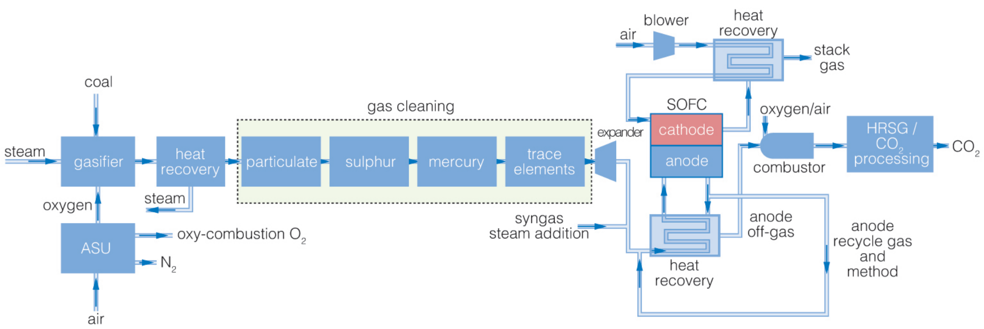
IEA CLEAN COAL CENTRE profiles

No 17-March 2015

High-efficiency power generation – review of alternative systems

A number of innovative power cycle concepts are being investigated as alternatives to the conventional steam Rankine cycle. This report reviews the R&D activities of and recent advances in these innovative power cycles. Analyses and evaluations of these power systems are also discussed in the report.

Fuel cells (FC) are electrochemical devices that convert chemical energy in fuels into electrical energy directly and so can produce power with high efficiency and low environmental impact. Solid oxide fuel cells (SOFC) and molten carbonate (MCFC) operate at high temperatures, which offer the best opportunity for thermal integration with coal gasification systems. Various coal-based FC power generation systems have been proposed and studied. Most of the proposed power systems involve the IGFC (integrated gasification fuel cell) combined cycle. The figure below shows a simplified flow sheet of a coal-fed IGFC power system. Studies show that IGFC systems with carbon capture could potentially achieve high net plant efficiencies in the range of 40-56%, with CO_2 capture rates up to 99%.



Flow sheet of a coal-fed IGFC power generation system

Gas-fired fuel cell simple-cycle power plants are already in commercial operation in many parts of the world. Coal-based fuel cell power systems are still under development. Japan's J-Power plans to demonstrate the IGFC with carbon capture in the third phase of its Osaki CoolGen demonstration project from 2021.

Chemical looping combustion (CLC) is an indirect form of combustion in which an oxygen-containing solid material, such as a metal oxide, supplies the oxygen to a fuel, and the spent oxygen 'carrier' is separately regenerated by air at high temperature. As there is no direct contact between air and fuel, CLC produces a stream of CO_2 and water vapour from which the CO_2 can be readily recovered eliminating the need for additional energy intensive CO_2 separation.

Several CLC processes fuelled by coal or coal-derived syngas are under development. In addition, several chemical looping coal gasification processes are being developed that provide flexibility to produce electricity, hydrogen or syngas. Recent work indicates that compared with conventional coal-fired plants with carbon capture, chemical looping based power plants could achieve higher efficiency and a high carbon capture rate with considerably lower energy penalty and costs for carbon capture. Currently, there are still a number of issues that require further investigation. For example, development of oxygen carriers with high reactivity and stability remains a challenge for CLC.

IEA Clean Coal Centre is a collaborative project of member countries of the International Energy Agency (IEA) to provide information about and analysis of coal technology, supply and use. IEA Clean Coal Centre has contracting parties and sponsors from: Australia, Austria, China, the European Commission, Germany, India, Italy, Japan, New Zealand, Poland, Russia, South Africa, Thailand, the UK and the USA.

Each issue of **Profiles** is based on a detailed study undertaken by IEA Clean Coal Centre, the full report of which is available separately. This particular issue of Profiles is based on the report:

High-efficiency power generation – review of alternative systems

Qian Zhu

CCC/247, ISBN 978-92-9029-569-3, 120 pp, March 2015

This report is free to organisations in member countries, £100 to organisations in non-member countries for six months after publication, and free thereafter.

A magnetohydrodynamic (MHD) power generator is a device that generates electric power by means of the interaction of a moving conductive fluid (usually an ionised gas or plasma) and a magnetic field. The MHD generator converts thermal energy of a fuel directly into electricity. Since the 1970s, several countries have undertaken MHD research programs with a particular emphasis on the use of coal as a fuel. A number of coal-based MHD power generation concepts such as direct coal-fired MHD-steam combined cycle, top or tail gasification MHD-steam combined cycle, and two-loop coal-fired closed cycle MHD power plant have been proposed and studied. Earlier work on MHD cycle analyses indicated that MHD systems could achieve a plant efficiency of 45–55%, with the potential to increase this to 60%. MHD power generation systems also have good environmental performance and are compatible with CCS systems.

Indirectly coal-fired combined cycle (IFCC) uses a topping gas Brayton cycle and a bottoming steam Rankine cycle with clean air being the working fluid to achieve high efficiencies and low emissions. In this power cycle, developed in USA as the US DOE's HIPPS (High Performance Power Generating System) Program, compressed air is heated in a coal-fired high-temperature advanced furnace. The air does not come into contact with the corrosive coal combustion environment. Either natural gas or a clean coal-derived fuel gas is used to boost the temperature of the air to the desired turbine inlet temperature. The heated pressurised air is then expanded in a gas turbine producing more than half of the cycle's power output. Heat is recovered from both the coal-fired furnace flue gas and the gas turbine exhaust to drive a conventional Rankine steam cycle to maximise electric power production. The HIPPS plant concept can be applied to new power plants or adapted to repowering of existing coal-fired plants.

The 58.8 MWe Gyeongg fuel cell power plant

Thermodynamic cycles alterative to steam Rankine cycle are under development. **The sCO_2 (supercritical carbon dioxide) cycle** can potentially achieve a higher thermal efficiency than steam Rankine cycles. A sCO_2 cycle has extremely compact turbomachinery designs and reduced BOP requirements, resulting in lower costs of a sCO_2 cycle power plant. The **Kalina cycle** uses a working fluid of multi-component with different boiling points, whilst **ORC** (organic Rankine cycle) uses organic working fluids with low boiling points. Both Kalina cycle and ORC perform better than a steam Rankine cycle system when operating with low or medium temperatures heat sources and have found applications in areas such as waste heat recovery, geothermal, solar thermal and biomass power plants and can potentially be integrated, as a bottoming cycle, with a steam Rankine cycle to improve the net plant efficiency of a steam power plant.

Solar-coal hybrid power plants integrate solar energy with coal-fired power systems. Solar thermal energy can be used to produce high pressure, high temperature steam, which can then supplement the coal power steam cycle to reduce the consumption of coal in the production of electric power at the plant. The solar generated steam can be directly used to drive the steam turbine, or to replace the steam extracted from turbine for feedwater heating. Alternatively, the solar thermal energy is used to preheat the combustion air. Off the shelf technologies are used in solar-coal hybrid power systems so no technology development work is needed. This approach can help utility companies to generate more renewable power with significant cost savings. Solar-coal hybrid plants can be new constructions, or solar fields can be retrofitted to existing coal plants.

Currently, coal provides about 40% of the energy for global power generation. It will continue to play an important role in the foreseeable future. If the technologies for alternative power generation systems can be developed into practical commercial systems, they could ultimately have a significant impact on coal-based power generation and greatly reduce its environmental impact.

IEA Clean Coal Centre 14 Northfields London SW18 6DD
www.iea-coal.org | +44 (0)20 8877 6280 | email: mail@iea-coal.org