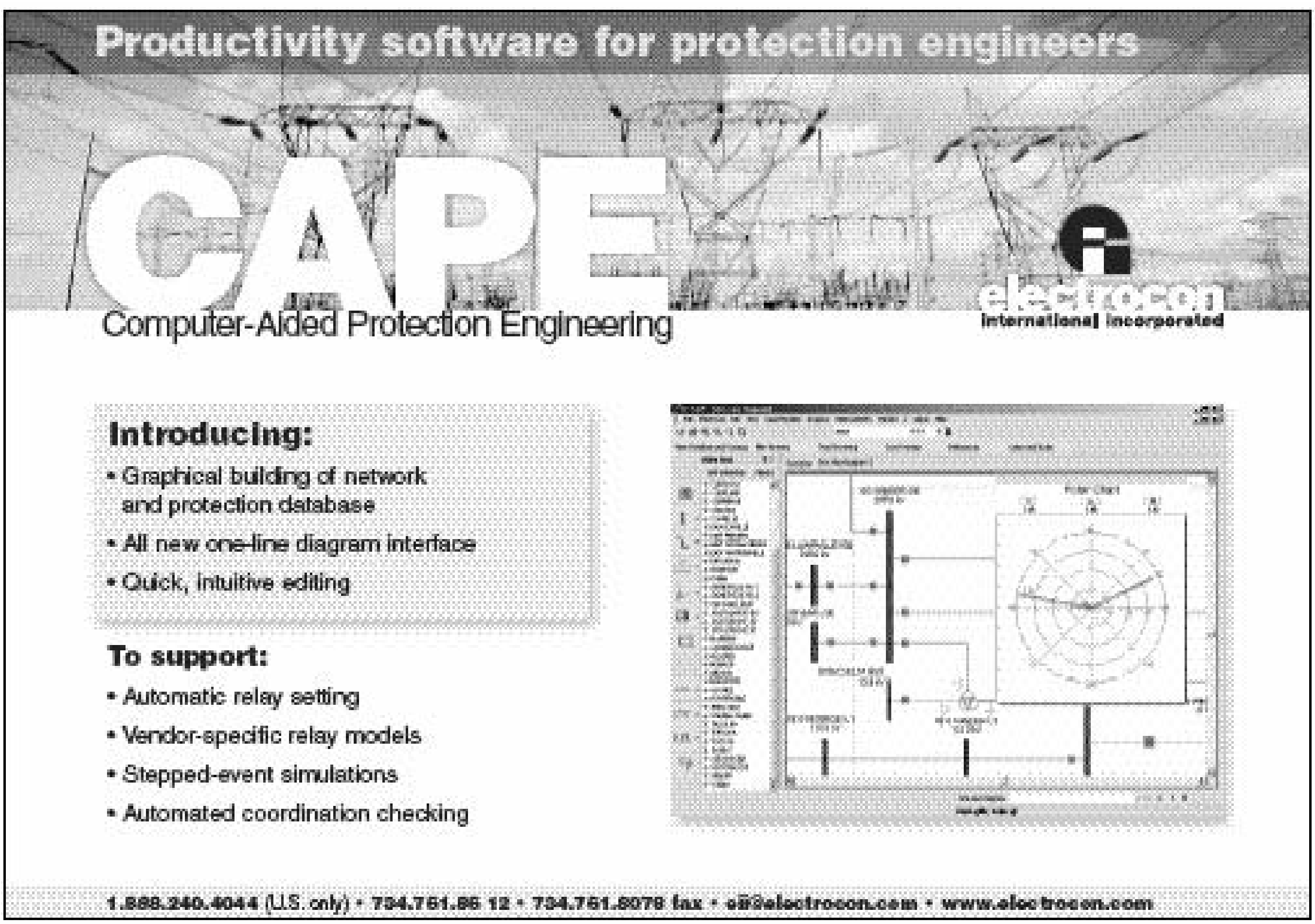
For example, on 29 November 2000, electricity prices at ERCOT (the Electric Reliability Council of Texas) were averaged at US$54.58/MWh, and gas prices at the Houston Ship Channel were averaged at US$5.83/MBtu. For a gas turbine with a heat rate of 7 MBtu/MWh, the spark spread is US$13.77/MWh $[(54.58 - 7) * 5.83]$. The spark spread was positive which meant that it was more profitable to buy gas for generating electricity and selling electricity off to the market. At a heat rate of 8 MBtu/MWh, it would still be profitable, though the spark spread would drop to US$7.94/MWh. However, the spark spreads would be –US$3.72/MWh and –US$15.38/ MWh at heat rates of 10 MBtu/MWh and 12 MBtu/MWh, respectively. Negative spark spread means that it would be more economical to purchase electricity from the market than to generate it locally. In a more general case, the profitability of a gas-fired unit is measured by generalized spark spread, which is based on a price-based unit commitment and considers such technical constraints as minimum on/off time and ramping.

Lower profitability due to high gas prices may force some gas-fired units to burn other fuels, such as fuel oil, which is an example of fuel switching. Some old thermal plants can burn gas or residual oil with similar efficiency. These plants have been a "sponge" market for natural gas for the past 25 to 30 years. Whenever gas prices dropped to the price for #6 oil, these plants would switch to gas.

As previously discussed, on the demand side, legislation, regulation, and efficiency drivers made gas the fuel of choice (as evidenced by the explosive growth of gas-fired generation). Currently, the basic trend is that demand growth outstrips supply growth because on the supply side production flattened as producing areas matured and access was limited (e.g., parts of the Rocky Mountains, the eastern Gulf of Mexico, and Alaska).

It is well known that natural gas has transportation limitations. That is, natural gas can be readily transported by pipeline but cannot be transported either in large quantities or economically by ship. So, the United States has historically depended on North American natural gas. Mexico has long since reduced exports to zero and is now a small importer. Canada supplied about 16% of U.S. consumption in 2002 but has had very disappointing exploration results in recent years, and exports to the United States declined 8% averaged across 2003. In spite of major increases in drilling, in 2003 the EIA revised its U.S. production projections from steady growth to essentially flat through 2020, and even that seems very doubtful in the light of recent trends. To keep gas supply and gas demand in balance, changes on either side will be inevitable. On the supply side, new domestic exploration will be revived on which an environmental price tag will be placed; another option is the import of LNG, which will inevitably increase dependence on foreign sources. On the demand side, certain levels of demand destruction will happen, which will adversely affect the standard of living. Demand-side management, such as conservation, can alleviate the problem to some extent. Other technological developments will emerge to reduce demand on natural gas. Renewables are on the front list; the revival of nuclear usage will also be helpful.

The bottom line is that natural gas cannot be a long-term fuel choice for generating electricity. We learned in the 1970s that natural gas was not well used in large stationary sources (e.g., power plants). At a minimum, we should not be using gas for large-scale, centralized, base-load power generation, because it is simply a waste of a precious resources when other sources like coal or nuclear are well suited to the task. Continuing to use gas for peaking power makes sense, because this is a task that only gas (or oil) does



well, due to practical as well as economic issues. Also, using gas for "more intelligent" applications like distributed generation or cogeneration should continue (indeed, be encouraged) because, once again, these are applications that only gas does well. These applications also have additional benefits, like relief of the grid and enhanced overall efficiency (due to the use of waste heat).

Instead, fuel diversification should be the correct direction for electricity and a long-term solution for the nation's energy need for a sustainable economy. In the near term, the import of LNG and coal gasification are among the options. LNG will be an important source of supply to meet US needs. The LNG industry is technologically mature, primarily serving Asian and Southern European markets. LNG can help the United States overcome the current shortage of natural gas and moderate high gas prices. However, not many efforts should be placed on the import of LNG because of its inherent dependence on foreign resources. Most optimists and many analysts believe that LNG imports will solve all of our gas problems. That is basically not true. Other countries such as Japan and Korea are competing with the United States for LNG imports. There is little hope the United States is able to import "cheap" LNG both in the short and long run, shipping capacity being one of the many limitations.

Another option, as an alternative to conventional coal, is integrated gasification combined-cycle (IGCC) coal (i.e., a gas turbine plant run on gasified coal). IGCC coal is somewhat more expensive (about 1 cent/kWh) than conventional coal, but their environmental impacts are a tiny fraction of those from conventional coal plants. IGCC's low emissions, high efficiency, and CO_2 capture capabilities will make it the key enabling technology for future coal-based power. Its ability to coproduce hydrogen adds potential for clean transportation fuel and a significant reduction of greenhouse gas emissions. Therefore, coal, while unpopular, is a reliable and stable source of generation, and IGCC offers many future benefits to make coal more productive in the future.

In the long term, nuclear units and renewables will play a vital role. Nuclear units generate cheap and clean energy with little emission. Currently, however, there are very long permitting and construction times for nuclear. The biggest obstacle for the development of nuclear units is its public image. Nuclear power is very unpopular because of nuclear waste disposal and reactor safety. Images of disaster at Chernobyl and the accident at Three Mile Island are still fresh in the public's mind and antinuclear activists will exploit those images for maximum effect. So, nuclear is going to be a tough sell unless the public is convinced that it's safe enough.

An extensive public education campaign is the key to the image issue. The public should be told that the only real issue is the overall risk per unit energy generated for various energy options. Some sources inflict risk under normal operation (e.g., coal), some inflict risk with a steady stream of smaller accidents (e.g., gas fires, explosions, and pipeline ruptures), and some (such as nuclear) have a risk of large-scale but low probability events. Nuclear's overall risks are much smaller than those of fossil fuels and even smaller than some renewables (only wind is lower), according to a study for the European Commission's ExternE project. So, the problem is not with nuclear itself; it's mostly a perception issue. Once the public image issue of nuclear units is resolved, the business climate will reinforce the value of nuclear plants because of its reliable, low-cost supply of electricity; secure, stable cash flows; hedge against fossil fuel price/supply

volatility; and safeguard against escalating environmental requirements.

Renewables include hydro, wind, solar, biofuels, geothermal, and tidal energy. Most renewables are abundant, but only wind is currently economical and easy to harness. Although renewables (especially wind) are ready to make a significant contribution, they are limited by their intermittent and diffuse nature and are also not able to provide all (or even most) future power.

Part of the solutions to renewables' supply intermittence problem is storage. For example, the low capacity factor on wind generation could be improved, storing energy when the wind blows at the wrong time or blows too much (excess energy) when other base-load plants meet the demand efficiently. Direct storage as electricity includes battery storage or superconducting magnetic energy storage (SMES), which are still expensive and need technological breakthrough. Indirect storage as other energy forms includes hydraulically pumped storage in reservoirs or compressed air storage in underground caverns.

On a final note, as a nation we cannot stake the nation's electrical energy future on a single fuel (i.e., natural gas) for which supply is inadequate to meet projected requirements; we cannot expect to support any significant economic growth as long as nearly all of our incremental electricity supply is expected to come from a single source (i.e., natural gas-fired generation). Fuel diversification and devotion to new technologies should be a common understanding among industry, government, academics, and the general public.

For Further Reading

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Biography

Zuyi Li received his B.S. in electrical engineering from Shanghai Jiaotong University, China, in 1995, an M.S. in electrical engineering from Tsinghua University, China, in 1998, and his Ph.D. in electrical engineering from Illinois Institute of Technology (IIT) in 2002. Presently, he is an assistant professor in the ECE Department of IIT. He is the coauthor of the book *Market Operations in Electric Power Systems*.