Development of CCS (Carbon Capture and Storage) Technology to Combat Climate Change
—Advancement of Environmentally Conscious Clean Coal Power Plant Technologies

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OVERVIEW: With considerable efforts being made around the world to counter global warming, the development of energy technology is at a turning point. Through its global research and development capabilities, Hitachi is working on development to realize a low-carbon society and commercialize CCS technologies including technology for CO_2 separation and capture based on a variety of environmental technologies that it has built up over time.

INTRODUCTION

COMBATTING climate change has become an important issue as energy demand expands along with worldwide economic growth. Coal-fired thermal power plants play an important role as a key source of energy in many countries because the coal is cheap and coal reserves are extensive and geographically widespread rather than being concentrated in particular areas. A problem with coal, however, is that it emits a large quantity of CO_2 (carbon dioxide) per unit of output and this has created a strong demand for the development of CCS technologies that can separate out and capture the CO_2 as a new approach that can help move toward a low-carbon society. Hitachi is working to achieve the practical realization of CCS based on the various environmental technologies that it has built up over time.

This article describes regulatory trends that affect CCS, Hitachi's development vision for CCS technology, and two CO_2 separation and capture techniques, namely CO_2 scrubbing and oxy-combustion.

REGULATORY TRENDS AND DEVELOPMENT ROADMAP

Regulatory Trends

A European Union (EU) directive[1] relative to CCS adopted in December 2008 stipulated rules on "capture-ready" that apply to new power plants with rated electrical output of 300 MW or more constructed from 2015 and later although a proposal to place a limit on CO_2 emissions of 500 g/kWh (equivalent to a reduction of approximately 40%) was deferred. Being "capture-ready" means a plant must be designed in such a way that CO_2 capture equipment can be retrofitted at a later date. That is, provided other requirements such as that to ensure a suitable CO_2 storage site is available, the coal-fired thermal power plant must provide sufficient space for CO_2 capture equipment to be installed. Also, as part of an EU economic recovery program, the European Commission decided in October 2009 to grant approximately one billion Euros to six CCS demonstration projects. Through a directive[2] amending the EU-ETS (EU emissions trading scheme), the EU then went on in February 2010 to offer financial support for eight demonstration projects covering CO_2 scrubbing, oxy-combustion, IGCC (integrated coal gasification combined cycle), and other technologies with the provision that these must commence operation by December 31, 2015.

The UK government also announced in April 2009 that no new coal-fired power stations should be permitted without CCS or at least without an obligation to retrofit CCS at a fixed point in the future and stipulated policy mechanisms for proceeding with

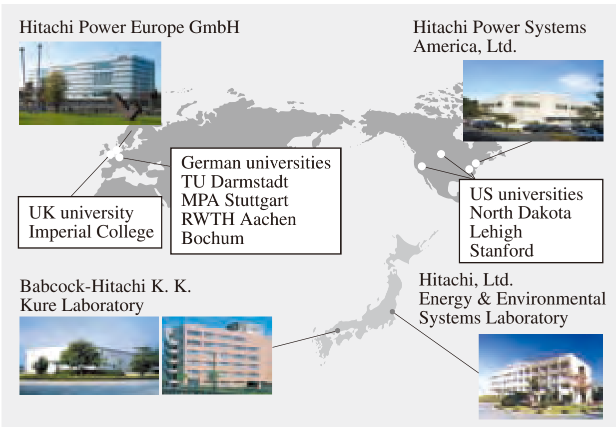


Fig. 1—Hitachi CCS Technology Development Network.
In addition to developing CCS (carbon capture and storage) technology at sites in Japan, USA, and Europe, Hitachi also collaborates on technology development with European and US universities and research institutions.

four demonstration plants.

In the USA, meanwhile, moves to place restrictions on the emission of greenhouse gases accelerated under the Obama administration which took office in 2009. First the American Clean Energy and Security Act[3] was passed by the House of Representatives in June 2009. This was followed by the Senate commencing debate on the Clean Energy Jobs and American Power Act[4] which passed before the Senate Committee on Environment and Public Works in November of the same year. Currently, debate on bringing the act into law is in progress. The proposed law includes a 50% reduction in the volume of CO_2 emissions from permitted coal-fired power up until 2020 and 65% from 2020 and beyond. A presidential memorandum released in February 2010 also contained specific proposals for five to ten CCS demonstration projects by 2016.

These developments indicate how moves toward placing restrictions on emissions (and requiring partial capture) of CO_2 from coal-fired thermal power generation are being firmed up in Europe and America and it is now clear that demonstrations of a number of CCS technologies will go ahead towards 2015.

Hitachi's Development Roadmap

Hitachi has established a global network with sites in Japan, USA, and Europe and collaborates with local research institutions in these countries on the development of technologies for CCS and for improving the efficiency of coal-fired power (see Fig. 1).

Four specific technologies under development are: (1) 700°C-class A-USC (advanced ultra super critical), (2) CO_2 scrubbing (a CO_2 capture technology), (3) Oxy-combustion, and (4) IGCC (see Fig. 2). A-USC is a technique for dramatically improving the efficiency of power generation, CO_2 scrubbing is a technology suitable for retrofitting existing power plants for partial CO_2 capture, and oxy-combustion is an efficient technology to achieve full CO_2 capture. IGCC, in turn, is an extremely clean technology that gasifies the coal and uses the resulting hydrogen as the primary fuel for power generation. The combination of these four technologies is capable of reducing emissions of NO*x* (nitrogen oxides), SO*x* (sulfur oxides), CO_2, and other pollutants to a very low level and mitigating the efficiency loss associated with CO_2 capture, and together they constitute a new generation of coal-fired thermal power that can also achieve economic viability. The following sections describe the CO_2 scrubbing and oxy-combustion methods of CO_2 capture.

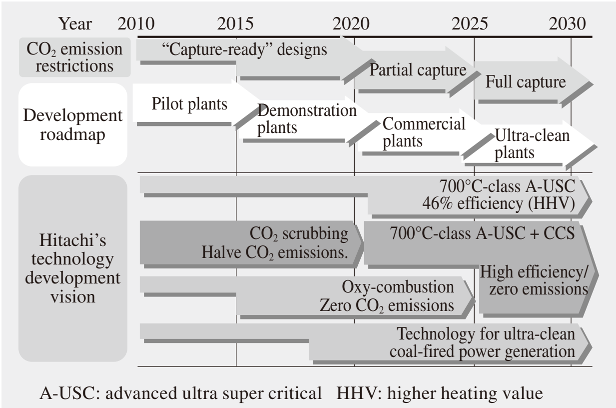


Fig. 2—Hitachi's CCS Business Vision.
To realize the next generation of coal-based thermal power, Hitachi is developing four technologies in parallel. These are two techniques for CO_2 (carbon dioxide) capture (CO_2 scrubbing and oxy-combustion), IGCC (integrated coal gasification combined cycle), and A-USC.

DEVELOPMENT OF CO_2 SCRUBBING

Overview

The use of CO_2 scrubbing to remove CO_2 is a technology that has already been proven in natural gas purification, chemical plants, and elsewhere. However, there are problems that need to be resolved before it can be applied in coal-fired power plants, including the significant reduction in generation efficiency caused by heat losses and the degradation of the solvent caused by oxide gases such as SO_2 (sulfur dioxide) in the flue gas.

Hitachi commenced research and development in the early 1990s and conducted trials including basic experiments and pilot testing using actual gas to develop solvents and equipment suitable for use with the flue gas from coal-fired boilers. Now Hitachi is working to put the technology into practice and Hitachi Power Systems America, Ltd. has received funding from the U. S. Department of Energy to collaborate with power companies on the FEED (front-end engineering design) of CO_2 scrubbing equipment for coal-fired power plants.

Solvent Development

Solvent development was performed using bench equipment together with basic experimental apparatus[5] (see Fig. 3). This equipment consisted of an absorber, desorber, and fluid circulation unit and allowed tests using a synthesized gas that simulated boiler flue gas to be carried out under a range of conditions. Hitachi conducted screening tests for a large number of different solvents over a period of time to develop the H3 amine solvent which is suitable for use with the

Fig. 3—Bench-scale Test Apparatus.
The properties of solvents suitable for the flue gas of coal-fired boilers were evaluated using a gas that simulated flue gas.

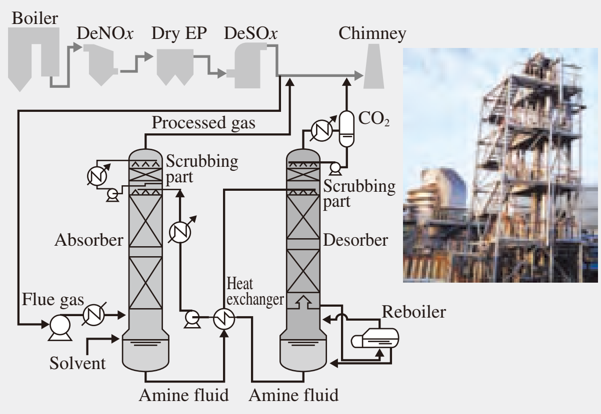


Fig. 4—1,000-m³N/h Pilot Plant.
The pilot plant was used to test a number of solvents including the H3 solvent and confirm their effectiveness.

flue gas from coal-fired boilers.

Previous solvents were primarily for CO_2 removal during natural gas production and were negatively affected by the oxide gases and oxygen in the flue gas of coal-fired boilers. Also, because the volume of gas to be processed is far larger, the design of the equipment needs to take appropriate account of the thermal properties, flow characteristics, and other basic properties of the solvent. Through this work, Hitachi selected the most suitable amine from a range of options and further optimized its performance using additives and other additions.

Demonstrations Using Actual Flue Gas

In joint research with The Tokyo Electric Power Company, a pilot plant capable of treating 1,000 m^3N/h of flue gas was installed at the company's Yokosuka Power Plant and demonstration experiments were conducted on actual flue gas using the H3 amine solvent developed by Hitachi[(6), (7)] (see Fig. 4).

After conducting various characteristics tests to confirm the performance, a 2,000-hour continuous operation test was performed. Fig. 5 shows some of the results of this test. A reliable and high level of CO_2 removal performance was achieved in a test using flue gas containing 30 ppm of SO_2. The removal ratio exceeded 90% and the captured CO_2 had a purity of 99% or better, both of which were excellent results. Also, the energy consumed to capture the CO_2 was 20 to 30% less than that for the standard MEA (monoethanolamine) solvent. Hitachi is now working to improve further the properties of amine solvents.

Another factor to consider is that a wide range of different coals are used around the world and this results in differences in characteristics such as the

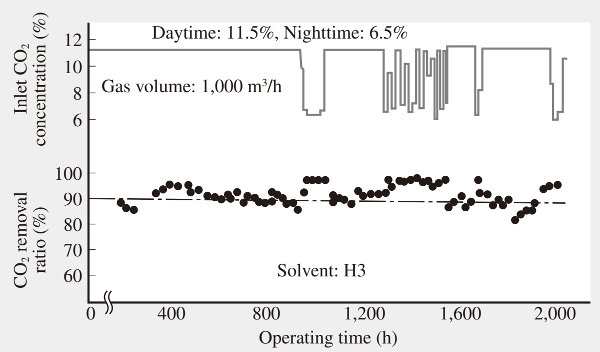


Fig. 5—Results of Continuous Operation Test.
The results of a continuous operation test lasting 2,000 hours are shown. The test using actual flue gas demonstrated CO_2 removal performance exceeding 90%. The variations visible in the CO_2 removal ratio were caused by testing of different operating conditions.

Fig. 6—Outline of 5,000-m³N/h Mobile Pilot Plant.
The outline of a pilot plant designed to conduct testing using actual flue gas in Europe is shown. Evaluation trials at existing power plants are planned to start from mid-2010 as part of joint research with a German utility companies.

amount of ash or concentrations of oxide gases in the flue gas. Accordingly, Hitachi also plans to conduct tests using actual flue gas in Europe. The pilot plant for this purpose has the capacity to treat 5,000 m^3N/h of flue gas (see Fig. 6) and evaluation tests at existing power plants are planned to start from mid-2010 as part of joint research with a German utility companies in which Hitachi Power Europe GmbH is taking a central role. The tests will also conduct experiments on a newly improved solvent.

Constructing Optimum System

To ensure that CO_2 capture plant can be incorporated into coal-fired power plants, it is necessary to construct an optimum system with consideration for providing compatible interfaces. The main items of investigation are as follows.

(1) SO_2 scrubbing upstream of the CO_2 absorber

Because the SO*x* contained in the flue gas from a coal-fired boiler will degrade the solvent, it is considered necessary to reduce the concentration to 10 ppm or less at the inlet to the CO_2 capture plant. For this purpose, configurations that locate an additional scrubber upstream of the CO_2 absorber are considered. Hitachi, however, has an existing FGD (flue gas desulfurization) system with excellent performance that has demonstrated 99% or better SO_2 removal efficiency at many different sites and this permits designs with no additional scrubber.

(2) Steam supply to desorber (bleed-off from steam turbine)

Hitachi also has considerable experience with steam turbines and is developing steam systems that minimize the reduction in efficiency associated with bleeding off steam. Hitachi is also developing a system to recover waste heat from the flue gas to minimize the quantity of steam that needs to be supplied from the turbine.

(3) Reuse of waste heat from CO_2 compressor

The captured CO_2 gas is either compressed and transported or compressed and liquefied so that it can be sequestered. The captured CO_2 gas has a high moisture content and recovery of the water, compression heat, and other by-products of this process is an important factor for improving the system efficiency. Because of the large volume of gas being processed, it is also essential to minimize the compression power requirements. Hitachi also has extensive experience in the manufacture of centrifugal CO_2 compressors for various types of plant including urea synthesis[8] (see Fig. 7). Development work on enhancements such as improving the overall efficiency of systems that use these technologies is under way.

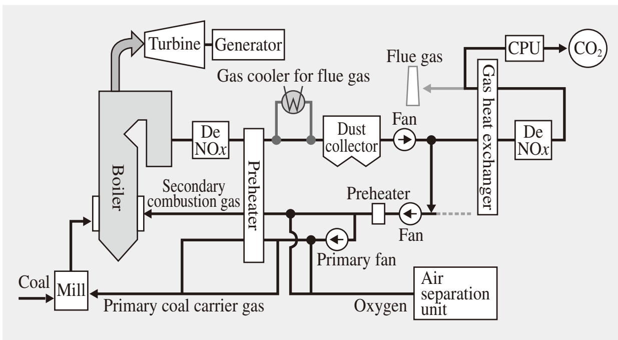
Fig. 7—Centrifugal Compressor for CO_2 Liquefaction.
A centrifugal compressor for liquefying CO_2 delivered to a urea synthesis plant in China is shown. The unit is powered by an 8,200-kW steam turbine and uses two casings to compress CO_2 gas from atmospheric pressure to 18.3 MPa.

DEVELOPMENT OF OXY-COMBUSTION

Overview

Oxy-combustion works by diluting oxygen with recirculated flue gas and using this instead of air as the combustion-supporting gas (see Fig. 8).

Because the resulting flue gas consists mainly of CO_2 and water, the CO_2 can be compressed and liquefied simply by removing the water and therefore large-scale capture equipment such as a CO_2 scrubber is not required. Also, because the volume of combustion gas for oxy-combustion is less than for air combustion, the boiler and flue can be made more compact. However, the issues that need to be considered in practical



CPU: compression and purification unit

Fig. 8—Example Oxy-combustion System.
Using a mixture of oxygen and recirculated flue gas as the combustion-supporting gas results in flue gas that is comprised mainly of CO_2 and water, and this simplifies CO_2 capture.

realization of this method include the changes in flame stability, heat transfer, and other characteristics that result from using a different combustion-supporting gas, and the corrosion caused by the build-up of SO*x* that results from flue gas recirculation.

Hitachi has been involved in the development of coal-fired boilers for many years and has world-class testing facilities (basic test equipment and pilot plants) and numerical analysis techniques that are being used to advance this work. Hitachi is also working with overseas electricity generation companies on developments that include scaling up this technology with the aim of bringing it into commercial use[9].

Development of Oxy-combustion Burner

With oxy-combustion, the main component of flue gas changes from N_2 (nitrogen) to CO_2. Because CO_2 has a greater retardant effect on combustion than N_2, it causes worse flame stability. In response, Hitachi has developed a new burner with a high level of flame stability even under oxy-combustion conditions. The combustion test rig shown in Fig. 9 was used in the development of this burner.

The test rig provides a model of the basic structure of an actual burner and can be used to evaluate combustion and heat transfer characteristics when the concentrations of CO_2, water, and other components are varied by recirculating the flue gas.

Hitachi is also participating in European projects through Hitachi Power Europe and is working on developments for use in demonstration plants. It is conducting 30-MWth-class burner combustion trials at the Schwarze Pumpe coal-fired power plant in Germany and evaluating reliability issues associated with scaling up this technology (see Fig. 10).

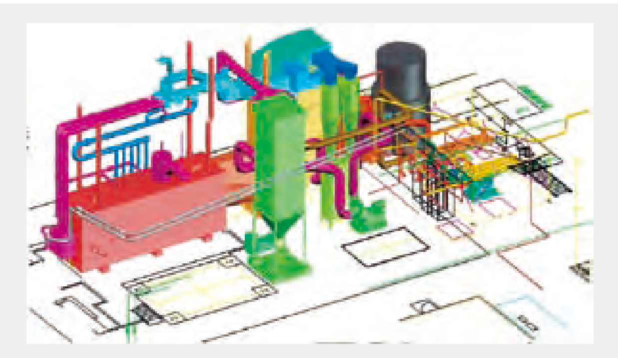


Fig. 9—Overview of 4-MWth Combustion Test Rig.
Flue gas recirculation is one of the distinctive features of oxy-combustion and this pilot plant which duplicates the basic structure of an actual burner can be used to evaluate the combustion and heat transfer characteristics when this technique is used.

Fig. 10—30-MWth Demonstration Plant at Schwarze Pumpe Coal-fired Power Plant.
A demonstration plant for coal-fired oxy-combustion that can be used to conduct 30-MWth-class burner combustion trials and to evaluate reliability issues associated with scaling up this technology is shown.

Development of Flue Gas Recirculation System

As the volumetric flow rate of flue gas produced by the reaction between fuel and oxygen is roughly one-fifth of that for air combustion, the concentration of SO_3 (sulfur trioxide) in the flue gas is approximately five times higher which increases the potential for corrosion in the flue gas line. In response, Hitachi has developed its own new recirculation system which reduces the concentration of SO_3 in the flue to a level at which corrosion is no longer a problem (1 ppm or less). Experiments to verify the operation of the complete system were conducted using a large-scale facility capable of testing the entire process from combustion to flue gas treatment, including this new recirculation system (see Fig. 11).

FUTURE DEVELOPMENTS

Hitachi is working with local utility companies in Europe and America on plans for CCS demonstration trials. For CO_2 scrubbing, Hitachi is involved in projects in Michigan in the USA, Saskatchewan in Canada, Germany, and the Netherlands. For oxy-combustion, Hitachi is involved in projects in Germany and Finland. Hitachi intends to advance international collaboration through these projects, integrate CCS technology with existing power generation technology, and investigate and overcome the obstacles to its commercialization which include economics and reliability.

Enhanced oil recovery, one of the potential methods for sequestering CO_2, is already in practical use and can be used to recover additional oil from old oil fields by injecting CO_2 under pressure. The economic benefits of this are large. Hitachi is making progress

Fig. 11—Test Facility for Combined Evaluation of Combustion and Flue Gas Treatment.
This is the only large-scale facility operated by a boiler manufacturer that is capable of testing the entire process from combustion to flue gas treatment.

toward the practical realization of CCS technology by combining the CO_2 capture technology it has developed with technology for transportation and sequestration.

CONCLUSIONS

This article has described regulatory trends that affect CCS, Hitachi's development roadmap for CCS technology, and two CO_2 separation and capture techniques, namely CO_2 scrubbing and oxy-combustion.

The International Energy Agency published a technology roadmap for CCS in October 2009[10]. The roadmap stated that, to achieve the objective of halving the level of CO_2 emissions by 2050, 100 CCS plants would be required worldwide by 2020 and 3,400 by 2050. This shows how CCS technology is essential to protecting the global environment. Hitachi will continue to work on technology development to contribute to preventing global warming.

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