Economic challenges for CCS and the role of natural gas

Rutt Bridges* is a leading geoscientist of his generation, venture capitalist, and a significant figure in the politics of Colorado. In this article he reviews some inconvenient truths about the timely implementation of CCS projects in the US, some of which may resonate in other countries seeking CO_2 reduction measures.

The greatest challenge to carbon capture and storage (CCS) is likely to be economic rather than technical. A September 2008 McKinsey report estimated that the first commercial scale CCS projects, potentially to be built soon after 2020, would cost €35-50 per metric ton of CO_2 abated. They assume that if 500+ projects were built by 2030, the cost might fall to €25-40 per ton. About two-thirds of that cost is for CO_2 capture.

It is interesting to consider those costs on a global scale. A study by Pacala and Socolow implies that we need to cut a cumulative 25 Gton of CO_2 over the next 50 years just to cap the CO_2 concentration in the atmosphere at a modest 500 ppm (we are now at 390 ppm). If all of our solutions cost €25 per ton, the economic impact would be €625 billion ($833 billion) over the next 50 years.

Reducing CO_2 is a global issue, but the US creates 20% of the problem. It also offers an interesting case study on the difficulty of finding practical solutions in a challenging political and economic environment. Hopefully along the way the reader will discover opportunities as well as pitfalls to avoid.

According to the US Department of Energy's Energy Information Administration (DOE-EIA), 98% of America's human-generated CO_2 comes from energy use, with 40% of that from electricity (coal and natural gas) and 33% from transportation (mostly petroleum). Coal produces 45% of America's electricity and natural gas produces 23% (see Figure 1).

McKinsey's study notes that 'Retrofitting of existing power plants is likely to be more expensive than new installations, and economically feasible only for relatively new plants (with high efficiencies).' But according to the DOE-EIA, over the past 20 years coal contributed only 3.7% of total added US capacity while natural gas accounted for 88%. Few modern, efficient US coal plants have been added in the past 20 years.

'Efficiency' is a term used to define the conversion of the theoretical energy content of a fuel into electricity. The McKinsey report notes that the energy required for the CCS CO_2 capture process increases the amount of coal that must be burned per MW-hour delivered, and estimates a CCS 'efficiency penalty' of 10%. This means that if a future coal plant could be built to achieve a 50% thermal efficiency, CCS would decrease that efficiency to 40%. Such a plant would be burning 50/40=1.25 times as much coal per MW-hour. And burning 25% more coal would also increase harmful emissions since CCS captures only about 90% of CO_2 and none of the other pollutants.

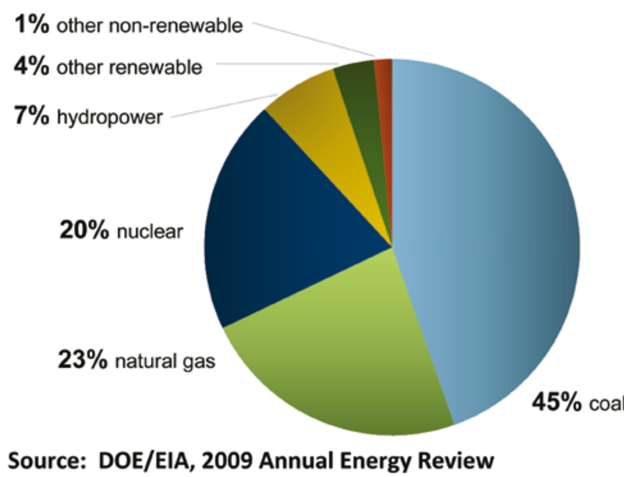

Figure 1 *US electricity energy sources.*

CCS also faces storage challenges, such as site selection, CO_2 transportation costs, pipeline and CCS site permits, and uncertainties in monitoring CO_2 sequestration. Leakage of just 0.5% per year would result in a loss of 64% of CO_2 to the atmosphere over 200 years. What company wants to expose itself to superfund-type legal and financial exposure with a time horizon that extends out a century or more? But the biggest challenge in the US may be the low efficiency levels of the installed base of coal-fired plants.

While the World Coal Association argues that new technology coal plants can achieve 45% efficiency, DOE/EIA data show that existing US coal plants only operate at an average efficiency of 33.5%. A 10% efficiency penalty would lower that efficiency to 23.5% and decrease the electricity output by almost 30%. Given the capital investment

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Technology	Lead Time (years)	Plant Cost/KW-hour ($2008)	Electricity Cost/KW-hour ($2008)
Conventional Coal	4	$2078	$0.1004
Gasified Coal (IGCC)	4	$2401	$0.1105
IGCC with CCS	4	$3427	$0.1293
Nat. Gas-Comb. Cycle	3	$897	$0.0793
NGCC with CCS	3	$1720	$0.1133
Advanced Nuclear	6	$3308	$0.1190
Wind-Onshore	3	$1837	$0.1493
Solar-Thermal	3	$4798	$0.2566

***Table 1** Plant lead time, plant cost and electricity cost. Sources: DOE/EIA Electricity Market Module, 2010 – Table 8.2, Annual Energy Outlook 2010 – 2016 Levelized Cost of New Generation Resources.*

required, this will likely make it marginally economic to add CCS to most existing US coal plants.

DOE-EIA estimates that natural gas combined-cycle (NGCC) generators can deliver electricity for 7.93 cents per KW-hour versus 10 cents for coal, including plant, operating, and fuel costs (Table 1). Based on Electric Power Research Institute CO_2 estimates for coal-fired and NGCC plants, this off-the-shelf technology also cuts CO_2 emissions by about 60% (without CCS) relative to conventional coal-fired plants. Of course, natural gas alone won't get us to near-zero carbon emissions without CCS. But it may be an effective bridge strategy to cut CO_2 while CCS matures. The biggest risk is the wellhead price of gas. But the development of unconventional gas may significantly mitigate that risk, especially in the US.

More on that later. The cheapest 'energy source' is of course conservation. But for now, let's look at the big three 'zero CO_2' alternatives: wind, solar, and nuclear.

Wind and solar

For the past several years there has been a growing passion for wind and solar energy. Expansion of electricity generation from these sources has proliferated at a remarkable pace. Concern for global warming and the risks to our grandchildren stirred passions in even the most conservative consumers. As investment capital poured into wind projects, majestic turbines whooshed their way onto our open plains. Wind energy skyrocketed from 12 GW in 2006 to 35 GW in 2009, providing 2.3% of America's electricity. Projects representing roughly 300 GW of power were in the queue for potential development, enough to raise wind's share of electricity to over 20%.

But a strange thing is happening. In 2010 all that changed. According to the American Wind Energy Association, 2010 year-to-date wind energy installations have dropped 72% compared with 2009, to the lowest level since 2006. In 2010, wind projects in the US were installed at half the rate of Europe and a third that of China.

The wind and solar industry has blamed this crash on the lack of adoption of a nationwide renewable energy mandate and inadequate sustained subsidies for the development of wind energy. They noted that such policies are already in place in China and Europe, resulting in more than $35 billion of expected investment in 2010, nearly four times that of the US. The industry called on a reluctant Congress, one faced with recession and record budget deficits, for action. But as November's Election Day came and went, it became clear that this industry now faces an even more reluctant Congress.

The US DOE claims that federal policy is now more favourable than at any time in the last decade. But it also notes that major policies expire after 2012, leaving uncertainty for future years. And uncertainty is a funeral toll for investors.

Solar and wind companies are dreading the expiration this year of the US Treasury's cash grant programme for renewable energy projects. Given the size and significance of the US market, a substantial decline in US investment in renewable energy could have worldwide implications.

Within the European Union, several countries have guaranteed prices for energy from sun and wind, and are on track to meet the EU's CO_2 goal of '20% by 2020'. About two-thirds of US states have adopted 'renewable energy standards' that set specific though varied goals. But exceptions are often allowed for 'economic considerations', and implementation is usually left to the states' Public Utility Commissions or other appointed boards. These regulators are guardians of citizen, business, and industrial utility rates. As with many political appointees, the horizon of their vision may be somewhat narrowed by election cycles. Especially in times of recession, they take seriously their mandate to protect the purses of their constituents.

Also, most people hoped that experience and economies of scale would reduce wind energy costs. But according to data from an August 2010 study by the DOE's Lawrence Berkeley National Lab, the prices for new wind-generated electrical energy from 2009 projects is almost 80% higher than projects developed five years earlier. High power prices combined with a steep US economic recession have proven to be a challenge for the fledgling renewable energy industry.

In some cases it is difficult to fault the decisions of the regulators. Rhode Island, for example, rejected a power purchase deal for an offshore wind project that would have cost 24.4 cents per KW-hour for electricity that on average otherwise costs consumers 9.5 cents.

But other decisions seem much harder to justify. Kentucky's attorney general argued that a 0.7% overall rate increase caused by a wind energy contract was 'a discretionary expense' that customers could ill afford. The contract was rejected. Virginia regulators declined a similar deal that would have increased the average resident's monthly utility bill by 0.2%, stating that 'the ratepayers of Virginia must be protected from costs for renewable energy that are unreasonably high.' Comparable actions have occurred in other states.

Solar energy efficiency has exhibited remarkable improvement in the past few years. But in spite of significant technology-driven cost reductions and substantial subsidies, solar remains 2.5 times more expensive than coal (Table 1) and provides less than 0.05% of US electricity.

Unless CCS or other fossil fuel carbon mitigation schemes become much more cost-effective, wind and perhaps solar energy will likely be essential if greenhouse gas goals are to be met. Over time, energy storage solutions may allow us to address the fact that about 65% of the time wind turbines are idle, but for now neither wind nor solar are suitable 'base load' 24/7 electricity sources. Meanwhile, natural gas may emerge as the bridge fuel that allows for an economic and environmental transition to avert sustained global warming. And it is worth noting that some bridges are longer than others.

Nuclear

Champions of nuclear power have been re-branding the industry as one of the world's greenest. The Organisation for Economic Co-operation and Development's Nuclear Energy Agency has argued that 'nuclear energy is virtually carbon-free' across its life cycle and 'the only carbon-mitigating technology with a proven track record on the scale required.' But opponents argue that there are major unresolved issues with safety, waste disposal, and the lead time and cost for building new nuclear plants.

In 1979 the core of Pennsylvania's Three Mile Island nuclear power plant melted down. The concrete containment structure did just what it was designed to do. The reactor was crippled but no radiation escaped. No nuclear workers or nearby residents were injured and most studies agree that there was no perceptible increase in cancer cases for people who lived near the plant. But public opinion quickly turned against nuclear energy. Seven years later, Chernobyl exploded. Though the reactor was built on design principles commercially forbidden in the West, the images of that disaster on the evening news locked in American attitudes. In spite of an extraordinary safety record for nuclear energy, there hasn't been a nuclear plant ordered up since then. More than 120 reactor orders were ultimately cancelled.

Americans also share a common fear of terrorist attacks on nuclear facilities, mostly involving large commercial aircraft. Though a US Nuclear Regulatory Commission study 'confirmed that the plants are robust' and have nonetheless taken specific precautions, this fear persists. Yet most Americans readily accept coal power, even though an Abt Associates study concluded that their pollutants cause 30,100 premature deaths annually in the US alone. In politics, perception is everything.

But perhaps this is a uniquely American problem. France gets 77% of its electricity from nukes, Belgium 58%, Sweden 45%, South Korea 40%, Switzerland 37%, Japan 31%, Spain 27% and the UK 23%. Xu Yuming, executive director of the China Nuclear Energy Association, stated that China 'plans at least 60 new reactors by 2020.'

Nuclear waste disposal is probably the biggest concern to most Americans, and is the biggest objection raised to the use of nuclear power. The US EPA recently revised standards to require that facilities be capable of safely storing nuclear waste for one million years. Even for geoscientists, a million years is a long time. Radioactivity wasn't even discovered until 1896, when we travelled mostly by horse and buggy. Yet the assumption appears to be that it will require a million years to learn how to safely reprocess spent nuclear fuel. If we assumed that somehow science might evolve a reasonable solution in, say, the next thousand years, the dominant issues associated with safe storage of nuclear waste would disappear.

The last major issue raised against nuclear power plants is lead time and cost. The economics of nuclear power plants are primarily influenced by the high initial investment necessary to construct a plant and the capital financing costs while it is being built. The Nuclear Energy Institute puts the cost of a single reactor at around $9 billion. Regulatory changes following the Three Mile Island disaster added years of construction delays, but subsequent changes should significantly shorten actual first-concrete-to-completion time. Recently built non-US plants have taken five to seven years. But the total time needed to build a US nuclear reactor, from acquiring site approval to operational phase, can extend up to 9 years. Too often it seems that new plants are treated as unique 'science projects', with no two solutions ever quite the same.

Nuclear could and should be a big part of how America slashes CO_2. But it remains to be seen whether objective logic and government efforts to expedite the permitting process can overcome a long history of cost overruns and the popular political mistrust of nuclear energy.

Small nuclear

How might the challenges of nuclear energy be overcome, or at least mitigated? An interesting recent development in the US and elsewhere is small modular reactor (SMR) technology. These designs often have their roots in the reactors used to propel aircraft carriers and submarines. SMR's have passive or inherent safety features that require no human intervention to work. Sometimes called 'nuclear batteries', SMR's can be buried well below the surface, then extracted and returned to the factory for refueling. This reduces risk from terrorists. Such smaller units are also better suited to lower-cost mass production.

Critics of SMR's argue that there was a reason why early settlers of the US West chose four strong oxen to pull their Conestoga wagons instead of a thousand chickens. The output of SMR's range from 25 to 300 megawatts versus 1000+ MW for large reactors. But SMRs can be clustered to meet larger power demands, and siting and construction are much simpler. While SMR technology is just emerging, it could address some of the real and perceived issues inherent to conventional nuclear power.

Unconventional geothermal

Conventional geothermal requires naturally occurring, but relatively rare, pockets of steam or hot water that are close to the earth's surface. But a new 'engineered geothermal' approach works in areas that are not necessarily volcanically active. Wells are drilled into deep fractured hot rocks and cold high-pressure water is injected, further fracturing the rocks. Producing wells bring hot water to the surface, which then vaporizes a more volatile secondary fluid to drive turbines.

Upfront costs are high. Electricity costs are initially estimated to be around 19 cents per KW-hour. The triggering of relatively small earthquakes is an issue, but proponents argue that plants can be located far from population centres. If costs can be reduced, perhaps by locating shallow high-temperature formations or drilling parallel injection/production horizontal wells, such engineered geothermal systems could tap an inexhaustible energy supply of carbon-free, renewable 24/7 'base load' electricity.

Coal versus natural gas

While there are certainly other significant energy sources that might contribute to cutting CO_2, the two major players this article seeks to compare are coal and natural gas. They are natural competitors for the electricity consumer's dollar, and together produce 68% of America's electricity and nearly 100% of 'electricity CO_2'. Let's look at their relative strengths and weaknesses.

According to DOE/EIA data, coal-fired power plants currently account for about 80% of CO_2 emissions from the US electric power industry and about 33% of all US CO_2 emissions. Modern NGCC generators create only 40% of the CO_2 of conventional coal plants per KW-hour of electricity. But if you ignore the cost of global warming, burning coal in existing, fully cost-depreciated plants is the cheapest way to generate electricity and the greatest barrier to more widespread use of natural gas. According to the DOE-EIA, the 2008 operations, maintenance, and fuel costs for producing a KW-hour of electricity from existing coal plants with sunk construction cost was 4.05 cents. Given that either a carbon tax or a cap-and-trade system are very unlikely to pass in America's current Congress, that will probably continue to be the case. While three local governments have passed carbon taxes, no US state has or is likely to do so.

But there are other issues with coal. Coal produces far more serious pollutants than natural gas. The cost of scrubbing these noxious gasses by retrofitting older plants is high. According to the DOE/IEA Natural Gas Issues and Trends (1998), natural gas compared to coal produces only a third as much nitrous oxide, a fifth as much carbon monoxide, 4% as much sulfur dioxide, and virtually no mercury, particulate matter, or solid waste. According to the American Coal Ash Association, burning coal creates about 75 million tons per year of solid waste that must be disposed of. In fact, the fly ash emitted by a power plant – a by-product from burning coal for electricity – produces 100 times more radiation than a nuclear power plant generating the same amount of energy. Natural gas produces virtually no radiation.

Why hasn't there been a greater switch from coal to natural gas? The answer is simple: cost. But the details are somewhat more complex. In fact, natural gas has accounted for over 80% of new US generating capacity built over the past 10 years (see Figure 2). Again, there is a good reason: cost. When you include plant construction costs, fuel cost, pollution mitigation, and other factors, a modern NGCC plant delivers electricity for 7.93 cents per KW-hour compared to 10 cents for coal and 14.9 cents for wind (see Table 1). NGCC plants can be built for less than half the capital cost of coal or wind, and when you consider the permitting lead time, in about half the time of coal plants. There are far fewer 'not in my back yard' objections, so smaller more modular gas-fired plants can be located nearer consumers.

But if you look closely at Figure 2, you will notice that in the past three years coal has made something of a comeback. Why? Once again, the answer is simple: cost. In 2007, natural gas wellhead prices which had held steady at

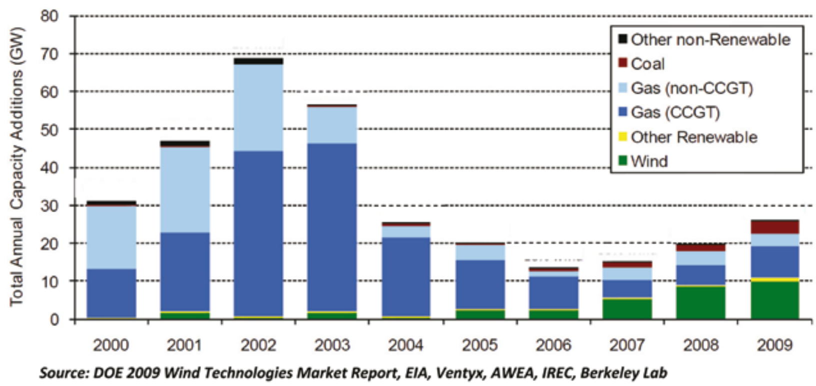

Figure 2 *Annual electricity capacity additions.*

around \$2 per MMBTU for 20 years peaked above \$11 per MMBTU (see Figure 3). While prices have recently fallen to \$4, mostly due to increased production of shale gas, Public Utility Commissions remain sceptical of the stability of natural gas prices. However, inflation-adjusted coal prices have also risen about 60% since 2000. Numerous wind subsidies (about \$23/MW-hour) will likely expire in the next few years. So while coal and wind have their own issues, the perception of price instability for natural gas remains a barrier to greater adoption.

DOE/IEA statistics report that America's existing natural gas power-generation capacity is 455 GW compared to 337 GW for coal. In theory, capacity exists to replace all coal electricity with natural gas, but the reality is that much of that capacity consists of low efficiency gas 'peaking plants', designed to be operated only a few hundred hours a year when power needs are greatest. Larger efficient NGCC generators, nevertheless, still represent about 40% of natural gas capacity.

A study by the US Congressional Research Service looked at the potential for replacing existing coal plant electricity generation with under-utilized NGCC generators. In 2007 only 13% of the NGCC plants operated above 70% capacity and a third were at less than 30%, while coal plants were at 75%. The report estimated that if existing NGCC plant utilization could be increased to 85%, then 640,128,780 MW-h (32%) of all coal power could be displaced, cutting electricity-related CO_2 by an estimated 19% (382 million metric tons) at a cost far below CCS retrofits to existing plants.

Unfortunately, however, there are some serious limitations to such a strategy. The study looked at congestion on the transmission grid, pipeline capacity, plant utilization patterns, and fuel cost. To minimize the transmission grid issues, the study considered only NGCC units located near large coal-fired plants. Using a limit of a 25 mile radius, the study computed a maximum possible displacement of 9% of total US coal power and a 5% (105 million metric tons) net reduction in electricity-related CO_2. This would also require an additional 4.5 billion MMBTU per day of natural gas.

In an analysis such as this it is always beneficial to look at 'end-members', regardless of how improbable they may appear to be. What if America replaced all current coal-fired electricity generation with NGCC plants? In 2008 DOE/EIA reported that coal-fired electricity generated 1943 million metric tons of CO_2. By switching coal to NGCC, about 60%, or 1166 million metric tons of CO_2 could be eliminated. Using the DOE/EIA 2008 total US estimate of 5839 million metric tons, cutting coal's CO_2 would reduce America's total CO_2 emissions by 20%. It would also require an increase in natural gas production of about 39 BCF per day, compared to total US consumption of 62 BCF per day, an increase of 56%.

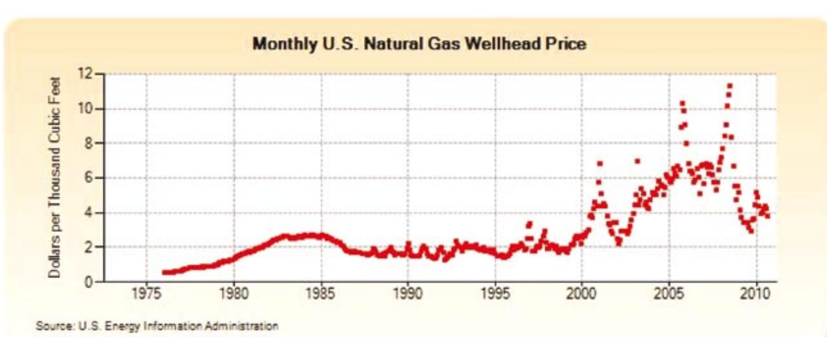

Figure 3 *US historical natural gas prices.*

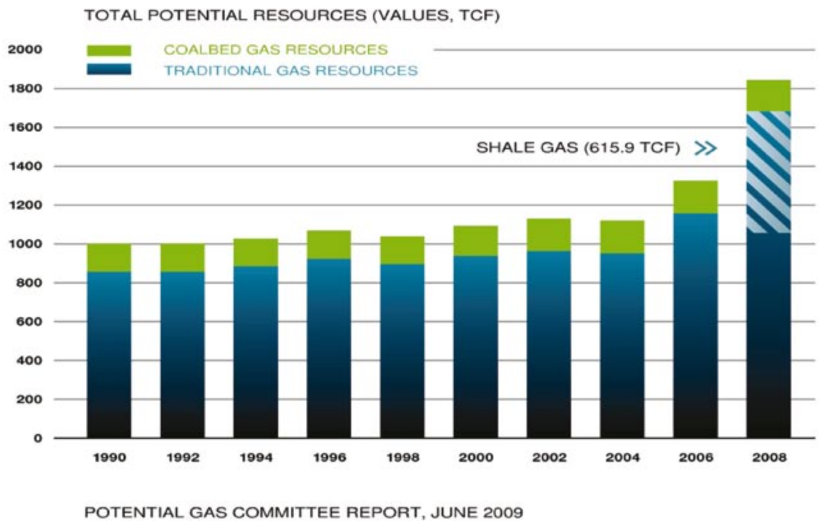

***Figure 4** The impact of shale gas on US reserves.*

Fortunately, shale gas development has recently substantially increased estimated US natural gas reserves (see Figure 4). While challenges remain in cutting the cost of development, at current consumption levels America has an estimated 100-year supply of natural gas. And shale gas reserves are just beginning to be recognized and developed, both in the US and in America's largest trading partner, Canada.

Figure 5 illustrates the extent of shale gas basins in America. Vast resources such as the Marcellus Basin are also located near the huge US east coast electricity market. Many of these basins are rich in hydrocarbon liquids, which improves the economics of development. While US shale gas potential reserves represent a substantial economic opportunity for domestic producers, development is likely to be delayed without a significant growth in markets. Some of the growth in natural gas demand is occurring from the patterns of new plant construction (see Figure 2) driven by the lower NGCC electricity costs for new construction (see Table 1). However, in some cases reducing air pollution may be a driver as well.

In 2009, Colorado was struggling to meet environmental air quality standards along the eastern Front Range of the Rocky Mountains. Recognizing the advantages of NGCC over coal, Governor Bill Ritter created a coalition of gas producers, environmental groups, Republican and Democratic legislators, and Xcel Energy, Colorado's dominant electric utility. After studying the costs of retrofitting existing coal plants with stricter pollution controls, the coalition proposed

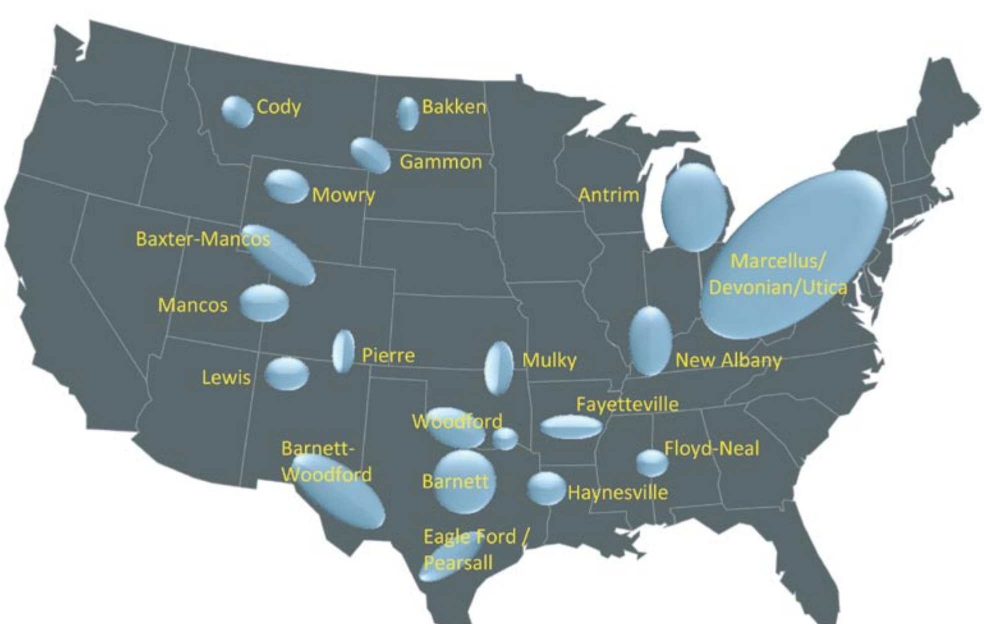

***Figure 5** Major US shale gas basins.*

replacing several ageing coal plants with NGCC generators. In spite of a $2 million campaign by the coal lobby, the bill passed by overwhelming majorities in Colorado's Senate and House of Representatives in a remarkably short 17 days. The net impact on consumer bills is estimated to be 1.7%, but that cost is $243 million less than retrofitting the existing coal plants. Clearly, similar opportunities may exist in other states.

Price instability is a significant barrier to more widespread use of natural gas. The DOE/EIA estimates spot wellhead natural gas prices at about $6–7 over the next 10 years. But any Public Utility Commissioner who has a look at the spikes and swings evident in Figure 3 will have reservations about committing to gas. It is easy to drown in a river that is an average of 2 ft deep.

To some degree this is already being addressed by long-term contracts and commodity price hedging. This has become a fairly common practice for most utilities and gas producers. As long as the long-term domestic supply is stable and guaranteed, deals can be made. And vast US shale gas reserves may also prove to be a game-changer. Partnerships might be another alternative to improve price stability. Utilities often have good access to capital, and need a reasonably-priced, long-term supply of natural gas. Developers have leases, a need for expanded markets, key land positions, and the critical resources to manage gas production efficiently. This would appear to be a potential win-win deal.

Conclusions

Carbon capture and storage is the only currently known solution for burning fossil fuels without adding significantly to greenhouse gases. In America, given the challenges facing nuclear and renewables plus the lack of suitable hydro-electric sites, the continued development of CCS will be essential to achieve long-term goals for CO_2 reduction. But given the lead times for CCS development, natural gas could well offer the only practical bridge to that future. It is not a perfect solution, but can we afford to let the perfect be the assassin of the good?

To summarize:

- In the US, additions of wind and solar power are likely to decline significantly without the renewal of subsidies and tax credits, and that decline appears to have already begun.
- Renewal of current subsidies and tax credits appears to be unlikely in the current political environment.
- The significant expansion of US nuclear power in America will be difficult to achieve.
- US electricity markets are increasingly price-sensitive, in part due to the recession and in part due to shifting political winds.
- Electricity generation is responsible for 40% of America's total CO_2. Coal produces 45% of US electricity but 80% of electricity-related CO_2.
- Opportunities for retrofitting existing US coal-fired plants to CCS are more limited in the US due to the low efficiencies of the installed base.
- Modern natural gas-combined cycle (NGCC) plants can provide electricity at a significantly lower cost than can new conventional coal-fired plants.
- NGCC plants produce 60% less CO_2 per MW-hour than conventional coal-fired plants.
- America has a 100-year domestic supply of natural gas at current consumption levels and rapidly growing unconventional gas resources.
- Though such a change is unlikely, replacing all coal-fired electricity with NGCC plants would cut total US CO_2 emissions by 20%.
- The low cost of electricity from existing coal plants will be a barrier to the greater use of natural gas, unless the external costs of greenhouse gasses and noxious pollutants are taken into account.
- Uncertainties regarding the stability of the price of natural gas are a deterrent to its expanded use, though long-term contracts, price hedging, and potentially utility-gas producer partnerships can mitigate this issue.
- Pollution control could offer a significant and immediate advantage for natural gas over coal in some markets.
- In spite of the challenges, ultimately a transition to renewable energy, nuclear, and/or CCS-assisted natural gas or coal will be necessary to meet long-term CO_2 reduction goals.

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