REPP **ISSUE BRIEF**
Renewable Energy Policy Project **May 1997 ● No. 8**

NATURAL GAS: BRIDGE TO A RENEWABLE ENERGY FUTURE

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Executive Summary

Today, inexpensive natural gas limits the market for renewable energy. Yet, substantial opportunities for renewable remain; the availability of gas is uneven across the world and accelerating climate change will require a conversion to carbon-free energy sources. Happily, competition between the two resources does not preclude cooperation since both technologies will benefit from similar policies and market structures. In the long term, natural gas can serve as a bridge to a renewable energy future if each community, acting in its own interest, supports the development of the other.

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A Message from the Renewable Energy Policy Project

The growing use of natural gas is among the most important recent developments in America's energy picture. In the following Issue Brief, Adam Serchuk and Bob Means address implications of this trend for renewable energy, both in the United States and globally. The paper provides a valuable resource for environmental and energy professionals seeking to understand the complex relationship between the two cleanest energy options now available.

For practical policy purposes in the near term, natural gas can be considered a "renewable" resource. Even in the United States, where the resource base is well known, new sources of gas are being discovered. Potential discoveries are even greater elsewhere. The supply of gas is finite but, for the time being, fears of depletion will not drive policy.

Increased natural gas use is both a boon and a bane to the renewables industry. On the plus side, natural gas is inherently cleaner than coal or oil, and the gas sector is a significant potential ally in the effort to achieve environmental goals. For example, both industries are well represented in the Business Council for Sustainable Energy, an important voice for action to reduce greenhouse gas emissions. Since renewables will be unable to meet most energy needs for some time, gas is an essential bridge to a renewable energy era. Opportunities for the complementary use of natural gas and renewable energy technologies are illustrated by the gas-supported solar thermal system developed in California by Luz International.

On the other hand, the low cost of natural gas is a serious obstacle to renewables. In recent years, gas has fueled most new generating plants built or planned in the United States. The prospect of improved drilling methods and continued low prices, as predicted by the Energy Information Administration, have caused a substantial reduction in the government's estimated contribution of renewable energy to U.S. energy consumption over the next decade.

However, the price of gas reflects not only supply and demand, but also discoveries and changes in technology. Price is therefore difficult to predict. The EIA has notoriously overestimated prices in past forecasts, but recently reduced its predicted price rises dramatically. Gas prices are increasingly volatile as well, fluctuating between $1.30 and $2.40 per thousand cubic feet in the 1990s. Renewable energy technologies would provide consumers a hedge against such disconcerting swings and facilitate the job of energy planners.

Unlike oil, gas is not easily or cheaply transported, and it is not uniformly available. For many countries, gas is unlikely to be a viable energy option. Moreover, transporting gas via ship or pipeline raises concerns about leakage, which would mitigate some of its environmental advantage.

Gas and renewables will not compete seriously in most markets until the price of gas goes up or the price of renewables comes down. The good news is that the alliance between the two, which have overlapping interests, can be strengthened with only modest compromise from both.

Alan Miller **April 15, 1997**

On April 14, Alan Miller, REPP's founder and first Executive Director, assumed a new position coordinating climate programs at the Global Environment Facility. We thank Alan for his creative work and thoughtful guidance, and we wish him the best of luck in his new endeavor.
Carl Weinberg, Adam Serchuk, and Susan Conbere

NATURAL GAS: BRIDGE TO A RENEWABLE ENERGY FUTURE

Adam Serchuk, Ph.D., and Robert Means, LL.B., S.J.D.[1]

Renewable energy technologies have made remarkable technical and economic progress in recent years. Despite these gains, American renewable energy firms face a serious competitive threat from natural gas. The price of gas has dropped startlingly since the mid-1980s. In most settings, no renewable energy technology can match the cost of gas-fired generating units in supplying power to the electric transmission grid. Changes in the electric industry have heightened the importance of this cost difference by exposing power generators to increased competition.

The competitive problems facing renewable energy concern not only the firms that sell the energy or the capital goods that produce it. Renewable energy has an essential role to play in meeting environmental goals, perhaps, above all, those related to mitigating global climate change. Its ability to play that role requires sustained and rapid growth; it therefore depends on expanding markets. Natural gas now defines one of the competitive boundaries for those markets.

The role of natural gas should be that of a bridge to a future in which renewables satisfy most of the world's energy needs.

Unlike coal, however, natural gas cannot be portrayed as an environmental villain. Natural gas offers some of the environmental benefits of renewable energy and today, it has one major advantage: there is a great deal more of it. The role of natural gas, therefore, should be that of a bridge between the present, in which the environmental benefits of renewable energy technologies are limited by the small amount of energy they produce, and the future, in which environmental necessities may require renewables to satisfy most of the world's energy needs.[2]

While natural gas and renewable energy inevitably do compete in the electric power sector, they also share important interests. They are linked by their joint use in hybrid facilities, by their roles in future distributed or hydrogen-based energy systems and, most importantly, by their environmental benefits. Institutionally, the natural gas and renewables communities can cooperate productively, as they do as members of the Business Council for Sustainable Energy. Their shared characteristics allow renewables and gas to benefit from some of the same energy policies.

The policy needs of natural gas and renewables also differ in fundamental ways. Natural gas is a mature industry which can—and should—be left to make its way in an unbiased marketplace. In contrast, renewable energy will require support for some time, partly because today's energy markets undervalue the

[1] The authors thank Christopher Flavin, Alan Miller, Karl Rábago and Carl Weinberg for their comments on this paper. The authors take responsibility for the opinions expressed, which do not necessarily reflect the views of the reviewers, REPP, or its Steering Committee.

[2] The notion of natural gas as a bridge to a clean energy future is well articulated in Christopher Flavin, and Nicholas Lenssen, *Power Surge: Guide to the Coming Energy Revolution* (New York: W.W. Norton, 1994).

environmental benefits that renewables offer, but principally because of the need to develop a much larger renewables industry to increase those benefits in the future.

This Issue Brief examines the two sides of the relationship between natural gas and renewable energy—natural gas as a competitor and natural gas as a bridge—and some of the policy implications of that relationship. We focus exclusively on the use of gas and renewable energy as resources for electricity generation. Rather than a comprehensive clean energy strategy, which lies beyond the scope of this paper, we outline the common and divergent interests between gas and renewables that would structure such a strategy. A secondary goal is to provide a primer on the natural gas sector for the environmental and renewable energy communities, while explaining the basic elements of global climate change and renewable energy issues to the gas community.

NATURAL GAS AS A COMPETITOR

The Recent Past: Declining Gas Costs Offset Renewable Energy Gains

A consumer in 1980 might have predicted that renewable energy would soon reach price parity with natural gas in the U.S. electric generation market. Its price disadvantage still was large, but its cost was declining rapidly, while the wellhead price of natural gas had more than quadrupled since 1970. Contemporary observers expected the decline in renewable energy costs and the rise in natural gas prices to continue.[3]

Indeed, renewable energy costs did continue to fall. For example, the cost of electricity from wind turbines declined from over 50 cents per kilowatt-hour (kWh) in 1980 to 5-6 cents today (prices in 1994 dollars) in areas with good wind resources; the price is even less for the best projects. At this level, wind would be more than competitive with natural gas in 1997 if gas prices had followed their expected path. Instead, gas prices also fell. The real wellhead price of natural gas in 1995 was more than 40% below its 1980 level; the price delivered to electric generators had declined by nearly 56%.[4] (See Figure 1.) As a result, natural gas today still enjoys a price advantage over renewable energy.

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[3] For example, an influential 1979 collection from Harvard Business School noted that "many, perhaps most, informed geologists believe that enough gas exists [in the U.S.] to sustain a national consumption rate equal to the current 20 [trillion cubic feet] level for at least twenty-five to thirty years, but at higher prices than American are accustomed to paying. Beyond that, there is doubt that even very considerably higher prices would sustain consumption much above the current rate." I.C. Bupp and Frank Schuller, "Natural Gas: How to Slice a Shrinking Pie" in Daniel Yergin and Roger Stobaugh (eds.), *Energy Future* (New York: Random House, 1979), 57. Another author in the same volume reported enthusiastically that from 1977 to 1979, the commercial price for a photovoltaic system had fallen from over $15,000 to as low as $3,000 per peak kilowatt. Modesto Maidique, "Solar America," in *Energy Future*, 208.

[4] American Gas Association, *1976-1985 Historical Statistics of the Gas Utility Industry*, 146; and U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 1997*, 115 (hereafter, *AEO 1997*). Summaries of *AEO 1997* appear on the Internet at http://www.eia.doe.gov/oiaf. General energy information is available from EIA's National Energy Information Center in Washington, DC at (202) 586-8800. More efficient gas-fired electricity-generating plants increased the effect of declining gas costs. Early industrial gas combustion turbines had efficiencies as low as 20-25%. New combined cycle units—which produce electricity in two stages, using hot exhaust gas from the first stage to produce steam for the second stage—exceed 50% efficiency. At 25% efficiency, the generation of one kilowatt-hour of electricity consumes 14 cubic feet of natural gas, worth about 2.8 cents at the average 1995 delivered cost. Doubling the efficiency reduces the fuel cost of that same kilowatt-hour to 1.4 cents.

The most important forces driving the decline in gas prices were deregulation and competition. Ironically, the federal government had regulated the wellhead price of natural gas in order to protect consumers against rising costs.[5] Price controls undoubtedly did limit the price paid by many consumers initially, but they also reduced and distorted production incentives. By the mid-1970's, these controls had created natural gas shortages in some regions. Partly in response to the shortages, the Natural Gas Policy Act of 1978 raised price ceilings for most gas supplies and created a mechanism for their gradual elimination.

The deregulation of wellhead prices was formally completed in 1992. Well before that date, however, price ceilings had lost their practical relevance. Market forces rather than regulation established the price at which producers sold their gas, and the administrative allocation of scarce supplies had been replaced by competition to sell a supply of natural gas that soon exceeded market demand.

A transformation in the role of natural gas pipelines increased the competition. In 1980, pipeline companies bought most of the natural gas sold by producers. They in turn resold the gas to end users and local distribution companies, most of which had few, if any, alternative sources of supply. Facing little sales competition, and knowing that they could pass the price they paid for gas directly to their customers, pipeline companies principally focussed on securing an adequate gas supply and only secondarily on the cost of the gas. Producers therefore shared the economic benefit of the pipeline companies' protected market position.

A combination of market forces and regulatory changes undermined the pipeline companies' position. The natural gas surplus that developed following the enactment of the Natural Gas Policy Act created a pool of uncommitted gas supplies, which market forces priced well below the prices that pipeline companies were required to pay producers under their long-term supply contracts. In response to gas users' calls for access to the cheaper supplies, the Federal Energy Regulatory Commission (FERC) effectively ordered the pipeline companies to transport the gas of competing sellers.[6] Unburdened by long-term supply contracts, gas producers and marketers then could sell directly to the pipeline companies' customers. The new competitors steadily gained market share at the pipeline companies' expense.

By 1993, the transition was complete. The gas merchants' role had passed to producers and marketers; pipeline companies transported gas but no longer bought or sold it. Unlike the firms they replaced, the new

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[5] In 1954, the United States Supreme Court directed the Federal Power Commission (predecessor to the Federal Energy Regulatory Commission) to regulate the wellhead price of natural gas sold in interstate commerce. The FPC began to impose price ceilings in 1960. Until about 1969, however, those ceilings probably were little if any lower than the prices that would have prevailed in an unregulated market. The gap between price ceilings and the presumed unregulated price subsequently widened with the general increase in energy prices resulting from the 1973 oil embargo.

[6] In Order No. 436 (1985), the FERC ruled that either pipelines could transport gas for everyone (including their competitors), or they would be disallowed from offering new transportation service to anyone. Pipelines proved unable to operate successfully without offering a transportation service. By 1990, every major pipeline company had agreed to carry gas on a non-discriminatory basis. In Order No. 636 (1992), the FERC abandoned the pretense of choice and ordered non-discriminatory pipeline transportation outright.

merchants did not enjoy a protected market position; the pipeline companies that transported their gas to market were equally ready to transport the gas of their competitors.

Deregulation and multiple gas merchants made the sale of natural gas a highly competitive business. To survive, producers streamlined their operations and embraced new technologies. Some producers nevertheless failed, but the rest sold gas profitably at prices that previously would have caused a loss.

Further changes in the regulation of pipelines are possible and perhaps likely, but analysts envision nothing comparable to the transformation of pipeline companies from gas merchants to gas transporters.

The cost of natural gas to electric generators includes not only the price paid to producers but also the price paid to pipeline companies for transporting it from the wellhead to their generating plants. The potential for cost reduction was smaller for those companies than for the producers. If costs could not be cut, however, they could be shifted to other customers. The efforts of the pipeline companies to attract and retain large shippers combined with changed regulatory policies[7] to produce a large shift in pipeline costs from electric utility and industrial customers to residential and commercial consumers. As a result, electric utilities' delivered cost of gas declined even more than its price at the wellhead.

The Future: Stable Gas Prices Permit Renewables to Improve Competitive Position

The institutional changes that produced the large decline in gas prices were a one-time event. Producers by now have eliminated the gross inefficiencies created by regulation and monopoly power. Further changes in the regulation of pipelines are possible and perhaps likely, but analysts envision nothing comparable to the transformation of pipeline companies from merchants of gas to gas transporters. Little room remains for shifting more of the transportation costs from electric generators to other natural gas users.

Future natural gas prices depend on the balance between the conflicting forces of resource exhaustion and technological progress. Over spans of time relevant to human beings, the physical supply of natural gas cannot be renewed. However, the availability of natural gas depends not on its total physical supply, but on the supply that developers can find and produce economically.

Generally, the process of finding and producing gas has not changed since the 1950s: [8] Geologists identify promising formations; drillers sink wells; gas is produced from the wells that are successful. In its detail, however, the process has undergone changes that have greatly reduced the cost of locating and extracting gas. Powerful computers depict geological formations in three dimensions, identifying gas reservoirs in greater detail and with more certainly. Horizontal drilling—redirecting the shaft in a horizontal direction after it reaches the desired depth—has permitted economical production from small reservoirs that developers previously could have exploited only at high cost or not at all.

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[7] Recently, both the FERC and the state commissions have shifted from policies aimed at protecting small residential gas consumers to policies emphasizing industrial development and economic efficiency.

[8] Prior to the 1950s, most American natural gas was produced as a by-product of oil.

NATURAL GAS SUPPLY

"Natural gas supply" can be an ambiguous term. It may simply connote the amount of natural gas delivered to end users. During 1995, the United States produced 19.0 trillion cubic feet (Tcf) of natural gas and imported another 2.6 Tcf, mostly from Canada. Losses during production and transportation totaled about 0.3 Tcf. End users received the remainder, about 21.3 Tcf.

Natural gas supply also may refer to the reserves supporting production. Reserves are themselves classified in several different ways, based on the likelihood that they exist and the cost of producing them. Developers know of *proven reserves* with reasonable certainty and can exploit them economically using available technologies. At the end of 1995, proven reserves in the United States were 169 Tcf, equal to about nine years of domestic production at the current rate.

This does not mean that the United States will run out of natural gas in nine years. Proven reserves form one part of *economically recoverable resources*: supplies that could be economically produced using currently available technology. Most economically recoverable resources have not been proven; many have not even been discovered. They therefore are subject to greater uncertainty than proven reserves. EIA estimates economically recoverable reserves in the United States at about 1200 Tcf.

Economically recoverable reserves in turn are part of the *ultimate resource base*: the total amount of natural gas underlying the United States and its territorial waters. Estimates of the ultimate resource base cover a wide range, but the base probably is at least several times as large as the economically recoverable resources.

Changes such as these do not increase the physical supply of natural gas, but they do add to the supply that can be economically recovered. The Energy Information Administration (EIA), an agency of the U.S. Department of Energy, estimates that domestic economically recoverable natural gas resources in 1990 were 1105 trillion cubic feet (Tcf) using technology available in that year. Using technology projected to be available in 2015, the figure would have been 1491 Tcf.[9] The difference of 386 Tcf would offset more than two-thirds of the 560 Tcf that analysts expect those resources to produce between 1990 and 2015.

In EIA's projections, this technological progress does not fully offset resource exhaustion. EIA expects natural gas prices to increase slowly by about 1.4% annually at the wellhead and 1.0% annually for electric generators.[10] (See Figure 1.) Of course, prices could diverge from the projected path if further reductions in the cost of finding and producing gas prove either greater or smaller than EIA assumes. If the reductions

[9] *AEO 1997*, 57.

[10] These projections parallel those of the American Gas Association (AGA) and the Gas Research Institute (GRI). AGA projects a 2010 wellhead price of $1.99 in 1994 dollars, representing a 1.5% annual real price increase from 1995. *Foster Natural Gas Report* (25 Jul. 1996), 33. GRI projects a 1.5% annual real increase in the price of gas delivered to electric generators over the same period. GRI, *Baseline Projection Data Book* (1996), 497.

exceed projections, gas prices again may rise less rapidly than expected or even decline. However, there is no prospect of a decline comparable to the one that occurred between 1980 and 1995.

The Competitiveness of Renewable Energy

In contrast to projections for natural gas, there is no consensus regarding future renewable energy costs. Table 1 presents a 1995 DOE forecast for the latter, but both more and less optimistic projections by other analysts also exist.[11] Nevertheless, DOE projections support the following conclusions:

1. Renewable energy costs will continue to decline and, in contrast to the recent past, little of that decline will be offset by falling gas prices.

2. Within the next decade, one or more renewable technologies are likely to reach price parity with natural gas in important segments of the U.S. electric generation market.
3. For the broader range of renewable energy sources, price parity *in the American grid-connected market* lies farther in the future. However, the market for grid-connected renewables appears more robust overseas.

However, simple projections of average prices do not fully capture the advantages of many renewable energy technologies. These advantages include soft environmental impact and insulation from price volatility. While renewable energy systems typically cost more per unit of capacity than gas-generating technology, this disadvantage is partially offset by their use of free fuel (except for those that convert non-waste biomass crops). Not only is the future price of gas uncertain, but it probably will be volatile, swinging both below

An important advantage of renewable energy technologies is that they remove the risk of energy bills that rise without notice and obviate the cost of financial tools to hedge that risk.

[11] For biomass, see Eric Larson and Christopher Marrison, Center for Energy and Environmental Studies, "Economic Scales for First-Generation Biomass-Gasifier/Gas Turbine Combined Cycles Fueled From Energy Plantations," prepared for Turbo Expo '96, the 41st ASME Gas Turbine and Aeroengine Congress in Birmingham, UK (10-13 Jun. 1996). CEES is located in Princeton, NJ at (609) 258-4966. For wind, see Alfred Cavallo, Susan Hock, and Don Smith, "Wind Energy: Technology and Economics" in Thomas Johansson et al. (eds.), *Renewable Energy: Sources for Fuels and Electricity* (Washington, DC: Island Press, 1993), 152. For solar thermal, see Pascal de Laquil, III et al., "Solar Thermal Electric Technology" in *Renewable Energy*, 280-281. For photovoltaics, see Tom Jensen (Strategies Unlimited, Mountain View, CA), "Scenarios for Global Capacity Building," presented at 25th Annual IEEE Convention in Arlington, VA (May 1996). For various technologies, see H. Ishitani and T.B. Johansson, "Energy Supply Mitigation Options" in R. Watson, M. Zinyowera, and R. Moss (eds.), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* (Cambridge: Cambridge University Press, 1996). This volume is one of three comprising the Intergovernmental Panel on Climate Change's Second Assessment Report, a compendium of climate science, policy and economics. It can be ordered from Cambridge University Press in England at 44-1223-325970. The IPCC Secretariat can be reached in Geneva at 41-22-730-8215. Summaries of the IPCC reports can be found on the Internet at http://www.unep.ch/ipcc/ipcc-0.html.

and above a gradually increasing trend.[12] Energy users can hedge these risks by signing long-term gas supply contracts. However, such contracts–add to the operating costs of gas and may not be available for those who use very small quantities of gas. Indeed, many electric utilities use fuel adjustment clauses to pass fluctuations in the price of fuel directly to consumers. In short, an important advantage of renewable energy technologies is that they remove the risk of energy bills that rise without notice, and they obviate the cost of financial tools to hedge that risk.–Renewables will be more competetive in energy markets that account for such characteristics.

Natural Gas in the World Market

Considering U.S. and global oil markets separately would make little sense. Reserves of both oil and gas cluster in a few regions of the world; while Middle Eastern countries harbor well over half of proven oil reserves, the former Soviet Union, Iran and tiny Qatar account for 60% of proven gas reserves.[13] Oil, however, moves easily from producing regions to the point of consumption. Shippers can easily redirect ocean tankers from one destination to the other. Pipelines provide the cheapest overland transportation for oil, but significant amounts also travel by rail, road and river barge.

Natural gas transportation is less flexible due to the low energy density of gas. At atmospheric pressure, a cubic foot of natural gas provides about 1,000 British thermal units (BTU) of energy; the same volume of gasoline (about two gallons) provides over 300,000 BTU. The energy density of natural gas can be increased by compression, but even at 1,000 pounds per square inch, gas carries far less energy per unit of volume than oil.

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[12]The mid-1990s featured bemusingly volatile gas prices. In winter 1992, wellhead prices fell to about $1.30/thousand cubic feet (mcf), but in October, soared to about $2.40/mcf. By 1995, prices tumbled back to about $1.40/mcf; average prices that year were only $1.55/mcf. By mid-1996, however, prices had bounced up to over $2.30/mcf. U.S. DOE, Energy Information Administration, *Natural Gas 1996: Issues and Trends* (December 1996), Figure ES-1, DOE/EIA-0560(96).

[13] U.S. DOE, EIA, *1995 International Energy Annual*, 107-109; U.S. DOE, EIA, *1995 International Energy Outlook*, 37.

GOVERNMENT ENERGY FORECASTS

In early 1997, EIA released the government's primary domestic energy forecast, the *Annual Energy Outlook* (hereafter *AEO 97*). To the dismay of renewable energy advocates and other environmentalists, EIA's reference case suggested that geothermal, solar, wind and biomass (including cogenerators) would supply substantially less new electric generating capacity than the agency had forecast in previous years. Whereas *AEO 95* had reckoned the combined contribution in 2010 from these resources at 24.4 gigawatts (GW), *AEO 96* shrank the estimate to 18.4 GW, and *AEO 97* cut it even further to 17.3 GW. The windpower forecast took an especially large cut. While *AEO 95* predicted 10.0 GW of windpower by 2010 (the latest year then considered), *AEO 96* cut that to 5.1 GW, and *AEO 97* reduced it to only 3.8 GW.

Policy shifts account for some of the changes. For example, in January 1995, the Federal Energy Regulatory Commission overturned California's Biennial Resource Plan Update, which had aggressively woven large amounts of renewable resources into the state's energy plan. However, *AEO 96* and *97* also embody the EIA's controversial decision—long sought by the gas industry—to reduce its natural gas price projections. In 1995, EIA had forecast wellhead prices of almost $3.50 per thousand cubic feet (mcf) for 2010, but *AEO 96* lowered that to $2.15, and *AEO 97* to $2.01 mcf. EIA attributed the reduction to falling drilling costs and rising yields per well.

Due to lower prices, EIA foresees combined-cycle gas turbines dominating the market for new electricity generating equipment. *AEO 97* predicts that electricity suppliers will add 319 GW of new and replacement capacity between 1995 and 2015; 81% of those plants will burn gas, or gas and oil. According to EIA, renewable energy resources, including conventional hydropower and municipal solid waste, will contribute only 4% to the additions. In the projections, the percentage of electricity generated from natural gas rises from 15% in 1995 to 31% in 2015, and gas consumption by the electric sector (excluding cogenerators) rises from 3.5 Tcf in 1995 to 8.5 Tcf in 2015.

For the gas industry's position on U.S. DOE forecasts, see Interstate Natural Gas Association of America, "Projecting Average Wellhead Gas Prices: An Analysis of Forecasts Made by the Energy Information Administration," Publication No. 95-4 (Sept. 1995). This report is available from INGAA at (202) 626-3200.

Unlike oil, natural gas therefore cannot be moved economically by truck or rail. Over land, only pipelines are economical and even pipeline transportation costs more for natural gas than oil. Pipelines also can transport gas under small bodies of water; a proposal exists to link North Africa and Europe by a gas pipeline under the Mediterranean Ocean. However, no one seriously proposes a trans-Atlantic or trans-Pacific pipeline. Problems of unsuitable terrain also may prevent the construction of a pipeline, or a modest projected flow may not justify investment in such a capital-intensive fixed facility.

Even where construction is technically feasible, gas firms and their investors may shun pipeline projects. In the United States, regulation can increase the price of a pipeline substantially by, for example, requiring environmental mitigation measures or simply delaying construction. At the same time, FERC regulation of pipeline transportation rates effectively limits the return that investors can earn. Elsewhere in the world, gas developers face different perils. For instance, efforts to exploit the rich gas fields of the Caucasus region take place amid—and help to fan—simmering political conflicts.

Non-pipeline transportation of natural gas depends on increasing its energy density. For small volumes, gas may be compressed or only its heavier butane and propane components may be used.[14] For larger volumes, liquefied natural gas (LNG) is the only current alternative.[15] The gas is not chemically transformed, but cooled to −164 degrees Celsius, at which temperature it forms a liquid. After transportation to market in a specialized tanker, it is regasified. All three stages—liquefaction, transportation, and regasification—increase the delivered cost of the gas. Nevertheless, LNG now accounts for about one-fourth of the international gas trade, although its share may decline with the completion of projected international natural gas pipelines.[16]

The cost and limited availability of natural gas transportation mean that high gas prices in some regions coexist with surplus supply elsewhere. For instance, in 1994 the delivered price of LNG in Japan was $12.89/thousand cubic feet (mcf), more than $10.00 higher than the average delivered cost of natural gas to electric generators in the United States.[17] Meanwhile, natural gas is literally worthless in regions where the quantity produced in the course of oil drilling exceeds the accessible market. In such cases, oil drillers simply "flare," or burn in the field, huge volumes of excess gas.[18]

In some cases, new pipeline projects will narrow these price differentials by providing a market outlet for the surplus gas of some producing regions and permitting some consumers to replace LNG with gas delivered by pipeline. However, constructing pipelines costs a great deal and they cannot reach every major market. For example, no pipeline will link Japan to the gas fields of Siberia in the foreseeable future.

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[14] Natural gas contains perhaps 90% methane (CH_4), but the gas stream at the wellhead also typically includes heavier hydrocarbons, such as propane (C_3H_8) and butane (C_4H_{10}). Refiners remove some of these substances for separate sale. Propane tanks abound in rural America, while butane serves small-scale uses such as camp stoves.

[15] Natural gas can be chemically converted into heavier hydrocarbons such as diesel fuel. While feasible for over half a century, this process has been too expensive to compete with products refined directly from oil. Recent technical improvements may make the conversion practical even at current oil prices. See "Exxon Project to Expand Use of Natural Gas," *Wall Street Journal* (30 Oct. 1996), A3. Even with the improvements, the resulting liquid fuel carries substantially less energy than the original gas. Due to this energy loss and the cost of the conversion plant, the process likely will be used only where the lack of a pipeline link to adequate markets makes gas very cheap. In this respect, its economics would be similar to those of LNG.

[16] *IEO 1995*, 38. LNG also proves useful for "peak shaving": Sellers store the gas in the market area as LNG during off-peak periods when pipeline capacity is not fully utilized and then regasify it to meet peak demand.

[17] *Handbook of Energy and Economic Statistics in Japan* (Tokyo: Energy Conservation Center, 1996), 41.

[18] The World Bank estimates that in 1990, Nigeria flared 21 billion cubic meters (bcm) or 76% of its gas production; the U.S.S.R., 19 bcm or 2% of production; and Algeria, 7 bcm or 5% of production. The world flared 107 bcm or 4% of total production. John Homer, *Natural Gas in Developing Countries*, Discussion Paper No. 190 (Washington, DC: The World Bank, 1993), Table 2.9. To order World Bank publications, call (202) 473-1155.

Renewable Energy in the World Market

The availability and cost of natural gas therefore will vary by location. This leads to several opportunities for renewable energy. First, large renewable energy facilities can supply national or regional transmission grids. In some regions, gas will compete robustly for this market. As the example of Japan illustrates, however, the flood of cheap gas will not swamp every market. The remaining "high ground" for renewables will include both rich and poor countries.

Where gas proves unavailable or too costly, renewables will also need to compete with coal or nuclear. In contrast to natural gas and renewable energy facilities, these technologies reward huge plants with economies of scale, and they exact a severe environmental price. Thus, without gas as a competitor, the non-price advantages of renewable energy (e.g., cleanliness, quick installation, and appropriateness for facilities of modest capacity) may count for more in some global markets than they do in the United States.

The second major market for renewable energy lies off-grid. Many people with the greatest need for energy services live far beyond the nearest electric transmission grid. Natural gas has some of the elements needed to compete strongly in this market. It produces relatively little local pollution and gas turbine generators now under development may soon efficiently serve loads as small as 24 kW.[19] But where the electricity transmission grid has not arrived at all, the natural gas transmission system is likely to be equally distant. Diesel delivered by truck will continue to be the principal competitor for renewable energy in meeting this type of off-grid demand. Compared to diesel, renewables often offer greater convenience and reliability, not to mention lower cost and price volatility.[20]

A third type of energy demand emerges where the transmission grid is operated at full capacity.[21] Rather than paying to upgrade the transmission system, users may prefer to install their own small, distributed generation technologies, either free-standing or connected to the grid. These technologies may include gas-fired micro-turbines, photovoltaic panels, fuel cells, solar water heaters and other devices. (Energy efficiency measures deliver similar benefits.) Indeed, as renewable energy and gas technologies become smaller, less expensive, and more efficient and flexible, some analysts expect the market for distributed generation to expand far beyond its use as a solution to crowded transmission systems. (This topic is discussed in greater detail below.) Gas and renewables may well coexist in the distributed market.[22]

The majority of grid-connected, off-grid and distributed energy demand for renewable energy today comes from overseas. For example, exports took 73% of U.S. photovoltaic production in 1996. Perhaps equally

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[19] Stuart Brown, "Here Come the Pint-Size Power Plants," *Fortune* (1 Apr. 1996), 64C.

[20] For this market generally, see *Rural Energy and Development: Improving Energy Supplies for Two Billion People* (Washington, DC: The World Bank, 1996).

[21] Such opportunities occur in rural and urban locations in developed and developing countries. See, for example, Michael Tennis et al., *Renewing Our Neighborhoods: Opportunities for Distributed Renewable Energy Technologies in the Boston Edison Service Area* (Union of Concerned Scientists, 1995).

[22] In contrast to renewable energy technologies, however, distributed gas systems will require a supply of high-pressure fuel, which may limit their success. H. Lawrence Goldstein, *Small Turbines in Distributed Utility Application: Natural Gas Pressure Supply Requirements*, NREL/SP-461-21073 (Golden, CO: NREL, 1996).

indicative, foreign firms had by then acquired about two-thirds of America's photovoltaic manufacturing capacity.[23] Also in 1996, as the American windpower sector merely held steady (adding only 10 MW of replacement machines) while other nations added 1196 MW of new capacity.[24]

Growing overseas demand for renewables often indicates a strong environmental ethos and high energy prices. In several countries, including Japan, Denmark and Germany, it also reflects significant government support. In 1996, for instance, subsidized programs for early adopters accounted for all of the growth in the world photovoltaic market.[25]

For some environmental purposes, where renewable energy markets develop matters. Solar energy in India will not reduce smog in the United States, although it may reduce global warming, to the benefit of both nations. Where renewable energy technologies are manufactured and used may have an indirect environmental impact as well: it may be easier to garner support for clean energy if citizens know that the industries in question employ Americans and channel profits into the U.S. economy. To achieve economies of scale and "learning by doing," however, the global market for renewables may be more important than the market in any particular country.

NATURAL GAS AS A BRIDGE

The environmental case for using natural gas as a bridge to a renewable energy future can be summarized as follows. First, natural gas pollutes more than renewable energy but less than oil or coal. Second, the supply of gas has limits, but for at least the next few decades, gas can generate far more electricity than all the renewable energy technologies combined. Third, due to its immediate availability, natural gas can displace many more tons of coal now and in the near future than renewable energy can.

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[23] "U.S. PV Cell/Module Shipments Increase 14.7%," *PV News* 16 (Feb. 1997), 7.

[24] "Global Wind-Energy Rated Capacity Grew 1200 MWe in 1996, as Expected: AWEA," *The Solar Letter* 7 (31 Jan. 1997), 35. For world wind news, see the American Wind Energy Association website at http://www.econet.org/awea.aweanews.html.

[25] "1996 World PV Cell Shipments up 15.5% to 89.6 MW," *PV News* 16 (Feb. 1997), 1. Japanese policy combines generous domestic support and aggressive exports. In 1997, the government is expected to ramp up its subsidized "70,000 Roofs" photovoltaic program to 10,000 homes served (about 40 MW), up from 1,866 homes the previous year, at a cost to the government of about $120 million. Participating households pay about $20,000 after receiving the subsidy, but the program still had to turn away some 9,000 families in 1996. "Japan's MITI Proposes 10,000 Roofs, 12 Billion Yen Subsidy For FY 1997," *PV News* 15 (Dec. 1996), 3.

Natural Gas and "Conventional" Pollution

All energy technologies, renewable energy not excepted, affect the environment.[26] Natural gas pollutes more than renewable energy, but it offers clear environmental advantages over other fuels, especially coal. (See Table 3.) Unlike burning coal or oil, gas combustion releases almost no sulfur which, in the form of airborne sulfur dioxide (SO_2), contributes to acid rain and harms human health.[27] Coal and oil plants beget masses of solid waste—up to 590 tons per day—while gas plants create none. Natural gas plants also release less waste heat, due to their higher efficiency.

Natural gas pollutes more than renewable energy, but it offers clear environmental advantages over other fuels, especially coal.

The most significant conventional pollutants released by gas combustion are oxides of nitrogen (NO_X) formed by heating air around the point of combustion. Harmful to human health itself, NO_X combines with airborne hydrocarbons to form ozone, a pervasive urban scourge. NO_X emissions are a precursor of airborne particulate pollution, which causes over 50,000 deaths per year in the United States.[28] For example, NO_X is responsible for up to one-third of total particulate matter in Los Angeles.[29] NO_X also contributes to acid rain. Because of their low NO_X emissions, some renewable energy technologies can make a greater immediate impact on environmental problems than natural gas plants. Advanced gas combustion technologies also reduce NO_X emissions significantly, although the majority of plants in service now use older technologies.

Natural Gas and Global Climate Change

Natural gas plays a more complex role in global climate change. This threat arises from increasing emissions of greenhouse gases, a class of atmospheric substances that allow sunlight to reach Earth's surface but partially block the radiation of Earth's heat back into space. Carbon dioxide (CO_2) is the principal greenhouse gas, and combustion of fossil fuels is the primary source of CO_2 emissions due to human activity. From a pre-industrial level of 280 parts per million by volume (ppmv), atmospheric concentration of the gas has risen to 350 ppmv. Under existing energy policies, experts expect it to increase throughout the 21st century.

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[26] For a summary, see Irving Mintzer, Alan Miller and Adam Serchuk, *The Environmental Imperative: A Driving Force in the Deployment of Renewable Energy Technologies*, Issue Brief No. 1 (College Park, MD: Renewable Energy Policy Project, Apr. 1996). Note that not all renewable energy technologies are zero-emission. Biomass combustion may release substantial pollutants, and geothermal facilities may emit the greenhouse gas methane. Some intermittent renewable energy plants co-fire with natural gas as well.

[27] Flue gas desulphurization (FGD) for coal and oil plants is possible, but expensive.

[28] D.W. Dockery et al., "Acute Respiratory Effects of Particulate Air Pollution," *Annual Review of Public Health: 1994* 15 (1994), 107-32. See also Deborah Shprentz, *Breath-Taking: Premature Mortality Due to Particulate Air Pollution in 239 American Cities* (New York City: Natural Resources Defense Council, 1996).

[29] Curtis Moore, *Life and Death: Protecting Human Health Under the Clean Air Act* (American Lung Association, Jul. 1995). The ALA can be reached at (202) 785-3355. See also Moore, *Dying Needlessly: Sickness and Death Due to Air Pollution*, Issue Brief No. 6 (College Park, MD: Renewable Energy Policy Project, Feb. 1997).

When burned, natural gas emits about 14 kilograms of CO_2 per gigajoule of energy produced (kg/GJ); oil and coal emit about 20 and 25 kg/GJ respectively.[30] The higher efficiency of gas-burning generators enhances the fuel's natural advantage; a gas-fired combined-cycle system with 48% efficiency releases only half the CO_2 of a conventional coal plant of the same capacity and 38% efficiency. Gas cogeneration, which captures waste heat for residential or industrial uses, performs even better. (See Tables 2 and 3.)

Methane leakage from the natural gas industry presents a less serious greenhouse problem than CO_2 emissions from the combustion of fossil fuels.

There is a complicating wrinkle, however. Natural gas consists largely of methane (CH_4), itself a greenhouse gas—indeed by weight or per molecule, a much more powerful one than CO_2. The World Bank reckons that if a gas plant loses 3% of its supply to the atmosphere, it relinquishes its greenhouse advantage over coal as well.[31] While experts disagree about leakage from the U.S. pipeline system, it certainly amounts to less than 3%.[32] However, poorly maintained systems leak more, perhaps much more. Recent unpublished data from Russian researchers suggests that the Russian gas system leaks 35 million metric tons of methane annually, implying leakage of 9% of throughput.[33]

In two respects, however, methane leakage from the natural gas industry presents a less serious greenhouse problem than CO_2 emissions. First, there is no technical mystery regarding the measures necessary to reduce gas leakage, at least to the level that the United States has achieved. Implementing such controls on the vast Russian pipeline system might be expensive, but a tighter system would also capture a large and immediate commercial benefit. At a value of only $1.00 per mcf, each 1% reduction in the rate of leakage would be worth nearly $200 million annually,[34] entirely apart from the value of forestalling catastrophic climate change.

Second, methane remains in the atmosphere for a relatively short time—perhaps a dozen years—compared with 50 to 200 years for CO_2.[35] Even under generous supply assumptions, dwindling stocks will reduce

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[30] Nebojsa Nakicenovic, "Energy Primer" in Watson et al. (eds.), *Climate Change 1995: Impacts*, 80.

[31] Homer, *Natural Gas in Developing Countries*, 18. For early warnings, see Jerry Bishop, "Global Threat: New Culprit is Indicted in Greenhouse Effect: Rising Methane Level," *The Wall Street Journal* (24 Oct. 1988), A1-A6; and Paul J. Crutzen, "Methane's Sinks and Sources," *Nature* 350 (4 Apr. 1991), 380-381. Crutzen suggests leakage of 6-9% of global natural gas production and warns that if the figure is accurate, "not even a switch from coal to natural gas would alleviate future global warming."

[32] A joint study conducted by the Gas Research Institute and the EPA reports leakage from the domestic gas industry as 1.4% ± 0.5%. *Methane Emissions from the Natural Gas Industry*, (Jun. 1996), 1, GRI-94/0257, EPA-600/R-96-080. See also "U.S. EPA Announces Voluntary Program to Reduce Methane Emissions from Natural Gas Industry," *Energy, Economics and Climate Change* (Mar. 1993), 13. Note that American methane emissions could climb should natural gas become widely used in less controlled, distributed applications such as an automotive fuel.

[33] See Fred Pearce, "Plug a Leak and Save the World," *New Scientist* 150 (25 May 1996), 7. Thanks to Nick Sundt of *Global Change* for this calculation. Sundt can be contacted for further information at (202) 547-0850.

[34] One percent of 588 bcm is equal to about 180 bcf, or 180,000 mcf.

[35] These numbers imply that even if a climate crisis impelled immediate and drastic CO_2 emission reductions, many decades would pass before enough CO_2 left the atmosphere to restore a more benign global climate. Indeed, reducing methane leakage would have a quicker effect. Note that atmospheric half-lives are complex and difficult to calculate; these figures are rough. J. T. Houghton et al., "Technical Summary," *Climate Change 1995: The Science of Climate Change* (Cambridge: Cambridge University Press, 1996), 15.

world natural gas usage by the latter decades of the next century[36] and the greenhouse effect of methane leakage during the period of high gas consumption will decline soon thereafter. The leakage therefore will have little impact on the long-run global temperature. The chief danger, then, is that methane leakage would cause a more rapid rise in temperature in the near future, reducing the time available to humans and other species for adapting to a warmer globe.

Scientists, policymakers and industrialists disagree over what limit on the atmospheric concentration of CO_2 should anchor a reasonable climate policy; a few still deny the need for any such limit (and any such policy). However, discussion frequently centers on a ceiling of 550 ppmv, about twice the pre-industrial level. That figure represents a political compromise between many conflicting concerns, most notably the protests of some government economists and industrial interests that a more ambitious goal would precipitate economic havoc. While we do not defend the 550 ppmv figure on substantive grounds, we use it for the sake of discussion in the following pages.

How Long Is the Bridge? The Supply of Natural Gas

Entirely replacing coal with natural gas would reduce current international, energy-related CO_2 emissions by about 20%.[37] A total displacement is scarcely plausible, however. Apart from the political ability of the world coal industry to forestall such measures,[38] there appears to be insufficient natural gas to support such a change.

The substitution of natural gas for coal can only reduce CO_2 emissions below their projected path if growth in gas supply substantially exceeds the availability that most experts predict (the "mainline" projections). Such a bonanza is unlikely in the United States. After decades of exploration and drilling, geologists have defined the American resource base reasonably well: uncertainty regarding future price and supply principally reflects the impossibility of predicting the rate of reductions in exploration and production costs.

Faster supply growth in other countries appears more plausible. In many regions, petroleum firms have had little incentive to explore for natural gas because no market exists for the gas already produced in association with oil. It is impossible to know how much gas a systematic exploration would reveal, but one study contends that new supplies could support consumption about 48% above mainline projections between 2020 and 2040.[39] Although this would not suffice to displace all coal, it could delay the date when

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[36] See, for example, *Power Surge*, 112.

[37] Coal combustion produces about 38% of energy-related CO_2 emissions. Displacement of coal by gas would reduce CO_2 emissions by about half through the combined effect of less CO_2 produced per unit of primary energy and the greater efficiency of gas-fueled generators. See Robert Watson, Marufu Zinyowera and Richard Moss, *Technologies, Policies and Measures for Mitigating Climate Change* (Intergovernmental Panel on Climate Change: Nov. 1996), 39.

[38] See, for instance, David Roodman, "Paying the Piper: Subsidies, Politics and the Environment," *Worldwatch Paper* 133 (Dec. 1996), 32-33.

[39] *Power Surge*, 112. We estimate the figure of 48% from a section of their graph corresponding to those years. Other experts posit—controversially—the practical exploitation of huge exotic sources of natural gas, such as undersea masses of methane hydrate. See, for example, Richard Monastersky, "The Mother Lode of Natural Gas," *Science News* 150 (9 Nov. 1996), 298-299.

a larger contribution would be required from increased energy efficiency and non-fossil energy to offset global climate change.

How long could natural gas forestall the time when nations would have to wean themselves from fossil energy? Given the compromise goal of 550 ppmv of CO_2 discussed above, *no plausible amount of natural gas could delay past 2050 the need to rely principally on increased energy efficiency and non-fossil fuels to meet the growing demand for energy services.* Substituting natural gas for coal alone would fall far short of meeting the 550 ppmv goal.

Given a compromise goal of 550 ppmv of CO_2, no plausible amount of natural gas could delay past 2050 the need to rely principally on increased energy efficiency and non-fossil fuels to meet the growing demand for energy services.

The 2050 date assumes first a supply of natural gas that is well above the mainline projections and second, that *all* the additional gas would displace coal—the best way to use gas to lower CO_2. An earlier shift away from fossil fuels might be required by a smaller gas supply, by using some of the gas to displace oil in transportation, or by a lower atmospheric concentration goal.

The Other Side of the Bridge

More efficient use of energy can satisfy some of the world's burgeoning demand for energy, but not all of it, especially if living standards for billions of people in developing countries are to be raised. To grasp the magnitude of the problem, consider Asia. With 56% of the planet's population, the region consumes only 23% of world energy, mostly in the industrial sector. As Asia's economies grow and liberalize, hundreds of millions of households and businesses will gain access to electric lighting, refrigeration, communication and other services. In the last decade, *per capita* energy demand in China, India, Malaysia, South Korea and Thailand has doubled. Even as Asia exploits gaping opportunities to boost energy efficiency, the resulting need for power will remain enormous.[40]

Barring the development of unforeseen exotic sources energy, what conservation cannot do must be done by nuclear power or renewables. The United States and other nations may resolve the economic, environmental and political problems confronting nuclear power in the coming decades. Indeed, the threat of global warming might impel their resolution, but it would be premature to count on such an outcome.[41] If we continue to find large-scale, worldwide expansion of nuclear power unacceptable, renewable energy ultimately must bear the responsibility of limiting CO_2 emissions.

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[40] Shelley Clarke, "Megacities in Crisis?" *Resources* 19 (Jan. 1997), 7. For example, in 1994, China's residential and commercial sectors together consumed only about 18% of the nation's power, compared with 68% the United States. *1996 China Energy Handbook* (San Francisco, CA: Lawrence Berkeley Laboratory, 1996), Table IV-33; U.S. DOE, EIA, *Monthly Energy Review* (Jun. 1996), Table 7.2, DOE/EIA-0035(96/06).

[41] Alan Miller and Irving Mintzer, "Global Warming: No Nuclear Quick Fix," *Bulletin of the Atomic Scientists* 46 (Jun. 1990), 30-34.

Some varieties of renewable energy do present a minor greenhouse threat. For example, some facilities back up intermittently available renewable resources by co-firing with natural gas, and geothermal plants can release methane. While biomass combustion releases only the amount of CO_2 absorbed during the plants' growth cycle, net CO_2 emissions result if fossil energy is used to cultivate, harvest or transport the biomass. However, overall, renewables are far less dangerous to the atmosphere than fossil fuels. Comparing renewable and fossil energy on the basis of full fuel cycles—that is, production and transportation of fuel, manufacture and operation of generating equipment, and disposal of waste—makes the greenhouse advantage of renewables apparent.[42]

The challenge is to use gas not just as a device to delay tough political and economic decisions, but as a way to prepare the energy sector for the next generation of energy technologies.

RENEWABLES AND NATURAL GAS: ELEMENTS OF A CLEAN ENERGY POLICY

Natural gas can displace coal immediately and slow the growth of our swelling greenhouse problem, but gas alone cannot eliminate the long-term threat of global climate change. Renewable energy must play an increasing role in that process and, ultimately, the dominant role.

A renewable energy industry capable of serving billions of people will not spring to life overnight. It will require an extended period of sustained and rapid growth. As a competitor, gas poses a formidable threat to that growth in the United States and some other regions. At the same time, however, natural gas can provide a cheap and reasonably clean bridge to a renewable energy future.

The challenge is to use gas not just as a device to delay hard political and economic decisions but as a way to prepare for the next generation of energy technologies. While it is well beyond the scope of this paper to articulate a comprehensive clean energy strategy, we use this final section to outline the common ground between renewable energy and natural gas on which such a strategy might be built.

Common Ground

Natural gas and renewable energy do compete. A unit of energy demand met by natural gas is not available for, say, wind. However, the same might be said about the relationship between two natural gas producers or between two manufacturers of wind turbines. Competition does not preclude common interests.[43] In the case of natural gas and renewable energy, those common interests can be found in four areas: (1) policies that push energy markets to consider environmental costs; (2) the development and deployment of hybrid

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[42] See Charles Herrick, *Assessment of the Environmental Benefits of Renewables Deployment: A Total Fuel Cycle Analysis of the Greenhouse Gas Impacts of Renewable Generation Technologies in Regional Utility Systems* (Alexandria, VA: DynCorp EENSP, 1995). DynCorp can be reached at (703) 998-3600.

[43] Exemplifying the tension, Joseph Romm of the U.S. Department of Energy recently declared, "I don't believe renewable energy is in competition with gas," and asserted that both resources could thrive in a restructured energy system. In response, the Natural Gas Supply Association objected that measures to protect the renewable energy industry "will displace gas." "Boosting Gas Use is Key to the Clinton Administration's Efforts," *Inside F.E.R.C.* (10 Mar. 1997).

systems that rely on both natural gas and renewable energy; (3) the suitability of both gas generators and renewables to small-scale, distributed installation; and (4) the role that they might play in creating a "renewable hydrogen" economy.

1. Environmental Benefits

Natural gas firms are not, in general, composed of environmentalists, but of businesspeople attracted to gas for its commercial characteristics, among which are its comparative environmental advantages over other conventional fuels. In contrast, many members of the renewable energy industrial sector classify themselves as environmentalists. That difference notwithstanding, both communities have a potential interest in the adoption of policies that encourage energy markets to consider environmental as well as private costs of energy use.

The most obvious policy—the inclusion of "environmental externalities" in energy costs in order to compare supply options—probably has a limited future due to abandonment of state-guided resource planning. Yet, both gas and renewables will benefit from a new generation of environmental policies that allow polluters increased flexibility in meeting standards in return for heightened environmental performance. Cap-and-trade regimes are a good example of this approach: regulators determine the maximum permissible emissions of various substances for each class of polluters—the "cap"—and allow firms with superior performance to sell or trade their extra pollution allowances to dirtier producers. Facilities using renewables or gas would thus produce an additional saleable product—emissions allowances. Indeed, the Clean Air Act awards such credits to renewable energy facilities for SO_2 emissions avoided, but polluters have found measures such as importing low-sulfur coal cheaper than zero-emission facilities. The Clinton Administration has proposed a similar cap-and-trade mechanism for carbon emissions; some environmentalists support cap-and-trade regimes for NO_X as well.

In several instances, the natural gas and renewable energy industries have cooperated on the basis of the environmental benefits that both energy sources offer. A notable example is a recent study co-sponsored by the American Gas Association, the Solar Energy Industries Association and the Alliance to Save Energy of how a market-driven energy future could lower emissions of greenhouse gases and major air pollutants.[44] More recently, the Business Council for Sustainable Energy, which advocates environmentally sound energy policy, has united members of the gas community such as the Gas Research Institute, Enron Corp. and Brooklyn Union with renewable energy firms and allies such as Zond Systems and the Worldwatch Institute.[45]

2. Hybrid Systems

The scale and relatively low fixed costs of gas-fired generating units make them a logical choice for providing backup power for intermittent renewable technologies such as photovoltaics and wind in order

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[44] ASE, AGA and SEIA, *An Alternative Energy Future* (Washington, DC: 1992).

[45] The BCSE can be reached in Washington, DC at (202) 785-0507. In January 1997, Enron Corp. purchased Zond. "Enron Acquires Zond, Launches Enron Renewable Energy Corp.," *Wind Energy Weekly* 16 (6 Jan. 1997), 1-2.

to enhance their value. For example, a co-located simple-cycle gas turbine and wind farm might achieve a combined capacity factor as high as 75%.[46]

In contrast to backup power, which generally operates only when the primary power source does not, natural gas and renewable energy also can be used simultaneously in the same unit. In one form of hybrid system, solar thermal, biomass or geothermal systems co-fire with natural gas. In the future, biomass gasification may supply a fuel stream to supplement the bottoming cycle of a combined-cycle natural gas turbine.[47]

3. A Distributed Energy System

Several industry experts find the cleanliness of both gas and renewable energy technologies almost coincidental. For these analysts, the most important characteristic of these technologies is their suitability to small-scale, distributed installation close to where consumers actually need energy. They envision a system of mass-produced, distributed resources which integrates small, cogenerating, combined-cycle gas turbines and natural gas fuel cells with renewable energy technologies, energy storage devices, and energy efficiency measures.

To some extent, the shift to a distributed energy system will follow from inevitable social, economic and technological trends.

To some extent, the shift to a distributed energy system will follow from inevitable social, economic and technological trends. Citizen frustration with local environmental degradation are likely to lead to even slower, more byzantine licensing and siting procedures for large, one-of-a-kind coal, nuclear and hydropower facilities and new transmission lines needed to serve scattered consumers. The resulting higher construction costs and longer delays will increase the cost advantage of small-scale distributed resources.[48] Entrepreneurs will develop and refine a wide variety of technologies to fill the growing market niche.

Energy policy will help or hinder the shift to a distributed energy system. To that extent, the same measures will prove beneficial or detrimental to both gas and renewables. For example, the FERC recently required that utilities offer open access to the transmission grid and “charge” themselves the same rate to transmit power over their wires as they would charge anyone else. Utilities must thus “unbundle” their rates—that is, list separately generation, transmission and distribution costs on electric bills. Likewise, federal and state

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[46] The U.S. DOE and the Electric Power Research Institute sponsored a conference on this topic: "Integrating Renewable Energy Technologies with Gas Turbine Systems" (27-18 Mar. 1996). The authors thank Doug Morris of EPRI and George Hay, III of the Collaborative Advanced Gas Turbine Program for supplying a workshop summary. Mr. Morris can be reached in Palo Alto, CA at (415) 855-2924, and Mr. Hay in Lafayette, CA at (510) 988-9792.

[47] Raw biogas damages turbine blades. For progress in making biogas clean enough for combustion in a gas turbine, see Hans Halling, "Green Gas to Light up the World," *New Nordic Technology* (Feb. 1996), 4-5.

[48] See Carl Weinberg, "How Will Clean Energy Services be Provided in the Future?" presented at the World Renewable Energy Congress IV in Denver, CO (17 June 1995), or contact Weinberg Associates in Walnut Creek, CA at (510) 933-9394. See also the work of Joseph Iannucci of Distributed Utility Associates in San Ramon, CA, who can be reached at (510) 866-1650; and *Power Surge*.

anti-trust principles will have the same impact on all distributed resources, as may policies with respect to transmission rates and what type of generators are subject to regulation.[49]

4. Hydrogen

Looking farther into the future, renewable energy and natural gas also are linked through their role in preparing for a renewable hydrogen economy. As a fuel, hydrogen produces virtually no pollution; its principal combustion by-product is water.[50] While most hydrogen is currently made from natural gas, it can be produced by gasifying biomass or by electrolyzing water with current generated by renewable energy. Because hydrogen can be stored, it frees intermittent renewable energy technologies from reliance on backup power from conventional energy sources. For the same reason, it provides a channel through which renewable energy can serve the transportation sector. Technologies using hydrogen have not yet reached the general market, in contrast to the other renewable energy technologies described in this paper. However, several energy analysts tout hydrogen produced with renewable energy as the ideal fuel of the future—an emissions-free, greenhouse-safe "hydrocarbon without the carbon."[51]

Natural gas is linked to this potential hydrogen future in three ways. First, it now serves as a feedstock for most of the hydrogen produced, and hydrogen derived from gas likely will provide the initial basis for any large-scale penetration of hydrogen into the energy market. Second, fuel cells that run on natural gas also can use hydrogen, and may do so in the future. Third and more speculatively, hydrogen might someday flow through the pipeline system that has been constructed for natural gas. This will require solving some technical problems: hydrogen tends to embrittle certain steels and, since it is lighter than natural gas, existing pipelines would require new compressors.

The Need for a Clean Energy Policy

As we indicate throughout this paper, natural gas and renewable energy alike would benefit from two basic reforms of energy policy. First, both resources would gain from a shift to *market-oriented environmental regulation* that permits polluters to satisfy environmental standards in the most cost-effective way, in return for heightened environmental performance. Second, both resources would profit

Both natural gas and renewable energy would benefit from two basic policy reforms: (1) a shift to market-oriented environmental regulation; and (2) a system of energy pricing that sends consumers accurate signals.

[49] John Nimmons & Associates, Inc. et al., *Legal, Regulatory & Institutional Issues Facing Distributed Resources Development* (Olympia, WA: Nimmons & Assoc., 1996), 13-17. Nimmons & Assoc. can be contacted at (360) 786-6040.

[50] Hydrogen combustion, like natural gas combustion, can produce NO_X in the air around the combustion point. Catalytic heaters minimize this process. For background, see James Cannon, *Clean Transportation: A Market Opportunity for Renewable Energy*, Issue Brief No. 7 (College Park, MD: REPP, Apr. 1997); Cannon, *Harnessing Hydrogen: The Key to Sustainable Transportation* (New York: Inform, Inc., 1995); Joan Ogden and Joachim Nitsch, "Solar Hydrogen" in *Renewable Energy*, 925-1009; Ogden and Robert Williams, *Solar Hydrogen: Moving Beyond Fossil Fuels* (Washington, DC: World Resources Institute, 1989).

[51] *Power Surge*, 288.

from a system of *energy pricing that sends consumers accurate signals,* showing them the true costs—including environmental costs—of their energy decisions.

For natural gas, such measures constitute the limit of appropriate policy; a market that gas cannot capture on such a playing field should be served by some other fuel. Although renewable energy would benefit as well from such measures, much of the resultant market might fall to gas—perhaps nearly all of it, given EIA's current forecast. The case for supporting renewable energy rests on the need for a much larger renewable energy industry in the future if climate change and other environmental goals are to be met. The creation of such an industry requires rapid and sustained growth during the intervening period.

To ensure such growth, government support will be necessary. That support can take various forms: government-funded research, tax benefits, or an assured market share.[52] Those interested in encouraging American renewable energy specifically may endorse indirect support for exports as well.[53] While renewables will grow increasingly competitive in several international markets, American renewable energy products will often compete against the heavily subsidized exports of other nations. Perhaps equally important, it is questionable whether a nation can build a powerful export market for any sector without supporting a domestic market in which to develop products. As noted above, the most successful exporters of renewable energy technology (e.g., Japan, Denmark, and Germany) also maintain a safe domestic haven for their firms.

To ensure the sustained growth of a much larger renewable energy industry, government support—in the form of government-funded research, tax benefits, or an assured market share—will be necessary.

Renewable energy also may benefit from permitting consumers to "choose green." Some environmentalists and entrepreneurs believe that consumers desire—and are willing to pay for—environmental attributes in their energy supply.[54] A few states have initiated pilot projects in which consumers select the "brand" of power they wish to buy, much as consumers across the nation now pick long-distance telephone carriers. In a Massachusetts pilot program, 66% of the residential and small business customers choosing to participate in the pilot decided on the basis of price, but fully 30% chose a firm offering some combination of "green" products—i.e., renewables, energy efficiency or both.

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[52] For example, Rep. Dan Schaefer (D-CO), chair of the House Commerce Committee's Subcommittee on Energy and Power, includes in his bill to restructure the electric system a provision to ensure that renewable energy contributes 4% of total generation. See "Schaefer Reintroduces Utility Bill, EPA Backs Renewables," *Wind Energy Weekly* 16 (17 Feb. 1997), 1-2. The Tellus Institute estimates the impact of such a measure on average national electricity prices at about 0.03 cents/kWh by 2010. "Analysis of Renewable Portfolio Standards," *Tellus Institute Energy Report* 5 (Feb. 1997), 4. Contact Stephen Bernow at sbernow@tellus.com.

[53] International trade agreements generally prohibit nations from barring imports outright, subsidizing the price of products produced domestically in order to discriminate against imports, or imposing prejudicial tariffs. Yet, there remain several ways in which governments can give their products an edge in the home marketplace. These range from government-supported R&D to more subtle devices involving, say, franchise licenses.

[54] See Barbara Farhar, *Energy and the Environment: The Public View*, Issue Brief No. 3 (College Park, MD: Renewable Energy Policy Project, Oct. 1996).

A well-structured green power market could prove large and lucrative. Nevertheless, there is no guarantee that enough consumers will voluntarily pay extra (at least in the near future) for clean energy to address environmental needs.[55] Some sort of policy safety net may be necessary to ensure that the green power market meets environmental goals.

In short, a sound clean energy policy must promote both renewables and natural gas (as well as energy efficiency). Growth in renewable energy will come at the expense of other resources, perhaps including natural gas; in coming decades, however, gas will win the lion's share of new generation contracts. Yet, an effective strategic alliance between gas and renewables will require concessions on both sides. Natural gas interests, seeking to portray their technology as environmentally superior, must concede that renewable energy has to play a growing role in the long run, and therefore must be assured a small[56] but growing market niche today. For its part, the renewable energy community must recognize the environmental contribution that gas can make today and in the near future, and the consequent need to remove artificial impediments to its expanded use. For any particular demand, the choice generally will be either renewable energy or natural gas. For environmental policy, the choice should be both.

TABLE 1
National Renewable Energy Laboratory
Levelized Cost Estimates in 1993 cents/kWh

Technology/Year	**1995**	**2000**	**2005**	**2010**
Wind	5.3	4.1	3.9	3.5
Geothermal	5.2	4.0	3.8	3.7
Photovoltaic	21.8	16.4	13.1	8.7
Solar Thermal	10.5	8.6	8.1	8.1
Biomass	8.5	8.1	7.5	7.2

[55] "Restructuring Roundup," *Quad Report* 5 (Jan.-Feb. 1997), 6. See Edward Holt, *Disclosure and Certification: Truth and Labeling for Electric Power*, Issue Brief No. 5 (College Park, MD: Renewable Energy Policy Project, Jan. 1997); and Dawn Geiger, "Competition & Restructuring of the Electric Industry: Pilot Project Review and Status of Electric Competition in Various States," Iowa Consumer Advocate Office (Jan. 1997), available on the Internet at http:/www.spratley.com/reach under "Expert Papers."

[56] Non-hydroelectric renewable energy supplies about 4% of the nation's primary energy. Most of this contribution comes from biomass; wind and solar together supply only about 0.05% of the total. *AEO 1996*, 76, 172. EIA projects a combined annual growth rate of 6% for wind and solar over the next decade. *AEO 1996*, 172. An increase in their annual growth rate to, say, 20% for the entire decade would reduce consumption of non-renewable energy by only about 0.2% in 2005.

Data from Blair Swezey and Yih-huei Wan, *The True Cost of Renewables: An Analytic Response to the Coal Industry's Attack on Renewable Energy* (Golden, CO: National Renewable Energy Laboratory, 1995), 15, NREL/TP-462-20032. Available from National Technical Information Service at (703) 487-4650.

TABLE 2
Daily Activity of a 450-MW Electric Power Station

PLANT TYPE/ IMPACT	Fuel Used (tons)	Energy Efficiency	Solid Waste (tons)	Waste heat (GWh)	SO_2 emitted (tons)	NO_X emitted (tons)	CO_2 emitted (tons)
Conventional coal	3600	38%	450	17	75	10-35	9000
Coal with 90% FGD	3650	37.5%	590	17	8	10-35	9100
Conventional oil	2250	39%	1	17	170	7-15	7500
Oil with 90% FGD	2280	38.5%	300	17	17	7-15	7600
Conventional gas	2100	40%	0	16	0	3-15	6000
Combined cycle gas	1750	48%	0	13	0	2-10	4500

These figures assume identical energy production by all plant types mentioned. FGD refers to flue gas desulphurization. Data from *Natural Gas in Developing Countries*, 14.

Table 3 compares the annual emissions of a co-generation plant producing 11 Mw_e of electricity and 9 tons of steam per hour at a 70% capacity utilization with those of a conventional, separated system.

TABLE 3
Comparison of Emissions From
Cogeneration and Conventional Energy Technologies in Tons/Year

PLANT SYSTEM/ EMISSIONS	Particulates	SO_2	NO_X	CO_2
Conventional: oil-fired steam plus coal-fired electricity	90	1060	410	206,000
Coal-fired cogenerating steam turbine	100	1190	700	188,000
Gas-fired cogenerating steam turbine	10	70	70	107,000
Cogenerating gas turbine	3	15	140	111,000

Data from *Natural Gas in Developing Countries*,16.