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RENEWABLES SA

Integrated Gasification and Coal to Liquids

Sankey Flow Diagrams

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PROJECT 101010-00576 - INTEGRATED GASIFICATION AND COAL TO LIQUIDS

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1 SUMMARY

Sankey diagrams have been produced to illustrate the typical energy process flows occurring in an example of an integrated Gasification Combined Cycle (IGCC) power plant and an example of a Coal to Liquids (CTL) power plant with integrated power generation.

The diagrams show that the gasification, power generation and (in the case of CTL) liquid hydrocarbon processes are integrated so that major savings are made in the use of energy streams which would otherwise have to be wastefully emitted to the atmosphere. These energy savings reduce the overall carbon intensity of the processes as compared to if similar processes were to be operated separately without such integration.

For clarity, some minor process flows have been omitted from the diagrams.

2 IGCC SANKEY DIAGRAM

2.1 What the diagram illustrates

The so-called Sankey diagram is intended to provide information about the magnitude and topology of energy flows in a physical process in graphical form.

The IGCC Sankey diagram has been drawn based on data output from a simulation of an integrated gasification combined cycle power plant.

Specific input data include that the plant was assumed to be using Shell gasifier technology, and "E" class gas turbine technology, with the plant fed by Lignite with an as-mined moisture content of 37%, typical of a known South Australian deposit, Westfield, proposed to be utilised under Altona Resources Arkaringa Project.

Advances in gas turbine technology, including the possibility for more advanced gas turbines to be able operate on gas streams originating from coal gasification may result in efficiency increases to the CCGT block. For a constant energy input, such efficiency increases will increase the net power output while reducing the stack gas losses, steam turbine condenser heat rejection losses, and other energy losses of the plant.

The key message which this model imparts is that the operation of the CCGT plant is highly integrated with the gasification and gas cleanup stages. To carry out the gasification without integration into a CCGT plant would result in significant waste of energy.

2.2 Why the diagram has been produced

By illustrating the energy flows in the form of arrows between defined blocks of equipment, with arrow width scaled according to the size of the energy flow, the diagram attempts to provide the reader with understanding of the way in which the different equipment interacts. Major energy flows can be easily identified, and the key fact shown, that the combined cycle gas turbine power island receives major portions of its input energy from both the Syngas stream chemical and heat energy, and also from steam produced as a by-product of the gasification cooling.

2.3 How the diagram has been produced

The IGCC plant was simulated using the Thermoflow GTPro power generation thermodynamic and cost modelling software package for a plant operating at standard conditions of 15 degrees Celsius and sea level atmospheric pressure.

The simulation model includes modelling of the processes of converting the incoming coal to synthetic gas or "syngas" by gasification, removal of undesirable contaminants in the raw syngas, which takes place in the gas cleanup portions of the process, and conversion of the clean syngas energy to electrical power in a combined cycle gas turbine (CCGT) power plant. In addition to the incoming cleaned Syngas flow, the CCGT plant also gains a significant amount of net input energy from steam produced in the gasification island during cooling of the syngas.

The gasification process produces raw syngas at high temperature and pressure by reacting coal in a pressurised gasifier with steam and injected oxygen. The oxygen is produced on site in an associated air separation plant. The raw syngas is principally composed of hydrogen, carbon monoxide, carbon dioxide and water vapour, with small amounts of sulfur-containing "acid gases", as well as ammonia and methane.

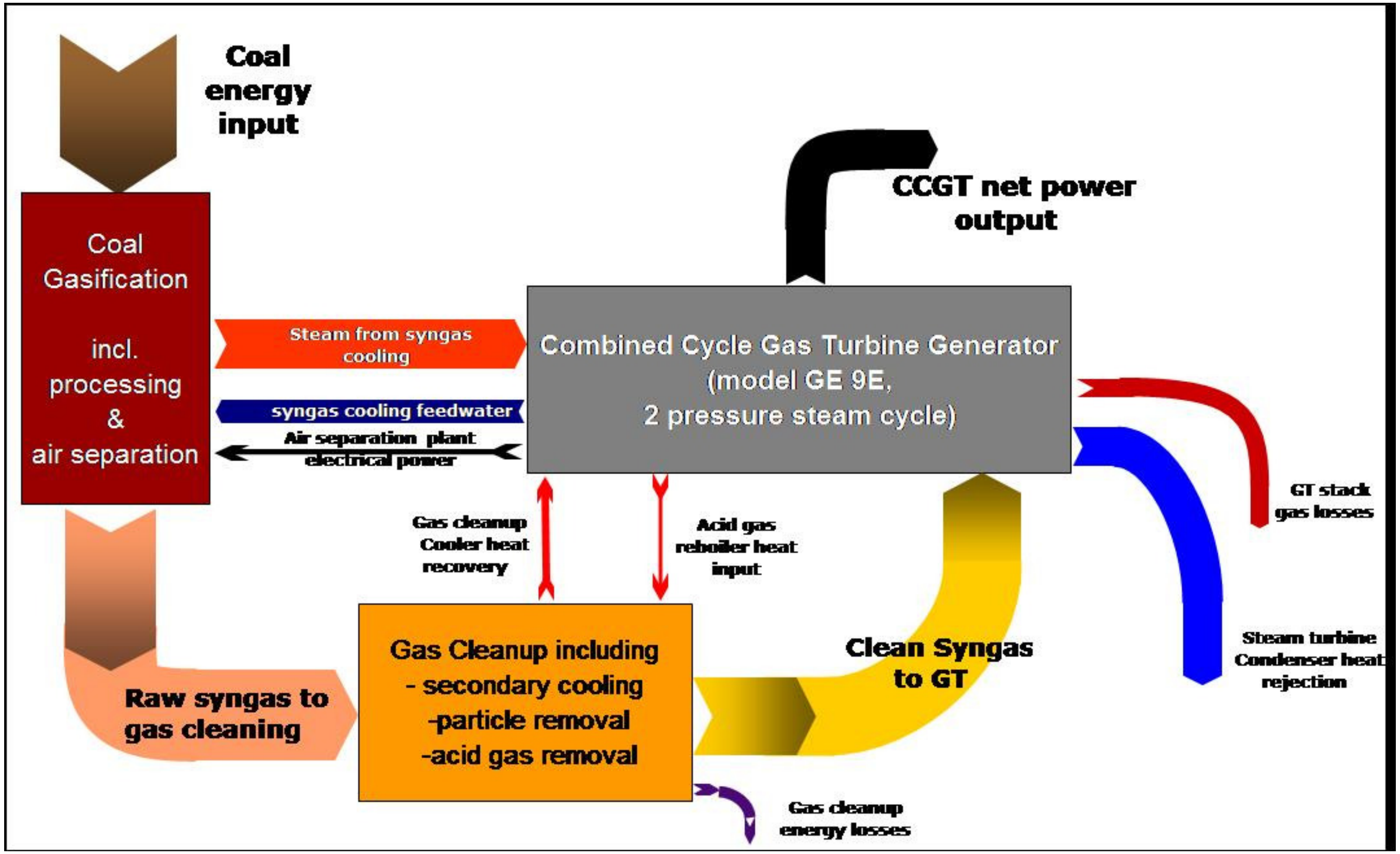
Gas cleanup of the raw syngas to remove unwanted "acid gas" was modelled as being carried out in an absorber-reboiler process which is typical for such installations. The gas cleanup system requires some electrical and thermal energy to be input, and in the case of the IGCC plant this energy is sourced from the CCGT island, as has been indicated on the Sankey diagram.

The model as simulated does not include removal of carbon dioxide from either the raw syngas stream, nor from the gas turbine stack exhaust gases. Capture and removal of CO2 from the raw syngas would involve additional stages of equipment to carry out the following processes:

- maximise conversion of carbon monoxide in the syngas to carbon dioxide and hydrogen gas by reaction with water (a process termed the "water gas shift reaction")
- Removal of as much CO2 from the syngas stream
- Cooling and compression of captured CO2 up to pressures suitable for transport for sequestration or sale.

Inclusion of these CO2 capture and processing stages would result in additional equipment costs and additional energy requirements which would reduce the plant net electrical power output.

Figure 1 Sankey Diagram,Brown Coal IGCC Power Plant



3 COAL TO LIQUIDS WITH IGCC POWER GENERATION SANKEY DIAGRAM

3.1 What the diagram illustrates

This diagram is conceptually similar to that for the IGCC power generation diagram, in that energy flows are illustrated as arrows of width scaled linearly with the magnitude of energy flowing between the various elements of the plant. In this case the simulated plant models a coal to liquid (CTL) hydrocarbons conversion facility, producing CTL diesel fuel and lighter liquid hydrocarbon fractions by conversion of the same assumed SA Lignite (Westfield coal, 37% moisture).

The process as modelled consists of the following main steps:

- Coal gasification to produce a raw syngas stream and waste heat which is converted to steam and directed to an associated combined-cycle gas turbine power plant;
- Gas cleanup of the raw syngas stream to remove undesirable constituents;
- Conversion of the cleaned syngas stream to hydrocarbons by a Fischer-Tropsch conversion process, with subsequent refining of the produced hydrocarbons to separate synthetic diesel fuel and light hydrocarbon (Naptha) streams;
- Use of the residual "tail gas" stream downstream of the Fischer-Tropsch process in a combined-cycle gas turbine power plant to produce electrical power. Additional steam to the steam turbine portion of the CCGT is produced by utilisation of excess heat from the coal gasification process.

The Sankey diagram shows the following key interactions in the entire coal to liquids process:

- 33% of the chemical energy of the incoming coal feedstock is converted to the synthetic diesel and naptha liquid hydrocarbon products
- 10% of the chemical energy of the incoming coal is converted to export electrical power.
- Around 57% of the incoming coal energy must be rejected as waste heat, either from the steam turbine, gas turbine, or coal to liquids processes;

These figures are typical and may vary slightly, depending on the selection of air separation, gasification, gas cleanup, Fischer-Tropsch conversion and CCGT technologies.

3.2 How the CTL and Power Generation Processes are integrated

The CTL process Sankey diagram shows that the energy flows to and from the major plant blocks is highly integrated, to the following extents:

- The energy contained in the Fischer-Tropsch tail gas stream is from 50 to 80% the magnitude of the net hydrocarbon product energy. If the CCGT plant was not integrated with the Fischer-Tropsch synthesis and hydrocarbons upgrade process, this energy would either be wholly wasted, or in case of major additional expenditure to recycle tail gas within the Fischer-Tropsch synthesis, partially wasted.
- Electrical power which is used internally in the plant, mainly in the oxygen separation plant, gas cleanup and Fischer-Tropsch synthesis and upgrade stages, is very close to half of the total gross generation (that is, of the gross generation, about 50% is exported, and 50% used internally in the plant). Separation of the gasification, Fischer-Tropsch and CCGT processes would require

provision of this large internal electrical load to the gasification and Fischer-Tropsch process by imported power from the electrical grid, increasing transmission losses. In addition, due to the need to run the entire process continuously, such power would likely need to be provided by base-load power stations, which in Australian context are mostly coal-fired.

- Around one-third of the energy input to the steam turbine power generation cycle comes from utilisation of waste heat from the gasification and CTL processes. Separation of the CCGT from the gasification and Fischer-Tropsch/CTL processes would require this energy to be dissipated to the environment, wasting the energy which could otherwise contribute to additional power generation from the steam turbine, and in case of a cooling tower cooled plant, wasting water resources for cooling water circuit makeup requirements.

Figure 2 Coal to Liquids / IGCC Power Plant