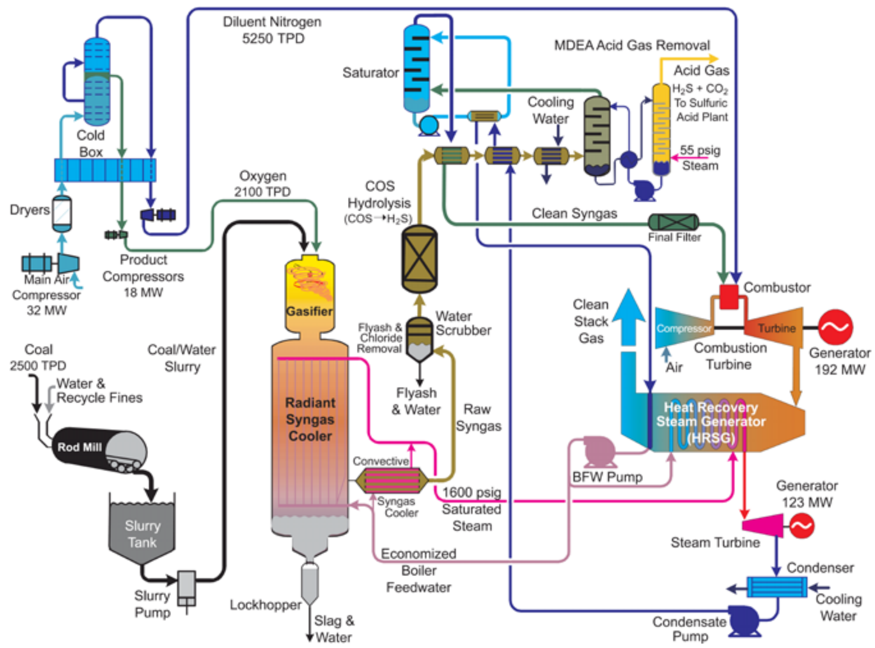
Control of Integrated Gasification Combined Cycle Power Plants with CO_2 Capture

Carbon dioxide (CO_2) emissions from today's coal-fired power-generation technology are a growing concern because of their implication in global climate change. Integrated gasification combined cycle (IGCC) power plants are an attractive prospect for clean coal power generation, with a few operational plants existing worldwide. The integration of CO_2 capture with IGCC is now being pursued, with the potential for significantly increased efficiency and lower cost of electricity than for CO_2-capture-integrated conventional pulverized coal plants. However, IGCC plants with CO_2 capture will require operation in a highly constrained and fluctuating environment. This complex environment requires the use of highly nonlinear dynamic models and poses several challenges in advanced control and sensors.



Schematic representation of an IGCC power plant

Pre-combustion versus Post-combustion CO_2 Capture

In conventional coal power plants, the fuel is pulverized and burned in a boiler. The "post-combustion" CO_2 by-product is emitted through the flue-gas stack. In IGCC plants, however, the coal is gasified and not fully combusted. The gasification process produces a synthesis gas containing "pre-combustion" CO_2 at much higher temperatures, pressures, and concentration levels, thereby facilitating the separation of the CO_2 from the synthesis gas. CO_2 capture requires the integration of a new, complex chemical engineering process. The more advanced capture systems include chemical solvents, whereas other capture processes at earlier stages of development employ novel methods such as solid sorbents or membranes.

CO_2 capture reduces the overall plant generation efficiency by 20–25% or more, but the efficiency loss is significantly lower for pre-combustion than for post-combustion technologies. In addition, the capital cost for an IGCC CO_2 capture unit is substantially lower than for the pulverized coal equivalent. Because of these factors, IGCC is often considered the preferred approach for clean coal power generation.

Current Status of IGCC Plants with CO_2 Capture in the U.S.

Several major IGCC power plants with full-scale pre-combustion CO_2 capture are moving forward in the U.S., including Mississippi Power's Kemper County lignite-fired 582-MW IGCC with 65% CO_2 capture, Summit Power's coal-fired 400-MW IGCC project with 90% CO_2 capture, and SCS Energy's petcoke-fired 421-MW IGCC with hydrogen production and 90% CO_2 capture. In these applications, the captured CO_2 will be used for enhanced oil recovery (EOR) from production wells. These large-scale projects will demonstrate the integration, operational, and control aspects of IGCC technology when coupled with CO_2 capture.

Mississippi Power's Kemper IGCC project with CO_2 capture (Source: www.biggerpieforum.org)

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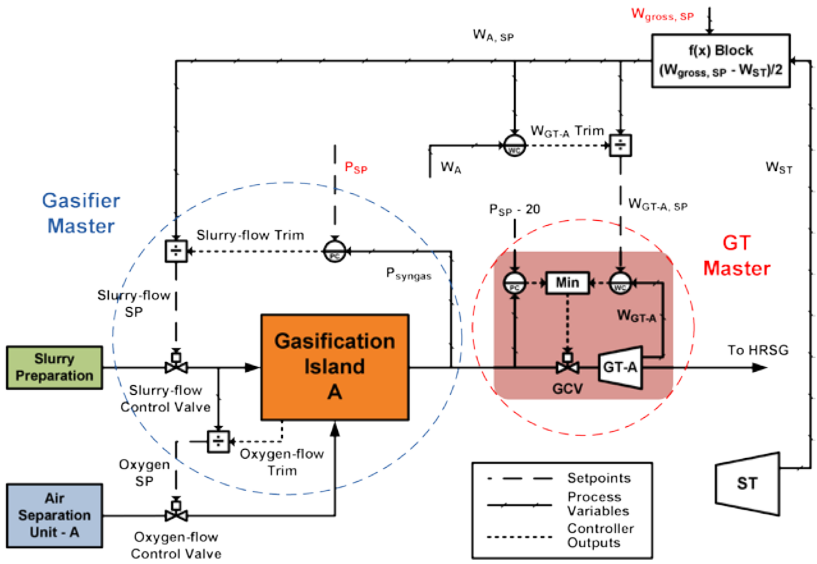
Advanced Control and Power Plant Cycling

Significant penetration of intermittent and variable renewable energy sources (e.g., wind and solar) into the grid is likely to require IGCC plants to vary their generation output in concert with renewable generation and load variations. Novel modeling and control strategies for power plant cycling and load following, while maximizing economic criteria and minimizing emissions, are needed. Cycling operations can be performed by manipulating the throughput of the gasifier and combined cycle islands in tandem, as shown in the control architecture figure at right.

Other advanced control-related challenges include:

- Fast and accurate reduced models for use in model-based control of highly nonlinear and stiff processes, such as gasification
- Solving large-scale equation systems in the multiple-software industrial automation environment
- Developing equipment damage models to assess the impact of IGCC cycling operations and control



Improved control architecture (GT leader/gasifier follower) for IGCC load following. Nomenclature: W – work, P – pressure, SP – controller setpoint, GT – gas turbine, ST – steam turbine, GCV – gas control valve (inlet guide valve), HRSG – heat recovery steam generator.

Sensors and Estimation

Because of ever-tightening environmental emission limits, the accurate estimation of pollutants (e.g., CO, CO_2, H_2S, COS, NH_3) emitted by power plants is becoming crucial. Monitoring the compositions of key process streams is also important for plant efficiency and safety. However, available composition sensors, especially for trace species, are costly, maintenance-intensive, insufficiently accurate, and do not provide real-time estimates. Development of real-time or near-real-time sensors for state estimation is required to improve advanced process monitoring and control of such species. Optimal sensor placement strategies are also needed for monitoring, disturbance rejection, and fault diagnosis.

Platform for Testing IGCC Control and Sensor Strategies

The AVESTAR® Center at the National Energy Technology Laboratory (NETL) and West Virginia University (WVU) provides a real-time IGCC dynamic simulator for developing and testing advanced control and sensor placement strategies. The figure on the left shows a distillation column in the virtual plant environment for which a control system was designed. The high-fidelity IGCC model can simulate plant performance over a range of operating scenarios, including variable-load operation, startup, shutdown, and variable CO_2 capture rates. The IGCC simulator is being used to develop novel model predictive control (MPC) strategies to improve ramp rates and load-following operation while satisfying CO_2 emission constraints. Distributed and hierarchical MPC of large-scale networked systems with embedded sensors and controllers is another area of active research.

For more information: S.E. Zitney et al., AVESTAR Center: Dynamic simulation-based collaboration toward achieving operational excellence for IGCC plants with carbon capture, Proc. of the 29th Annual International Pittsburgh Coal Conference, Pittsburgh, PA, October 15-18, 2012; http://www.netl.doe.gov; http://www.che.cemr.wvu.edu.