Changing Prospects for Natural Gas in the United States

W. M. Burnett and S. D. Ban

Natural gas has emerged as one of the primary options for satisfying the need for environmentally clean energy: the resource base is large, it is the cleanest burning of the fossil fuels, and it can be used efficiently. New engine, combustion, and energy conversion technologies are emerging that will result in use of natural gas in electric generation, emissions reduction, transportation, and residential and commercial cooling.

In the middle to late 1970s, most energy analysts subscribed to the theory that natural gas, along with petroleum, was a depleting resource (*1*). Prospects for its future use at the prevailing usage rate seemed dim. Today, just 10 years later, many analysts are now extolling natural gas as the fuel of the future, a solution to both energy and environmental problems (*2*). What are the causes of such a dramatic change in the prospects for natural gas? Three major developments have been responsible for this change in attitude: (i) knowledge of the size of the domestic (and world) natural gas resource base and the technologies for natural gas exploration and production have been improved; (ii) local and global environmental concerns have emerged as a driving force for future energy decisions; and (iii) new technologies have been developed for the efficient use of natural gas in both historical and new applications.

Historical Perspective

As a fuel source, natural gas has stood in the shadow of petroleum for most of its history. Petroleum's role as a dominant fuel source is well deserved (*3*). Its steady displacement of coal was the result of resource availability, low production costs, ease of transportation and storage, and simplicity of use. Its growth as a fuel also coincided with the evolution of automotive and air transportation as major energy demand sectors. Natural gas was a by-product of oil exploration and production, rather than a primary goal. However, in the United States, once long-distance gas pipeline technology had been developed, natural gas was able to enter the residential and commercial space conditioning markets successfully as a premium fuel and the industrial market as a low-value boiler fuel sold on an interruptible basis.

In the 1970s, conditions changed dramatically, but not necessarily to the advantage of natural gas. In the decades of rapid global economic expansion after World War II, petroleum's success as a preferred fuel in many applications and the low prices set by world trade favored the lowest cost oil resources, which are geographically concentrated in the Middle East. The opportunity for monopolistic pricing soon overcame the economics of production in determining oil prices. National energy policies emerged that were dominated by fear of the economic and geopolitical consequences of dependence on other nations for energy. Energy security became a political goal in the 1970s—to be achieved either by self-sufficiency or substantially reduced dependency (as in the United States), or by diversification of supply (as in Japan).

The United States adopted three paths to reduced dependency: (i) increased electrification based on the use of abundant domestic nuclear and coal resources, (ii) use of synthetic liquids to replace petroleum, and (iii) increased conservation of oil and natural gas, which were seen as depleting domestic resources. Regulation of natural gas prices at relatively low prices since 1954 had discouraged oil and gas producers from exploring for natural gas, and reserves appeared to be rapidly depleting. Because of this negative perception of natural gas supply and increasing prices, natural gas markets eroded in the 1970s, a process that was given further impetus by moratoriums in many states on new gas connections (*4*). Natural gas consumption fell by approximately 10% from 1972 to 1979, while national energy use increased by 10% (*5*, p. 126). By 1987, the effects of conservation led to a further reduction of about 15% in the use of natural gas, while national energy use declined only 3.5%. The decline was even more pronounced in the choice of gas-fueled equipment in new markets. For example, the share of gas equipment in new, single-family homes fell from 60% in 1971 to 36% in 1978. This market was lost to electric heating equipment, despite its higher operating costs.

Despite these circumstances, key actions were taken in the 1970s that would ultimately lead to today's improved prospects. The gas industry itself acted to expand its knowledge of the resource base and formed the Gas Research Institute (GRI) to build a technology base for the future. And, in 1978, the Carter Administration and Congress formulated the Natural Gas Policy Act (NGPA), which established incentive prices for the pursuit of new natural gas resources.

Changing the View of the Natural Gas Resource Base

The first key to the current changed view of the role of natural gas was a major worldwide change in the perception of the size of the natural gas resource base. This change was the result of an increased understanding of the geology of natural gas as independent from petroleum, and the extent of the response of the gas industry to the

W. M. Burnett is Senior Vice President, Research and Development Management, and S. D. Ban is President and Chief Executive Officer, Gas Research Institute, 8600 West Bryn Mawr Avenue, Chicago, IL 60631.

NGPA. By 1980, the potential for significant deep gas resources had been identified (*6*, p. 35; 7), and the potential for unconventional natural gas resources was analyzed by both GRI and the National Petroleum Council (*8*). Initial pursuit of these resources verified their existence, but at recovery prices above the level that the market would bear. Early production, under the incentive pricing structure of the NGPA, drove the price of natural gas above that of competing fuels and led to market and price instability.

The missing ingredient was technology. A research effort was undertaken to develop the technology needed to reduce the cost of recovering natural gas from low-permeability formations—by GRI, the Department of Energy (DOE), and the major oil companies for tight sand formations, by GRI for coal seams, and by GRI and DOE for Devonian shales (*9*). Improvements in fracturing techniques and well placement, which enabled producers to take advantage of natural fractures to increase productivity and lower production costs, were researched and developed. New technologies, based on both improved geologic models and advanced wellbore instrumentation, have emerged to improve our knowledge of gas-bearing formations. A notable scientific advance has been the development of real-time seismic profiling (*10*, *11*), which relies on the transmission of seismic energy from the drill bit in the well to geophones on the surface. Advanced seismic analysis of the area around the wellbore during drilling can lower costs. Other technology developments have resulted in instruments for determining the length and orientation of underground fractures (*12*). These data are being used to produce three-dimensional models of the growth of fractures induced by hydraulic pressure. Ongoing research has the goal of developing methods for the control of fracture growth in real time to optimize the hydraulic fracture operation. Research in recovery of coal seam gas has the additional goal of developing a method of fracturing multiple thin seams of coal simultaneously. Work at a field-based laboratory in the Black Warrior Basin of Alabama has verified that such controlled fracturing is feasible (*13*).

The U.S. Department of Energy (*14*), in consideration of results of improved resource analysis and new technology, has recently assessed the quantities of technically recoverable gas from both conventional and unconventional resources. The study concluded that the domestic gas resource base is much greater than was previously believed. With current technology, 180 trillion cubic feet (Tcf) [5000 billion cubic meters (Bcm)] of gas can be recovered from low-permeability reservoirs, 48 Tcf (1340 Bcm) from coal seams, and 31 Tcf (870 Bcm) from shales. Gas producers are increasing their efforts to recover these resources. Coal seam gas, disregarded only a few years ago (*15*), is perhaps the best example. Gas production from coal seams in the Black Warrior Basin in Alabama has increased from less than 2 billion cubic feet (Bcf) (0.06 Bcm) per year in 1982 to approximately 17 Bcf (0.48 Bcm) in 1987 (*16*). In the San Juan Basin in the western United States, several hundred wells have been drilled since 1984, and some workers estimate that over 1000 wells will be drilled there by year-end 1990 (*17*).

As a result of the reassessment of the resource base, supplies of natural gas are now believed to be more than adequate to support its use in new applications. The DOE assessment (*14*) concluded that the technically recoverable resource base of natural gas in the lower 48 States is 1,059 Tcf (29,650 Bcm). This amount represents a greater than 50-year supply at the current usage rate. The improved prospects are also reflected in the actual production of natural gas compared to oil. In 1988, natural gas production may, for the first time ever, exceed oil production in the United States on an energy equivalent basis (*18*). Domestic exploration and drilling specifically for natural gas (as contrasted to finding it as a result of drilling for oil) is now occurring. The worldwide situation is even more promising. The International Gas Union Committee on World Gas Supply and Demand estimates that even by the year 2000, the static lifetime of world gas reserves will be 112 years (*19*).

Natural Gas and Environmental Issues

Among the wide range of environmental concerns related to the production of energy, the impact on the atmosphere is currently perceived as the most important. The growing concern over the effects of acid rain, high levels of tropospheric ozone, and the greenhouse effect may provide significant impetus to greater use of natural gas.

The environmental benefits of natural gas use are generally acknowledged. Natural gas contains virtually no sulfur or sulfur compounds, which are major contributors to acid rain and decreased visibility. In 1980, coal and oil (including gasoline) accounted for approximately 99% of fossil fuel emissions of sulfur dioxide (SO_2) and 84% of nitrogen oxides (NO_x), the other major contributor to acid rain (*20*). By comparison, in the same year natural gas accounted for only 13% of the total NO_x emissions and virtually none of the SO_2 emissions while supplying 27% of the fossil-fuel energy consumed (*20*).

Natural gas is the least carbon-intensive of the fossil fuels, and therefore contributes the least amount of carbon dioxide (CO_2) per unit of energy. There is debate over just which gases are responsible for the greenhouse effect, but it is generally held that CO_2, if not the chief cause, is at least a principal contributor (*21*). The CO_2 in our atmosphere has increased from 290 ppm to 345 ppm, or 19% in the last 100 years, accompanied by what may be a related increase in the average temperature at the earth's surface of 0.5°C. Half of the CO_2 accumulation has occurred in the last 28 years, corresponding to the large increase in CO_2 released by the combustion of fossil fuels, particularly since 1945. Several studies have demonstrated that the combustion of fossil fuels correlates with the accumulation of atmospheric CO_2 (*21*). There is considerable uncertainty, however, regarding the correlation between the increase in atmospheric CO_2 and a global temperature increase.

For the same thermal energy delivered, gasoline and coal produce 40 and 85% more CO_2 respectively, than does natural gas (*22*). As a result of both the carbon content in fuel and efficiency losses in electric generation, CO_2 output in electricity generation from coal is nearly five times the output from natural gas for an equal amount of energy delivered to a residence (*23*). Although methane, the principal constituent of natural gas, is itself a greenhouse gas, its presence in the atmosphere is generally attributed to natural causes rather than to natural gas production and distribution (*24*).

A major atmospheric problem in the troposphere is the presence of ozone. Ozone has adverse health effects and many of the major metropolitan areas in the United States are in nonattainment of existing Environmental Protection Agency (EPA) standards. Reactive hydrocarbons, which result primarily from vapors of gasoline or from unburnt hydrocarbons because of incomplete combustion in liquid-fueled engines (automobiles, buses, and trucks), are a major ingredient in the formation of ozone in the lower atmosphere. Methane is a nonreactive hydrocarbon. Combustion of natural gas, even when incomplete, will not produce such amounts of reactive hydrocarbons.

Finally, natural gas contains no constituents that generate particulate matter. Both coal and oil, especially oil-fueled diesel engines, generate particulate matter upon combustion.

Direct substitution of natural gas for other fuel sources in residential, commercial, and industrial markets will have immediate environmental benefits. The market sectors that produce the most significant amounts of pollutants, however, are electric generation and transportation. In 1987, the EPA promulgated vehicle emissions standards (*25*), applicable to new urban transit buses in 1991 and other heavy duty diesel vehicles in 1994, that cannot be met by current heavy duty diesel technology. In addition, the EPA is considering sanctions against cities that have not complied with the National Ambient Air Quality Standards; it is widely recognized that vehicle emissions are major contributors to nonattainment (*26*).

Increased Efficiency of Gas-Using Technologies

The third factor causing a changed view of the future for natural gas is the rapid adoption of gas-using equipment with markedly higher efficiencies. The natural gas industry has historically encouraged conservation of the gas resource base through efficient utilization (*6*, p. 124). As part of this effort, GRI has been actively involved in the development of new highly efficient technologies for all of the energy demand sectors. As a result, some 24 new products or processes that use natural gas more effectively have been introduced to the marketplace since 1980 (*12*).

Energy efficiency efforts have had significant impacts on the residential energy use sector. The Pulse furnace, marketed in 1982, was the first condensing furnace to be introduced with an efficiency greater than 90% (*27*), and a number of competitors quickly followed (*4*). The Gas Appliance Manufacturers Association (*28*) has estimated that 30% of the furnaces sold in 1987 were high-efficiency models (annual fuel use efficiency above 80%); as compared to only 15% in 1983. The overall effect of more efficient equipment, improved building insulation, and sealing to reduce air infiltration has been a reduction in the average gas use for a residential customer of 29% since the early 1970s and 18% since 1982 (*5*, p. 128).

These improvements, as well as the improved perception of gas supply, have led to a reversal in the trend in the choice of gas heating equipment in new, single-family homes. The share of gas has steadily increased since 1982 to 52% in 1987, the highest level since 1972 (*5*, p. 137).

Major improvements in efficiency have also occurred in the industrial sector. In particular, heat recovery, combustion control, and new burner systems have had large impacts (*12*). Three new burner systems have been developed and are in use in a variety of applications—oxygen-enriched burners (*29*, *30*), the TwinBed (*31*) regenerative burner, and the Pyrocore fiber-matrix radiant burner (*32*, *33*).

New Opportunities for Natural Gas

The combined effects of an extensive resource base, environmental advantages, and the development of new products and processes that offer significantly higher efficiencies are the driving forces for a changed view of the opportunity for natural gas. The most important of these opportunities are in three energy demand sectors: electric generation, transportation, and residential and commercial cooling.

Gas-fueled prime movers, or other advanced conversion systems such as fuel cells, will greatly enhance the market opportunities for natural gas. Natural gas–fueled reciprocating engines are currently being used as prime movers in commercial and industrial applications in size ranges of 50 to 1000 hp. Because of the ready access to the fuel, these engines have been used for decades in the gas and oil industry to provide air compression, power generation, drill rig operation, and fluid pumping (*34*). Diesel engine technology is ideally suited for the use of natural gas in a broad range of applications; however, continued research will be necessary to overcome the two primary shortcomings of burning natural gas in reciprocating engines: (i) production of excessive NO_x when gas is burned with optimum ignition timing (*35*), and (ii) the susceptibility of gas to premature detonation under the high compression ratios common to contemporary diesel engines. Design modifications and retrofit kits allow successful reduction of compression ratios from the normal 18:1 to about 10:1 to 12:1, however shaft efficiency is also reduced from about 37 to 30%. Lean-fast-burn combustion technology, a refinement in the precombustion concept used in diesel engines, is being explored to overcome these problems. The combustion chamber geometry of these engines is redesigned to create multi-zone combustion and mixture turbulence and to control propagation of the flame front.

A spark-ignited automotive-marine engine has been successfully modified to operate on natural gas fuel, and shaft efficiency improved from 30 to 32%. With improved control of the lubricating oil in the engine, its service interval has been raised from 750 to 2000 hours, and recent laboratory results have shown that a further doubling of oil life to 4000 hours is possible. Improvements in valve train materials promise increases in the time between valve overhauls to as much as 24,000 hours (*34*).

Opportunities in the electric generation sector. The application of gas-fired combined-cycle systems for electric power generation represents a significant opportunity for natural gas to provide a positive environmental impact (*36*). A combined-cycle system consists of a natural gas–fueled combustion turbine combined with a heat recovery steam generator and a steam turbine. The improved efficiency of this system (about 8%), coupled with the advantage that the primary combustion of gas produces 46% less CO_2 per unit of heat than coal, means that combined-cycle systems produce less than half the CO_2 per kilowatt-hour of state-of-the-art coal-fired generating systems. And, natural gas–fired combined-cycle systems produce virtually no SO_2, volatile organic compounds, or particulates. They create 40% less NO_x than coal and require essentially no stack gas clean-up (*39*).

Combined-cycle systems currently yield overall efficiencies of up to 43%, as contrasted with simple-cycle gas turbines (used for peaking) that have efficiencies of around 30% (*37*, *38*). Improved gas turbines promise efficiencies approaching 50% (*39*). Combined-cycle systems have demonstrated high availability (*40*) and reliability (*39*), even though gas turbine systems experienced reliability problems when new models were first introduced.

Combined-cycle systems also offer flexibility in utility planning and financing. Because they are designed as pre-engineered modules, they can be in service in 3 years or less (*39*). Phased installation permits initial generation from the gas turbine part of a facility in as little as 12 to 18 months. Finally, the capital cost of a combined-cycle system is less than half that of a conventional coal-fired system (*38*, *39*) and life cycle cost advantages have been calculated (*39*) for at least five geographic regions.

Steam-injected gas turbines represent a variation on the combined-cycle system in that the steam is injected into the combustion chamber of the gas turbine, and thereby the steam turbine is eliminated. A recent study (*41*) showed that steam injection was economically preferable to combined-cycle systems for installations of 50 MW or less. Steam injection has three demonstrated performance advantages: (i) NO_x is reduced (*42*, *43*), (ii) gas turbine efficiency is increased 3 to 10% (*38*), and (iii) power output of the gas turbine is increased 40 to 70% (*38*). Premixture of steam, air, and fuel, as well as staged introduction of cooling air, offer still further opportunities for reduction of NO_x, as well as carbon monoxide.

Another opportunity for gas-fueled electric power generation is through industrially or commercially owned cogeneration facilities (*44*). Cogeneration is the generation of electrical or mechanical power at the site where both power and heat are needed. Recovery and utilization of the otherwise rejected heat produces increases in overall fuel use efficiency to as much as 60 to 80%. The most common application is the generation of electrical power with the utilization of the discharge heat recovered from the exhaust for water or space heating, or both. Applications to date are all based on reciprocating engine and gas turbine prime movers. However, fuel cell cogeneration systems have recently been introduced to the market and offer some important performance and environmental advantages (*45*).

Combining cogeneration and steam injection installations (Fig. 1) provides an important option: the ability to vary electrical versus thermal output to follow more closely load requirements. The output from the boiler can provide steam either for direct use in the facility or for reinjection into the turbine to increase electrical output.

Emission reduction in coal-fueled utilities. With the use of techniques known as cofiring and reburn, natural gas can contribute substantially to the control of both emissions and cost at existing coal-based, electric utility plants. Gas-coal cofiring involves the introduction and combustion of small amounts (1 to 10%) of natural gas into the primary furnace combustion zone of a pulverized coal boiler. Cofiring is a particularly useful method of reducing NO_x, SO_2, opacity, and particulate emissions from coal boilers that are in marginal compliance with emission regulations because of varying coal supplies and aging equipment. Cofiring also ameliorates operational problems such as slagging, fouling, and excessive fly ash carbon content, and it assists in start-up, efficiency improvement, and capacity variation (*46*).

In gas reburn technology (*47*), 80 to 90% of the boiler heat capacity is fired by coal in the primary furnace combustion zone. The remaining fraction of capacity is fired by natural gas injected higher in the furnace such that it creates a fuel-rich, sub-stoichiometric reburning region that converts 50 to 60% of the NO_x to molecular nitrogen. Air is added above the reburn zone to complete combustion at a lower temperature (1200°C) than in the primary furnace combustion zone, thereby minimizing NO_x formation in the secondary combustion zone. Particulate emissions and SO_2 are reduced in proportion to the fraction of natural gas used. Gas reburn technology can be easily retrofited to essentially all boiler designs at a first cost of 1 to 2% of the total cost of a new generating system. Although this technology has been proposed primarily for coal-fired boilers, recent research indicates that it can be used in waste-fired boilers to help stabilize operations and destroy other harmful pollutants in the exhaust gas stream, as well as reduce NO_x emissions.

Reburn can also be combined with solid sorbent injection technology whereby a dry sorbent, such as calcium carbonate (limestone) or calcium hydroxide hydrate (slaked lime), is injected with the reburn gas and air. The sorbent is calcined in the reburn zone, and SO_2 is captured by reaction with the sorbent (Fig. 2). Systems are undergoing experimentation that have estimated costs of 5 to 8% of the total cost of a new generating system and can remove upwards of 60% of both NO_x and SO_2 emissions (*47*).

Opportunities in vehicular transportation. In 1987 the transportation sector accounted for 27% of total U.S. energy consumption, over 60% of our demand for oil (*48*), and significant portions of NO_x, hydrocarbon, particulate, and CO_2 emissions. Competitive natural gas–fueled prime movers for vehicular application are under development. Fuel logistics are less certain because of the low energy density of natural gas. Furthermore, the nation has a well-developed infrastructure for the handling and distribution of liquid fuels for transportation. However, large fleets of transit and delivery vehicles that operate on regular routes and schedules and travel high mileage are well suited to the centralized refueling facilities currently required for compressed natural gas (*26*), and these vehicles are the likely early market entry for this technology. With current crude oil and gasoline tax levels, it is unlikely that the lower energy price of natural gas would be sufficient to attract the general public to invest in the added equipment, such as high-pressure tanks, needed to store natural gas on board automobiles with general purpose, moderate-mileage capacity. However, environmental regulations will drive alternate-fueled vehicles into the market regardless of market economics.

Compressed natural gas fuel management technology is essentially in place to permit market entry. Recent testing has demonstrated that on-board storage at 160 to 200 atm in steel and aluminum pressure vessels is feasible (*26*). Increased space and weight require-

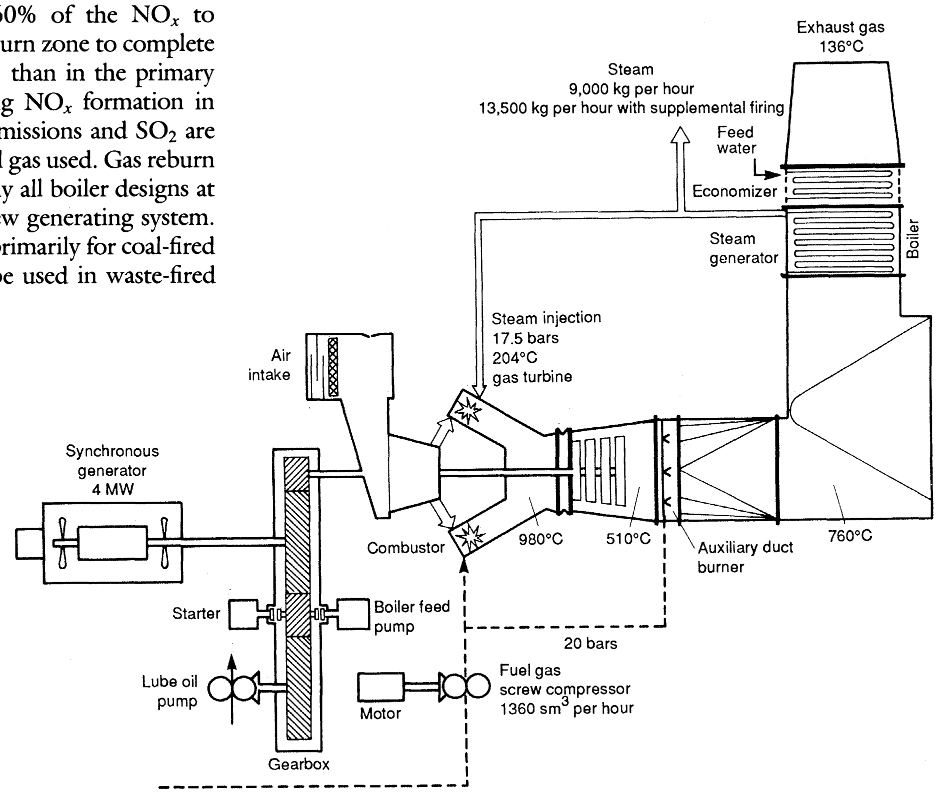

Fig. 1. Steam injection cogeneration system.

ments are not proving to be prohibitive. Check valves, pressure regulators, and the inherent strength of the high-pressure vessels render the systems at least as resistant to catastrophe in an accident as their liquid-fuel counterparts. The low energy density and rapid dispersal of a buoyant gaseous fuel offer safety advantages. Because the primary supply lines to centralized fleet fueling stations are in place, and a straightforward compression technology is available, natural gas–fueled vehicle technology presents a viable solution to meeting the environmental standards for urban mass transit buses and commercial-route, fleet, and delivery trucks. Other nations with abundant natural gas reserves, such as New Zealand, Canada, and the Soviet Union, are reportedly making efforts to expand the use of natural gas as vehicular fuel.

Opportunities in residential and commercial cooling. The most common method of cooling is the electric motor-driven vapor compression cycle. One system for cooling with natural gas is a standard compressor driven with a natural gas–powered prime mover. A 150-ton vapor-compression chiller that is driven by an automobile-derivative engine fueled with natural gas is on the market for commercial space cooling, and systems with capacities of from 15 to 500 tons are under development (*49*).

The absorption process is a variant of the vapor-compression cycle in which the refrigerant is absorbed by a liquid, is compressed in an absorbed state, and then is desorbed and condensed (*50*). Multiple stages of desorption can be used to release additional refrigerant, making more efficient use of the available heat. These systems are referred to as double-effect, dual-cycle, or triple-effect absorption systems.

The advantage of the absorption process over the conventional vapor compression cycle is that, rather than being driven by mechanical power, absorption is driven by heat, which can be provided by a variety of sources, such as the direct combustion of natural gas, or the heat recovered from the exhaust of a prime mover.

Depending on the humidity of the air being cooled, a large part of the energy consumed in conventional cooling systems may be needed to remove moisture from the air. A large part of the comfort derived from air conditioning results from the dehumidification that has taken place, in addition to the actual cooling of the air. Dehumidification in conventional systems is achieved at an energy use premium, however, because the air is first overcooled to below its dew point and then reheated to the desired temperature level.

An emerging technology is dehumidification of the air with a desiccant followed by cooling (*51*). In one approach, the air being conditioned is passed through one segment of a rotating wheel, where a solid desiccant removes the moisture from the air stream (*52*). The wheel continually rotates so that a stream of heated air can be passed through the saturated segment, extracting the moisture by evaporation. The regenerated wheel can then pick up moisture again. The hot air containing the moisture is exhausted to the outdoors. Because the heat of condensation resulting from moisture capture by the desiccant heats the wheel, cooling of the dry air is usually required even if the ambient temperature is satisfactory. Cooling is typically accomplished with a substantially smaller vapor compression cooling system: because cooling the air to below its dew point is not required, this system is more efficient than one which must accomplish both cooling and dehumidification (*52*).

Desiccant-based cooling systems are ideally suited for supermarkets, where humidity control has a higher priority than temperature. Food refrigeration represents a major portion of a supermarket's energy budget, and excess humidity condenses on the cooling coils of refrigerators and freezers, lowering efficiency and requiring more frequent and costly defrosting and restart. Effective dehumidification can reduce or eliminate many of these problems (*53*).

Electric heat pumps have been operational in commercial and residential installations for a number of years. Essentially a reversible vapor compression system, the heat pump can provide either cooling or heating. Electric heat pumps are less effective in the heating mode than in the cooling mode, and in colder climates supplementary heat is typically required and is added by electric resistance heating, generally the most expensive form of space heating.

If electric motors are replaced with natural gas–fueled engines, the exhaust heat can be used to supplement the pump's heat output in the winter season. A first generation of gas engine heat pumps has been introduced in Japan (*54*). Performance of these Japanese heat pumps does not appear to be sufficient in terms of engine efficiency and useful life to achieve market entry in the United States. Current research is concentrated on designing a durable, high-performance prime mover (*55*) that can be matched with compressors, refrigerants, and heat exchangers to produce a gas-fueled heat pump.

A New Role for Natural Gas

The above opportunities present a new and expanding role for natural gas in meeting national energy and environmental needs. However, even if all these new technologies are successfully developed, it will be many years before the energy mix is impacted in any major way. In terms of natural gas use, the impact of energy-efficient technologies already introduced and those on the drawing boards will continue to reduce demand in historic applications, offsetting much of the need for gas in new applications. In the absence of any major new environmental policies, natural gas consumption is projected (*48*) to increase from 17.6 Tcf (492.8 Bcm) in 1987 to 19.4 Tcf (543.2 Bcm) by 2010; however, implementation of

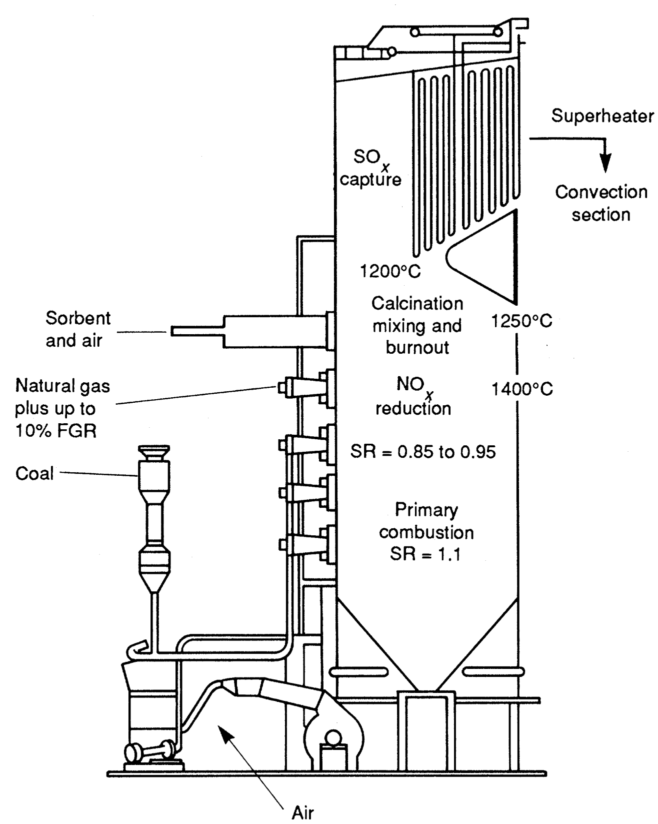

Fig. 2. Reburn-sorbent injection technology applied to a power plant boiler; SR, stoichiometric ratio; FGR, flue gas recirculation.

environmental policies, which would lead to an increase in natural gas use for incineration, transportation vehicles, and electric generation, could increase consumption in 2010 by 1.5 to 4.5 Tcf (42 to 126 Bcm). These increases are not so large as to strain the natural gas transportation and distribution system (which delivered 22.7 Tcf in 1972) and appear to be within the gas supply capability well into the next century.

Natural gas has long been relegated to a secondary role in meeting the energy needs of the United States. Historically, both political and economic forces had an impact in defining that role, but new forces—technological and environmental—are forcing a reexamination of its role and creating new opportunities for natural gas use. The gas industry has been aggressively pursuing research and development initiatives that have reshaped our view of the resource base, our means of delivery, and our consumption at the burnertip. Traditional applications, such as space heating, are being made more efficient, and new developments, such as heat pumps and fuel cells, show promise for the future. Environmental concerns have given a new urgency to examining all of our assumptions with regard to energy consumption. The least-cost equation has now been expanded to include national productivity, competitiveness, and longer term environmental impacts as well as short-term economic concerns. Natural gas as an energy alternative is ready to respond to many of these concerns and to assume a substantially increased role in fulfilling the need for economic energy with minimal environmental impact.

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