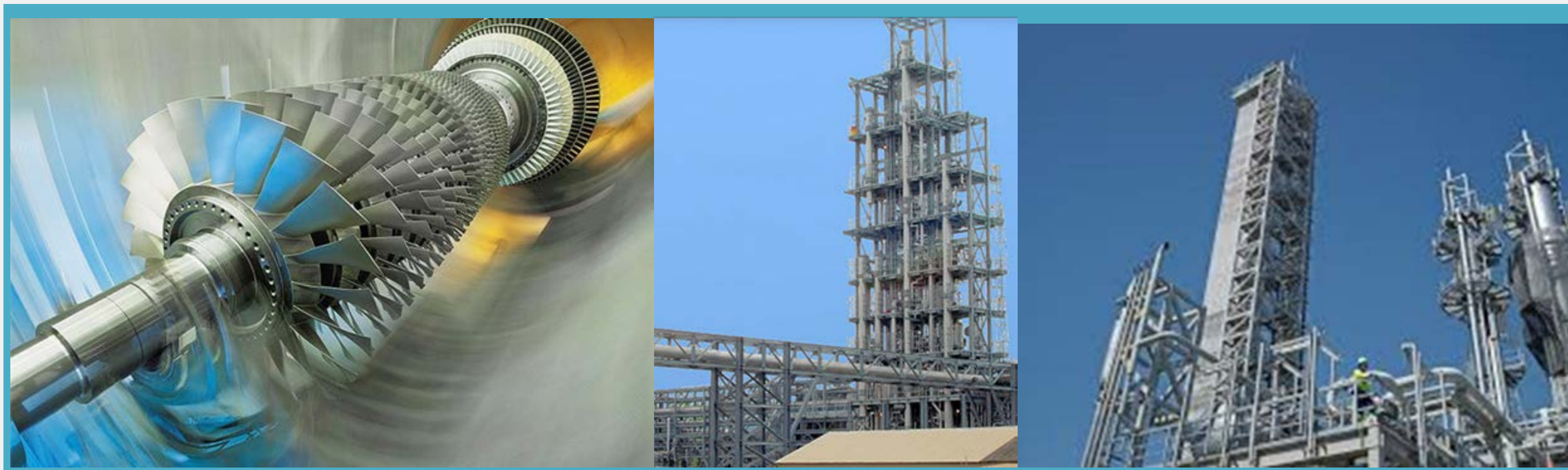


Carbon Capture Opportunities for Natural Gas Fired Power Systems

Changing Role of Natural Gas in Energy Generation

The past decade has brought dramatic changes to both U.S. and global energy use.

Globally, the EIA forecasts that, assuming no new policies, natural gas generation will grow at a rate of 2.7% per year between 2012 and 2040, accounting for nearly 30% of total worldwide energy generation by 2040—nearly equal to projected coal generation. The EIA forecasts that coal generation will decline from 40% of global generation in 2012 to 30% in 2040 as production of shale gas expands globally and as policies to reduce greenhouse gas emissions are adopted.[2] This forecast trend reflects an assumption that many countries will look to natural gas to reduce the carbon footprint of their energy sector, as both a primary generation source and as back up to other low-carbon variable generation sources.

In the U.S., as recently as 2006, gas fired power generation was less than 20% and coal-fired generation was almost 50% of U.S. totals, compared with expected 33% and 32%, respectively by the end of 2016. This recent increase in domestic natural gas generation will only grow due to the recent discovery and production of inexpensive domestic shale gas.

In August 2016, the Energy Information Administration (EIA) reported that, for the first time since 1972, U.S. energy-related carbon dioxide (CO_2) emissions from natural gas exceeded those from coal. This change in emissions sources was due to increases in natural gas consumption and decreases in coal consumption in the past decade.[1] In addition to natural gas-fired power plants and natural gas used for heating, natural gas is also consumed in the industrial sector. Major industrial sources of CO_2 emissions in the United States include natural gas processing, refineries, metals and cement production and lime manufacturing.[3] There has been dramatic growth in the use of natural gas in these industrial applications, also due to low cost and expected long-term availability. All reported industrial sources represent nearly one-third of total U.S. greenhouse gas (GHG) emissions, excluding electricity production. Some of these sources, such as natural gas processing, present highly accessible targets for application of carbon capture, utilization and sequestration or storage (CCUS).

CCUS for Environmental Sustainability

CCUS technologies provide a key technology pathway to address the urgent U.S. and global need for affordable, secure, resilient, and reliable sources of clean energy. There is now increasing international consensus both in the government and industrial sectors that CCUS technology is an important technology solution and necessary for sustainable and cost-effective production of electricity and other products. In addition, key sources within the industrial sector, cannot be deeply decarbonized without

CCUS. Industry leaders are increasingly reaffirming the importance of CCUS technologies to advance sustainable and affordable low-carbon fossil fuels. In November 2016, the CEOs of ten major oil companies announced the "Oil and Gas Climate Initiative" and a pledge of $1 billion to accelerate development of low-emissions technologies such as CCUS.[5]

Economic Growth Opportunities

Deployment of CCUS technologies not only creates a viable pathway to being environmentally sustainable, but it also has the potential to catalyze domestic employment. CCUS can bring with it significant economic benefits across a range of sectors, including coal mining and extraction, energy infrastructure, the manufacture of CCUS equipment, and supply chains including component parts and raw materials for the utilization of CO_2. CCUS can benefit from several near-term opportunities for the utilization of CO_2, such as enhanced oil recovery (EOR), as a working fluid, bio-refining, and production of high-value products.

For instance, the U.S. electric power generation and fuels production industries employed 1.6 million people in 2015. Of this total, just over 1 million people were employed in fossil fuel-based electrical generation and fossil fuel extraction and mining.[4] Deployment of CCUS technology will keep these resources viable for the long term while significantly reducing carbon emissions.

The U.S. is a global leader in both CCUS and CO_2-EOR. Maintaining this technological edge will create jobs in the United States and provide economic opportunities to export our CCUS technologies, products, and services to other countries. Given the necessity for environmentally sustainable technologies in the global marketplace, those countries that succeed in developing CCUS technologies stand to play a significant role in the global market for clean energy.

Existing Carbon Capture Technologies for Natural Gas

The rapid growth in gas-fired power generation underscores the fact that carbon capture technologies can no longer be limited to coal-fired applications. Carbon capture technologies appropriate for natural gas systems have been proven technically feasible through decades of small commercial deployment in the energy and industrial sectors. But currently, these technologies are too expensive to deploy across the energy sector because they have not been proven at full scale, and the capital and operating costs are too expensive when compared to the limited revenue generating applications for CO_2 that are currently available. These technologies include first-generation, amine-based solvent systems that have been used to separate CO_2 from natural gas generated flue gases at power plants, and a variety of amine-based compounds and advanced polymeric membranes that have been used in the industrial sector to remove CO_2 during natural gas production and purification operations. Research and development is necessary to reduce costs to enable wide-scale deployment.

The Bellingham natural gas combined cycle (NGCC) power plant in south central Massachusetts demonstrated the commercial viability of carbon capture using Fluor's Econamine FG PlusSM™. The 40 MW slipstream capture facility operated from 1991 to 2005 and captured 85-95% of CO_2 that would have otherwise been emitted. Figure 1 shows the power plant and the capture system. The CO_2 captured from this facility was purified and sold to the food industry.

Figure 1: Bellingham Carbon Capture Plant (Source: Fluor)

Recently, there have been positive, new developments. Several advanced solvent technologies—including those produced by Shell-Cansolv, Aker Solutions, Carbon Capture Solutions India, and Alstom—have been validated for post combustion capture on natural gas flue gas at the large pilot scale at the Test Centre Mongstad (TCM) facility in Norway. The TCM facility hosts a 13MW solvent system and a 15MW chilled ammonia capture facility. These facilities are supplied flue gas from a NGCC power plant and a catalytic cracker from a neighboring refinery.

Generally, these first-generation capture technologies have proven that carbon capture from natural gas power plants is an available technology and can be scaled for commercial application. To date, however, the costs to do so would likely require significant financial incentives, or revenue raised through sale of the CO_2 for industrial uses, such as enhanced oil recovery or chemical production. Full commercial deployment requires a robust, well developed industry sector, R&D program, and set of policy incentives, as we have seen happen with photovoltaic solar, onshore wind, LED lights, etc.

Advanced Technology Options and R&D Challenges

While DOE's coal CCUS research, development, demonstration and deployment (RDD&D) program has many synergies with natural gas CCUS, there are also areas unique to natural gas CCUS that require additional RDD&D. Emissions from natural gas power systems have a higher oxygen content and lower CO_2 content relative to coal-based systems. This lower CO_2 content requires a larger solvent-based absorber and demands more energy and surface area for a membrane-based capture system. Advanced CO_2 capture technologies are being developed by DOE that can be directly applied to natural gas power plants in the near term including:

Post Combustion Capture: Post-combustion capture is similar to the 1st generation technologies used at the Bellingham plant. It requires the separation of CO_2 and nitrogen after the combustion of natural gas with air. Challenges include high oxygen content, which can lead to faster solvent degradation rates and purity of permeate through a membrane system. Natural gas systems also tend to operate at higher temperatures, which can lead to the undesirable formation of nitrogen oxides and issues with durability of materials. Simple cycle gas turbines, absent the secondary heat recovery in a heat recovery steam generator, have higher exit gas temperatures and lower cycle efficiencies, which negatively affects the economics of capture. Examples of advanced carbon capture technologies that could be applied to natural gas power systems include advanced solvents and membranes as illustrated in figures 2 and 3.

Oxy-combustion: A natural gas oxy-combustion system separates oxygen from nitrogen prior to the combustion process (see Figure 4). These systems combust natural gas with a mixture of oxygen and recycled CO_2, which results in a flue gas that is primarily CO_2 and water. Oxy-combustion R&D challenges include higher flame temperatures than experienced when using air during combustion. In addition, the issues associated with corrosion of construction materials for gas turbine/oxy-combustion systems are poorly understood. Finally, oxy-combustion has not yet been demonstrated at commercial scale on either coal or natural gas power systems.

Integration Challenges: NGCC power plants and pulverized coal steam plants have very different integration needs, and would require modified engineering designs for post-combustion capture plant integration. For coal-fired units, the upstream pollutant capture systems impose fuel-specific requirements, including the amount of parasitic power demand on the host plant. In addition, load-following in applications where a substantial amount of variable renewable energy is dispatched is a critical consideration and is more likely to be associated with gas turbine applications than for coal-fired units, putting significant demands on the carbon capture system to ramp with the power plant. The capital cost of the required equipment and the increased plant footprint may pose challenges to both coal and natural gas facilities.

Figure 2: MTR 1MWe Polymeric Membrane System, installed and operational at a coal fired boiler

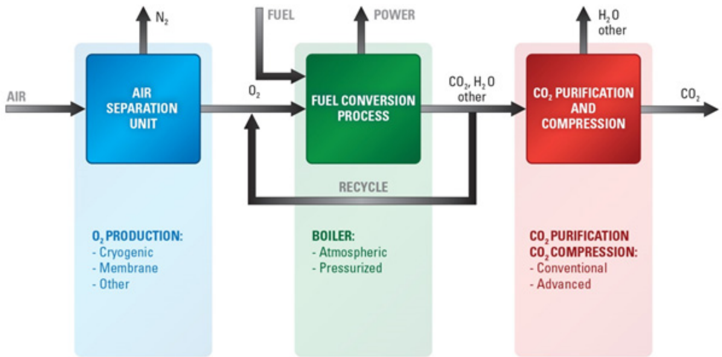
(Source: MTR, Inc.)

Figure 3: A Non-aqueous solvent (NAS) planned for testing at Tiller facility. The NAS will reduce water content and energy demand for regeneration as well as reduce the reactor size, resulting in better economics

(Source: RTI International)

Figure 5 shows the R&D challenges facing both coal and natural gas power systems, where they are similar, and how they are different.

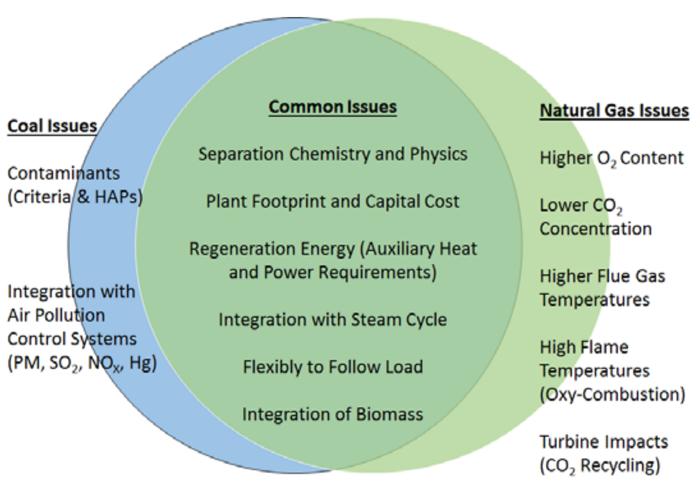
Figure 4: Oxy-Combustion Process



Economics of Carbon Capture on Natural Gas

First-generation carbon capture technologies at a NGCC plant would raise the cost of electricity by approximately 50% and cost $70 per tonne to capture CO_2.[6] A robust R&D program is necessary to reduce the costs of carbon capture from natural gas power and industrial facilities. Successfully addressing the RDD&D challenges and demonstrating advanced carbon capture technologies has the potential to reduce the cost of electricity by as much as 30% and the cost of captured CO_2 by as much as 50%.

Figure 5: A Comparison of Coal and Natural Gas CCS Issues



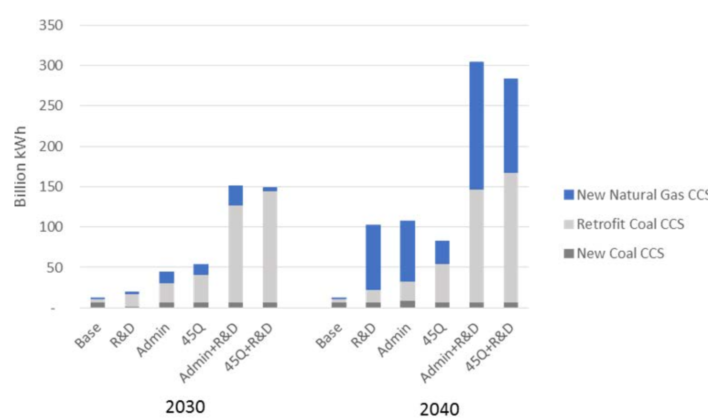
Using a version of the National Energy Modeling System, DOE analyses have explored the impact of RDD&D and tax incentives on the deployment of CCUS technologies. The results have shown that, if advanced carbon capture technology is available, technology advancement and effective incentives lead to significant deployment of CCUS for natural gas systems in the 2020 to 2040 timeframe, as shown in figure 6 below.[7]

Demonstration of Advanced Capture Technologies

Demonstration of natural gas-specific advanced carbon capture technologies at 50MWe in scale or larger would allow DOE and its industrial stakeholders to address the key issues associated with optimizing carbon capture systems for a natural gas power plant. The results of field testing under conditions relevant to natural gas power generation could then be used to inform the design basis, materials selection, and assessment of capital and operating costs of future wide-scale commercial deployment.

Because of the many similarities between natural gas and coal fired power systems, DOE's current CCUS program does address many natural gas issues. However, because natural gas CCUS faces some unique issues, more RDD&D is needed to focus on natural gas CCUS at a relevant scale. DOE is prepared to support a demonstration program to evaluate the adoption of these technologies and to reduce the cost of carbon capture for natural gas power systems.

Figure 6: Generation from Power Plants with CCS - Modeled Impact of RDD&D, Policy, and Tax Incentives Deployment



Summary

Natural gas use is experiencing strong growth, which is expected to continue. CCUS for gas-fired power generation is critical in order to meet both U.S. and global efforts to use this fuel and be environmentally sustainable, as well as providing significant employment and economic benefits across a range of economic sectors. First-generation technologies are already available, but more effort and R&D is required to advance into full commercial application. CCUS for natural gas systems will be necessary in the future to ensure it is readily available for power generation and as a feedstock for the industrial sectors.

1 See: http://www.eia.gov/todayinenergy/detail.php?id=27552
2 Energy Information Agency – International Energy Outlook 2016, May 11, 2016 - https://www.eia.gov/forecasts/ieo/electricity.cfm

3 See: https://www.epa.gov/ghgreporting

4 Carbon Capture, Utilization, and Storage: Climate Change, Economic Competitiveness, and Energy Security, U.S. DOE August 2016, http://energy.gov/sites/prod/files/2016/09/f33/DOE%20-%20Carbon%20Capture%20Utilization%20and%20Storage_2016-09-07.pdf

5 Oil and Gas Climate Initiative, http://www.oilandgasclimateinitiative.com/news/announcing-ogci-climate-investments

6 Cost and Performance Baseline for Fossil Energy Plants, DOE/NETL-2015/1723, July 6, 2015. https://www.netl.doe.gov/energy-analyses/temp/CostandPerformanceBaselineforFossilEnergyPlantsVolume1aBitCoalPCandNaturalGastoElectRev3_070615.pdf

7 Carbon Capture, Utilization, and Storage: Climate Change, Economic Competitiveness, and Energy Security, U.S. DOE August 2016, http://energy.gov/sites/prod/files/2016/09/f33/DOE%20-%20Carbon%20Capture%20Utilization%20and%20Storage_2016-09-07.pdf