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executive summary

Power generation from coal using supercritical CO_2

The 2016 IEA World Energy Outlook concluded that coal would remain the second-largest energy source worldwide until 2030. World coal consumption is projected to increase by more than 20% by 2040. Coal-fired power plants are a major source of CO_2 emissions. The Paris Agreement aimed to cap global warming at well below 2°C (1.5°C if possible). Carbon capture and storage (CCS) could contribute to significant CO_2 emission reductions, and may make an important contribution to meeting the global climate target of the Paris Agreement. Therefore, advanced technologies are required to increase efficiencies, to reduce emissions of coal power plants and to facilitate CCS. Several technologies are under development such as chemical looping and the supercritical CO_2 (sCO_2) cycle.

The supercritical carbon dioxide power cycle is an innovative concept for converting thermal energy to electrical energy using supercritical CO_2 as the working fluid medium. An sCO_2 power cycle can potentially reach thermal efficiencies of 50% or greater. The high energy density of sCO_2 means the components are small and hence, so is the overall plant footprint. The high efficiency, small size and simple layout of sCO_2 power cycles coupled with other technology attributes could result in potentially large reductions in capital and fuel costs, and decreased greenhouse gas emissions from coal-fired power generation. sCO_2 cycles can be applied to power generation using a range of energy sources such as nuclear, fossil fuels, solar thermal and waste heat.

Two primary sCO_2 cycle configurations have been investigated for power generation from coal: an indirectly-fired closed cycle and a semi-closed, directly-fired, oxy-combustion cycle. In a closed cycle, the working fluid (CO_2) is circulated in a closed loop and is heated indirectly with an external heat source, similar to the operation of a steam Rankine cycle. In a semi-closed, directly-fired, oxyfuel cycle, fuel is burned in relatively pure and near stoichiometric oxygen in a high-pressure combustor. The resulting high-temperature, high-pressure stream which contains mainly CO_2 and H_2O is used to drive the turbine. The remaining heat in the stream exiting the turbine is recuperated and the stream is then further cooled to condense the water out, leaving a stream of high concentration CO_2 that is ready to be compressed for storage. The semi-closed, oxy-combustion sCO_2 cycle has the additional benefit of facilitating CCS.

R&D needs

The main challenges of developing sCO_2 power systems include: elevated pressures throughout the cycle; a large duty heat exchanger as well as materials compatible with operation at high pressure and temperature in sCO_2; and thermal integration and optimisation at cycle and process level. R&D is required for:

- CO_2 expansion turbines, compressors and recuperators for both indirectly- and directly-fired cycles;
- CO_2 heaters for indirect-heating and combustors (in particular, oxyfuel combustors) for directly-fired sCO_2 cycle;
- some subcomponents such as bearings, seals and valves;
- materials testing;
- configuration and optimisation of sCO_2 power cycle for a given application; and
- assessment of performance and cost of the sCO_2 cycles and individual components.

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, China, the European Commission, Germany, India, Italy, Japan, Poland, Russia, South Africa, Thailand, the UAE, the UK and the USA.

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

Power generation from coal using supercritical CO_2

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

Recent developments

Significant progress has been made recently in developing both the indirectly-heated, closed sCO_2 cycle and semi-closed, directly-fired oxy-combustion sCO_2 cycle. Several small-scale closed-loop sCO_2 test facilities of up to 1 MW have been built. Tests have been conducted to determine the feasibility of sCO_2 power conversion systems and the performance of turbomachinery components and heat exchangers. Small sCO_2 turbines and compressors have performed close to the design value and have operated effectively above and below the critical temperature. Therefore, it is anticipated that there will not be major surprises in the turbomachinery design and operating efficiency as the technology is scaled up to higher power levels. At the same time, extensive work is ongoing to develop and optimise the designs of compact heat exchangers for use in sCO_2 cycles, to identify materials that are compatible with the high-temperature, high-pressure sCO_2 operation, to ascertain optimal cycle configurations and to develop subcomponents. Considerable progress has been made in these areas.

In 2014, the first 8 MWe closed sCO_2 cycle heat engine EPS100, developed by Echogen Energy Systems, was brought to the market. It turns waste heat from various industrial processes to electricity and operates at relatively low temperatures. Echogen Energy Systems now offers heat engines of 1–9 MWe in size and has extended the application from waste heat recovery to solar and geothermal power. Currently, extensive R&D is ongoing to develop indirectly-heated, closed-loop high-temperature sCO_2 cycle for power generation from nuclear, solar and fossil fuel combustion. In October 2016, the US Department of Energy awarded up to US$80 million for a six-year project to design, build and operate a 10 MWe sCO_2 pilot test facility. The test facility is scheduled to be operational in 2020. GE Global (USA) has completed the conceptual design of the 10 MWe high-temperature, high-pressure sCO_2 turbine and is now trying to scale it up to 50 MWe.

NET Power has been developing a 50 MWth (25 MWe) gas-fuelled Allam Cycle demonstration power plant in La Porte, Texas (USA). The Allam Cycle is a semi-closed, oxy-combustion transcritical CO_2 power cycle. The core process is a gas-fired, high-pressure, low-pressure ratio cycle, operating with a single turbine that has an inlet pressure of approximately 30 MPa and a pressure ratio of 10. Toshiba has developed and built the sCO_2 turbine and the high-pressure oxyfuel combustor for the Allam Cycle demonstration plant, which is scheduled to start operation early in 2018. The demonstration process will match the operating conditions of the core Allam Cycle and the expected commercial plants. The Allam Cycle can achieve nearly 100% carbon capture without the need for additional CO_2 separation and/or compression, avoiding the high capital costs and parasitic loads normally incurred with CCS. Furthermore, the Allam Cycle is simple, using only a single gas turbine with an oxyfuel combustor, heat exchangers and compressors/pumps. The Allam Cycle can use a variety of hydrocarbon fuels including natural gas and syngas with target net efficiencies of 50% for coal and of 59% for natural gas, and full carbon capture. 8 Rivers Capital, the inventor and developer of the technology is also developing the Allam Cycle power system fuelled by syngas from coal gasification.

The sCO_2 cycles hold great potential for providing alternative power generation systems that can achieve higher plant efficiency and full carbon capture at lower costs. There are some outstanding technical issues that need to be addressed. Some small, low temperature sCO_2 Brayton cycle power systems are starting to emerge in the commercial market. If solutions can be found to resolve all the technical challenges in developing the sCO_2 power cycles, they could revolutionise the future power generation from coal in a carbon constrained world.

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