Building on History: Pathways to Energy Independence and Sustainability through Gasification and Sequestration

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1.0 Historical Perspective

For over 150 years, products derived from coal gasification have found wide commercial applications. For example, "town gas" is a product of coal gasification that is composed of 50% hydrogen, with most of the remaining fraction being methane (CH_4) and carbon dioxide (CO_2), and a relatively small percentage of carbon monoxide. In 1816, Baltimore, Maryland, began using "town gas" to provide lighting for residences, streets, and businesses. Baltimore Electric Town Gas followed in 1842, as gasification met demand for lighting in a pre-electric, pre-natural gas distribution system world. For the remainder of the 1800s and into the 1900s, additional gasification processes were developed. The Lurgi gasification process was developed in the 1880s. Gasification of coal for Fischer-Tropsch (F-T) liquids was used by Germany and Japan during World War II to produce fuels when oil supplies were limited. Production of Fischer-Tropsch fuels continued in the 1950s under South Africa's Sasol I, followed by other Sasol developments in the 1970s and 1980s. Over the last 50 years, there has been a steady progression of projects internationally (Figure 1). In each case, gasification-derived fuels have been developed to meet consumer needs, sometimes providing an alternative when oil-based fuel and natural gas supplies were constrained.

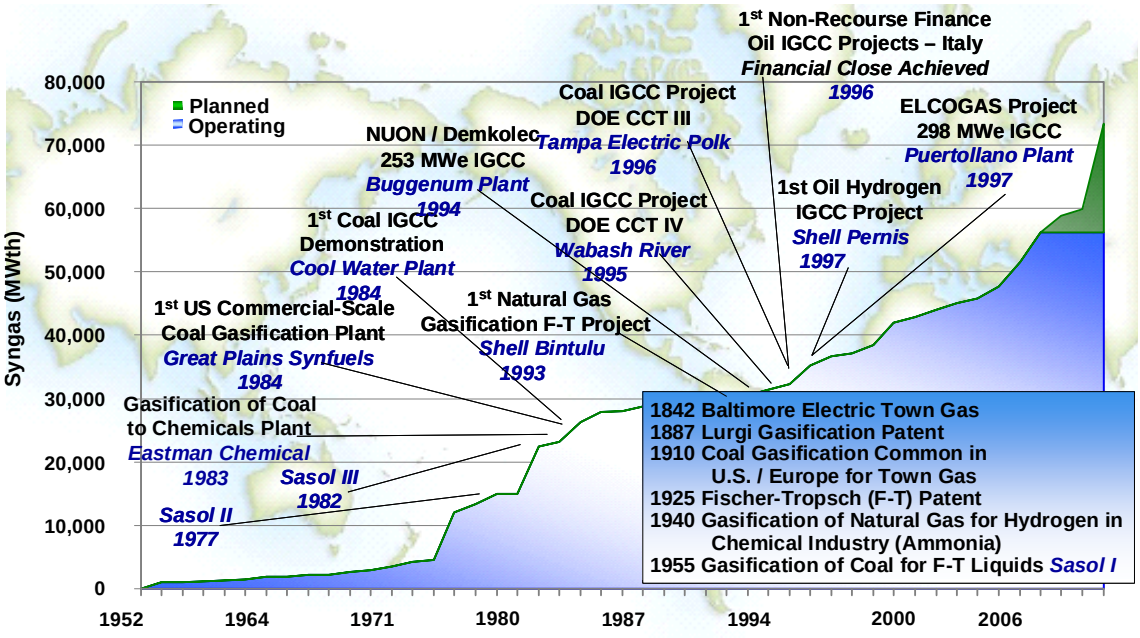

Figure 1: Progression of IGCC Projects over the Last 50 Years

2.0 DOE and IGCC - Pathway to Energy-Petrochemicals Security-Sustainability

The foundation of the U.S. Department of Energy (DOE) fuels policy rests on four cornerstones: (1) energy diversity to reduce dependence on oil; (2) reducing environmental impact and greenhouse gas (GHG) emissions; (3) enhancing the flexibility and reliability of the U.S. energy supply infrastructure to meet energy demand; and (4) strategies for cost-effectively improving the energy efficiency of the U.S. economy, thus reducing fuel demand. In pursuit of this policy, DOE has sponsored research and development (R&D) of a portfolio of

technology solutions. Since the early 1980s, DOE has placed increasing emphasis on development of gasification technology as an energy security and sustainable fuel solution.

As high prices for natural gas and highway transportation fuels persist, coal gasification has offers an increasing attractive option to convert our nation's abundant coal resources into synthetic natural gas, transportation fuels, and hydrogen for fuel cells. Also, DOE has fostered development of coal-based integrated gasification combined cycle (IGCC) technology, which combines gasification with combined cycle generation of electricity. IGCC is energy efficient and has excellent environmental performance, and has been demonstrated, with support from DOE's Clean Coal Technology Program, and proven out in two commercial-scale plants operated by U.S. utilities.

FutureGen is DOE's vision for zero emissions power production, including carbon capture and storage (CCS) technology. Working with industry, the U.S. government plans to use federal funding to demonstrate cutting-edge CCS technology in commercial-scale IGCC and advanced coal power plants. The intent of the initiative is to build multiple commercial-scale generating plants, each with electricity generation capacity of at least 300 megawatts. DOE released a Funding Opportunity Announcement (FOA) valued up to $1.3 billion on June 24, 2008, for investment in IGCC/CCS generating plants. The FOA timeline includes return of proposals to DOE by October 8, 2008, and anticipated project selection by December 2008.

2.1 DOE Gasification Program and IGCC

DOE's gasification technology research program addresses the challenges of developing low-cost systems with zero emissions and high energy efficiency. The effort to reduce pollutants in the IGCC plants includes nitrogen oxides (NOx), sulfur oxides (SOx), arsenic (As), cadmium (Cd), selenium (Se), particulates, and carbon dioxide (CO_2). DOE has defined R&D pathways to achieve these goals. For instance, for IGCC plants coming online in 2010, goals include achieving 85% capacity factor and 98% carbon conversion. By 2015, additional technical advances (e.g., chemical looping gasifiers that concentrate H_2 and CO_2 streams without costly and energy intensive cryogenic oxygen production, hydrogen gas turbines, and solid oxide fuel cell topping cycle) would enable a 90% capacity factor. For IGCC systems coming online by 2010 and 2015 (2015 plants without carbon capture), DOE's performance and capital cost targets are:

- Energy Efficiency – Increase from 45-50% (HHV) by 2010 to 50-60% (HHV) by 2015
- Capital Cost – Decrease from $1000/kW by 2010 to $900/kW by 2015 (year 2002 dollars)

Additionally, by 2012, DOE's target is to demonstrate IGCC systems with CO_2 capture with no more than a 10% increase in the cost of electricity.

To reach its targets, DOE's R&D programs are addressing major technical issues involving gas cleaning, oxygen separation membranes, and hydrogen-carbon dioxide separation (as a post-water-gas shift reaction process) technologies and the use of low-rank coal (Figure 2).

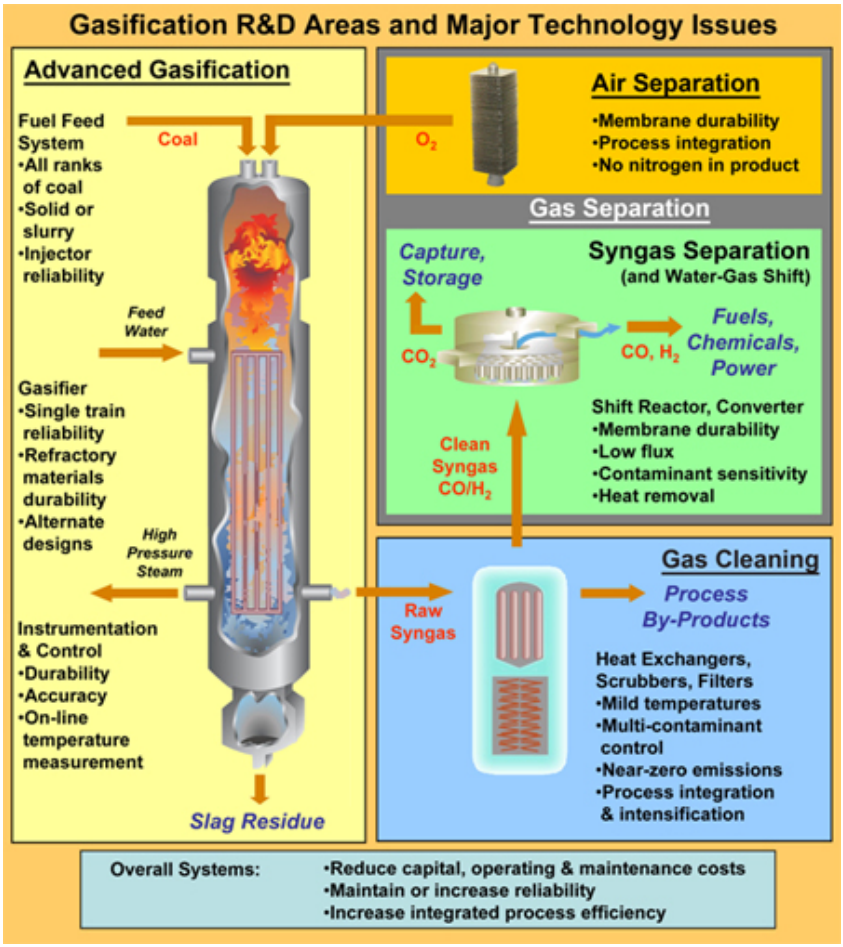

Figure 2: Gasification R&D Areas and Major Technology Issues

2.2 Flexibility of Gasification Feedstock

The flexibility of the gasification process opens the door to using energy feedstocks other than coal. Gasification processes can use sustainable renewable biomass, petroleum refining byproducts (e.g., pet coke and heavy reside), and waste products (e.g., refuse-derived fuels and municipal solid waste) as feedstocks, thereby converting these low- or negative-value feedstocks into high-value marketable fuels and chemicals.

2.3 Global Warming Considerations – Managing the Carbon Footprint: Carbon Sequestration

Based on detailed engineering studies by DOE's National Energy Technology Laboratory (NETL) and many other organizations, IGCC plants are likely the cheapest coal option when the power system cost equation includes CCS. For example, DOE has estimated that the addition of carbon capture to the average IGCC plant will increase the cost of electricity generation by 36%, but this increase is offset by the $42 per tonne CO_2 avoided cost.

2.4 From Gasification to Petrochemicals

Output of the gasification process includes a variety of chemicals that are building blocks for a multitude of consumer products (Figure 3). Syngas, a carbon monoxide and hydrogen mixture, that is the primary gasification process output, is a source of hydrogen and can be used in F-T syntheses to produce other chemicals, including naphtha, high-cetane diesel, jet fuel, and waxes. Conventionally, naphtha, a feedstock for producing basic petrochemicals such as ethylene and propylene, is a product of petroleum refining. Thus, the gasification/F-T path to naphtha promotes petroleum-independent production diversity. Examples of other gasification process by-product applications include:

- Slag for construction materials
- Hydrogen sulfide, leading to sulfur and sulfuric acid production
- Nitrogen for ammonia-based fertilizers
- Syngas conversion to synthetic natural gas
- Syngas conversion to methanol and ethanol

In each case, these applications offer potential for feedstock diversification away from fossil fuel alternatives.

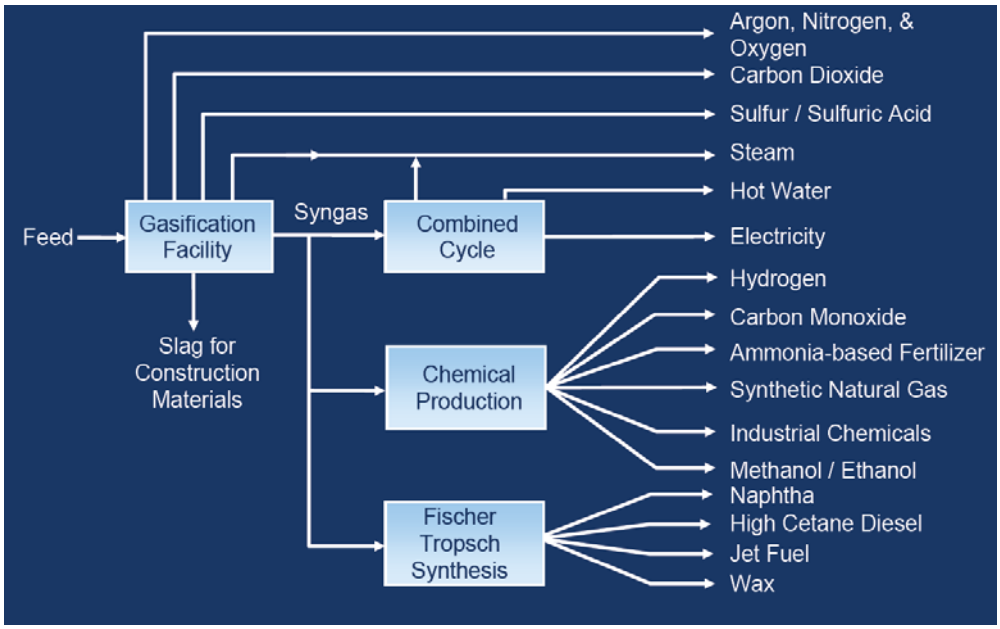

Figure 3: Gasification as a Source of Chemical Products

3.0 Progress Leveraged by International Collaboration

DOE takes an active role in fostering international cooperative efforts. Examples of organizations in which it takes a leadership role include the following:

Carbon Sequestration Leadership Forum (CSLF) – CSLF http://www.cslforum.org/ is an international climate change initiative for developing cost-effective carbon sequestration technology. It also addresses the regulatory environment needed to develop and commercialize such technology. CSLF includes 21 member countries and the European

Commission. The CSLF fosters R&D cooperation among member countries and has Task Forces that address Capacity Building in Developing Economies and Financing. The Capacity Building Task Force has conducted workshops in Brazil (2), Saudi Arabia, and the United States.

Asia Pacific Partnership on Clean Development and Climate (APP) – Government, industry, and academia in the seven APP **www.asiapacificpartnership.org** member countries – Australia, Canada, China, India, Japan, Korea, and the United States – are cooperating to address growing energy needs and related issues, such as energy security, environment protection, and climate change. The Partnership has established public-private Task Forces in eight key sectors: (1) cleaner fossil energy; (2) renewable energy and distributed generation; (3) power generation and transmission; (4) steel; (5) aluminum; (6) cement; (7) coal mining; and (8) buildings and appliances. The Task Forces are designed to meet Partnership goals through international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging and longer term cost-effective, cleaner, more efficient technologies and practices among the Partners through concrete and substantial cooperation so as to achieve practical results. Advanced power generation technologies, including supercritical and ultra-supercritical pulverized coal, IGCC, and oxy-fuel combustion, along with CCS have been identified by the Cleaner Fossil Energy (CFE) Task Force as priority areas for cooperation. Under this Task Force, several cooperative IGCC and CCS R&D and capacity building projects have been endorsed. Several joint R&D projects have been initiated between organization's member countries. Also, several workshops and seminars have been held:

- Integrated Gasification Combined Cycle with Carbon Capture and Storage (IGCC/CCS) Workshop and Design Information for APP Country Coals (Tokyo, Japan, September 4, 2007)
- Seminar on Integrated Gasification Combined Cycle (IGCC) combined with Carbon Capture and Storage (Melbourne, Australia, March 31, 2008)
- Workshop on Ultra-Supercritical Pulverized Coal and Carbon Capture and Storage (Melbourne, Australia, March 31, 2008)
- Seminar on Carbon Storage Technologies (Melbourne, Australia, April 1, 2008)
- Seminar on Technologies to Improve the Environmental Performance of Power Generation (April 1, 2008)

Asia-Pacific Economic Cooperation (APEC) – The United States has been a guiding force since the founding of APEC (http://www.apec.org/). In 2007, APEC Member Economies issued a Declaration on Climate Change, Energy Security and Clean Development. The declaration included a program of practical, cooperative actions and initiatives. The Expert Group on Clean Fossil Energy, which has been chaired by the DOE Office of Fossil Energy since its establishment in the early 1990s, is conducting a vibrant program of technical and policy studies, seminar, and capacity building activities. The EGCFE (www.egcfe.ewg.apec.org) completed the first-ever analysis of the carbon storage prospectivity of Southeast Asia and conducted capacity building workshops in Korea, China, and Mexico. Two additional workshops are being planned.

International Partnership for the Hydrogen Economy (IPHE) – The IPHE www.iphe.org was founded in 2003 to accelerate transition to an international hydrogen economy. It

currently includes 16 member nations from around the globe and the European Commission. IPHE enables partners to coordinate hydrogen and fuel cell and provides a forum for members to address common codes and standards. The United States, through DOE, is a member.

International Energy Agency (IEA) – The IEA (www.iea.org) advises its 27 member countries and the European Commission on energy policy. In addition to developing energy market statistics, IEA conducts a broad fossil and renewable energy research program involving member country participants. It also is involved in energy technology collaboration and outreach to non-member countries such as China, India, Russia, and the OPEC countries. As a member country, the United States, through DOE, participates in many of the IEA's research activities.

Under the IEA's Working Party on Fossil Fuels (WPFF, www.iea.org/about/wpff.asp), the Task Force on Zero Emissions Technologies Strategy (ZETS) was begun in 2001 as a key strategic activity to accelerate the development and deployment of these technologies (e.g., IGCC and CCS). The ZETS initiative has been characterized by regular planning, workshops, and reports to address science and technology challenges and topics and implementation strategies. DOE plays a major role in ZETS through its chairing the WPFF.

Another area where the Office of Fossil Energy cooperates with the IEA is the Greenhouse Gas Programme (http://www.ieagreen.org.uk/), which was established in 1991. The Programme's three main activities are:

- Evaluation of technologies aimed at reducing greenhouse gas emissions,
- Promotion and dissemination of results and data from its evaluation studies, and
- Facilitating practical RD&D.

The IEA GHG Programme's activities to date have covered all the main anthropogenic greenhouse gases (CO_2, CH_4, nitrous oxide, and high global warming potential gases). Its current work is focused on ways to control and reduce CO_2 emissions from fossil energy facilities.

DOE is a major supporter of the IEA's Clean Coal Centre (www.iea-coal.org.uk). A collaborative project established in 1975, this Centre supports its member's efforts to make the production, transportation, and use of coal sustainable. It accomplishes this through a program of work that includes studies, reports, newsletters, seminars and workshops that are of considerable significance for all countries involved in the use or supply of coal. Among its notable activities is the Centre's annual International Conference on Clean Coal Technologies for our Future.

In addition, DOE's National Energy Technology Laboratory has recently signed bilateral agreements with several key countries on advanced coal conversion and CCS, including:

- Ministry of Science & Technology (China)
- Pontifical Catholic University of Rio Grande do Sul (Brazil)
- Brazilian Coal Association (Brazil)
- Interdisciplinary Center, Herzliya (Israel)

- Central Mining Institute/Institute for Chemical Processing of Coal (Poland)

Several additional agreements with China and India are being developed.