Underground Coal Gasification

Overview

Underground coal gasification (UCG) converts coal in place (underground) into a gaseous product, commonly known as synthesis gas or syngas, through the same chemical reactions that occur in conventional above-ground gasification plants. It has many of the advantages of conventional gasification with respect to flexibility in commercial use, but has a potentially lower cost and a superior environmental profile. UCG could increase coal resources available for utilization enormously by gasifying otherwise unmineable deep or thin coal seams.

UCG may have a cost advantage over other coal conversion technologies. This advantage may be particularly relevant to the area of carbon dioxide capture and storage (CCS).

As a result, UCG may not only provide an important avenue for low carbon use of coal in the U.S., but also eventually in rapidly developing economies.

UCG technology was first developed in the former Soviet Union (FSU) in the 1920s. The U.S. and Europe also conducted several tests in the 1970s and 1980s. In the 1990s, China began UCG research and development and is continuing with this effort.

UCG is currently experiencing a resurgence with the development of a handful of initial commercial start ups in the last decade, as well as some successful pilot projects. However, a significant research and development effort is needed to fully commercialize the technology and make it available for wide-scale use.

History

Between 1974 and 1989, the U.S. was the site of major research and deployment efforts in UCG. This was largely driven by the OPEC oil embargos and increasing oil prices, and ended effectively with the 1986 drop in oil prices. During this time, there were 33 UCG pilots in Wyoming, Texas, Alabama, West Virginia, and Washington. These plants were laboratories for major technology developments and validation of cavity growth and gasification models. The Department of Energy (DOE) sponsored much of this research, and Lawrence Livermore National Lab was a major participant, managing 50% of the pilot plants.

The FSU was the first nation to initiate a national program of UCG research and development, in 1928. Underground experiments had begun by 1933 in parallel with the experimental and theoretical programs. Commercial-scale production of syngas was achieved at numerous locations and for long periods of time, most notably at Angren, Uzbekistan. The Angren mine began production in 1959 and still has UCG technology in place to produce 18 billion cubic feet of gas for the Angren power station. By 1996, UCG plants in the FSU had extracted and processed over 17 million metric tons of coal.

UCG production peaked in the FSU in the mid-1960s, and then decreased in the 1970s. It is likely that the discovery of extensive natural gas deposits curtailed support for the UCG effort to build gas pipelines and other infrastructure. UCG ceased to be economically competitive with this new gas resource.

Current Activity

Currently, only a few companies in Canada, Australia and China claim commercial readiness. There is little activity in the U.S. The ability to expand commercial operations is limited by experience, know-how, and availability of staff with past experience in this area.

In 2007, the South African power utility Eskom initiated a UCG pilot plant. The results have been extremely positive, and Eskom, the Ministry of Coal, and Ministry of Energy have announced plans to build a 2,100 MW combined cycle plant to run entirely on UCG syngas.

In addition, the XinAo Group (one of China's largest private companies and largest natural gas distributor) initiated a pilot project in 2007. The results have been sufficiently positive to develop a 20,000 ton/year coal-to-methanol plant by summer 2008, and have prompted an expansion project for a 300,000 ton/year coal-to-methanol plant by end of 2009.

Several proposed projects are proceeding with lease purchases, exploratory drilling, and local construction. These include projects in Australia, New Zealand, China, India, South Africa, Brazil, Canada, the United Kingdom, and the U.S. In particular, GasTech announced its plans to build and begin a UCG pilot in the Powder River Basin in 2006. In 2007, BP and GasTech announced a joint venture in which BP would assess the project for potential sponsorship of the field pilot.

Key Advantages

UCG has several key significant advantages including:

- A 300% to 400% increase in recoverable coal reserves is possible by using coals that are unmineable (too deep, low grade, thin seams);
- No conventional gasification facilities are needed; hence, capital costs are substantially reduced;
- UCG with CCS appears cost-competitive with other coal-based technologies (e.g. super critical combustion, IGCC) without CCS;
- Conventional coal mining is not a part of UCG facilities, reducing operating costs and surface impacts, as well as eliminating mine safety issues;
- No coal is transported at the surface, reducing cost, emissions, freight congestion, and facility footprint associated with coal storage and shipping;
- Most of the ash in the coal stays underground, thereby avoiding the need for additional syngas clean-up, and the environmental issues associated with ash storage;
- There is no production of some criteria pollutants (e.g., SO_2, NO_x) ,and many other pollutants (mercury, particulates, sulfur species) are greatly reduced in volume and easier to handle; and
- Commercial UCG applications use substantially less water than conventional gasification technologies.

Limitations/Concerns

Even though UCG has a number of advantages, the technology has several limitations and potential concerns:

- Siting and operation of UCG have environmental consequences, including groundwater impacts and ground subsidence. Current knowledge and practice can eliminate or reduce these environmental risks.
- While UCG may be technically feasible for many coal resources, a number of deep seams may be limited by geologic and hydrologic hazards.
- UCG operations cannot be controlled to the same extent as conventional gasifiers. Many important process variables, such as the rate of water influx, the distribution of reactants in the gasification zone, and the growth rate of the cavity, can only be estimated from measurements of temperatures and product quality and quantity.
- While UCG economics appear promising, uncertainties in capital and operating costs are likely to persist until such time as a reasonable number of UCG-based power plants are built and operated.
- UCG is not a steady-state process, and both the flow rate and the heating value of the syngas will vary over time.

Environmental Management

UCG may impact ground-water. Also, the issue of surface subsidence needs to be addressed. Careful site selection and adoption of best management practices for operations will minimize both of these issues. Examples of this include the RM 1 test in Colorado in the 1980s and the pilot at Chinchilla, Australia in 2000. Also, operations at the Chinchilla pilot plant employed "clean cavity" technology that flushed contaminants from the reactor cavity and treated the waste water after a controlled shut-down.

Solutions to that can be employed to protect groundwater impacts include:

- Balancing operating conditions to minimize outward transport of contamination from improperly over-pressurized burn zones;
- Siting plants where geologic seals sufficiently isolate the reactor from surrounding strata;
- Selecting sites with favorable hydrogeology to minimize widespread movement of potential contaminants;
- Isolating UCG locations from groundwater resources (e.g., choosing deep seams); and
- Removing potential contaminants and undissolved pyrolysis products after the reactor feedstock is gasified.

Surface subsidence can be mitigated using three key steps:

- Appropriate site selection, including depth and strength of rock volume;
- Spacing of UCG reactors to leave walls and pillars between produced zones; and
- Identification and avoidance of structural weaknesses (e.g., pre-existing faults).

Carbon Management

Carbon management policies will create further support for UCG. The composition and outlet pressures of UCG streams at the surface are comparable to those from conventional gasifiers; as such, the costs and methodologies for pre-combustion separation are directly comparable. Conventional post-combustion options may also be applied to UCG-fired power plants. In addition, the close spatial coincidence of conventional CCS options with UCG opportunities suggests that operators could co-locate UCG and CCS projects.

There is also the possibility of storing some fraction of captured CO_2 in the subsurface reactor (reactor zone carbon sequestration). While this appears to have many attractive features, there remains scientific uncertainty and some risk in storing CO_2 this way. As such, reactor zone sequestration needs additional research.

Conclusions

The NCC has recommended that DOE should further assess the use of UCG technology. There are multiple possible actions DOE could take, either solely from government action or in collaboration with industry or other nations. The NCC recommendations include:

- Renewed Research Program – Since 1989, no government agency has sponsored research into UCG processes or products. A number of outstanding technical issues, including costs and economics, process engineering, subsurface process monitoring and control, risks and hazards, and synergies with carbon management remain unexplored.
- Detailed Engineering Analysis - Given the relatively minimal experience in the U.S. with UCG, a detailed engineering analysis of each step in the entire process should be undertaken, along with a thorough economic analysis that includes estimates of the costs at various stages of development and operation and a comparison of UCG with other power generation technologies.
- Engage with Field Demos – The two pilot plants in China and South Africa and the emerging programs in North America and India provide near-term opportunities for investigating key technical and non-technical concerns. Also, projects might be pursued through the Asian Pacific Partnership. Public-private partnerships should be investigated.
- Develop Standards – At present, there are no broadly accepted standards for siting and operation of UCG facilities. Commercial development would be facilitated by a 3-5 year research program aimed at providing industry, regulators, and decision-makers with the technical basis needed to find acceptable sites and encourage sound investments.
- Assessing UCG with CCS - These two technologies are fundamentally distinct and have their own technical, commercial, and environmental issues. A formal program to assess the incorporation of UCG with CCS would identify potential synergies that could enhance economics and site performance.