# Highly Efficient Power Stations with Carbon Capture

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*OVERVIEW: Worldwide, coal currently contributes over 40% of electricity generation and its share is expected to increase steadily over the coming decades. The continued dominance of coal in the global energy structure and growing concerns about climate change necessitate accelerated development and deployment of new technologies for clean and efficient coal unitization. Coal-fired power plants with CCS are widely expected to be an important part of a sensible future technology portfolio to achieve the overall global $CO_2$ reductions required for stabilizing atmospheric $CO_2$ concentration and global warming.*

## INTRODUCTION

AS a global technology and equipment provider for complete thermal power plants, Hitachi is actively developing $CO_2$ (carbon dioxide) capture technologies for coal power with the following approach:
(1) Development of two flexible $CO_2$ capture processes utilizing advanced amine-based PCC (post-combustion capture) and oxyfuel combustion technologies
(2) Design of optimized heat integration of the processes
(3) Total plant re-optimization involving the boiler, turbine, AQCS (air quality control system), and CCS ($CO_2$ capture and sequestration) system
(4) Pilot scale evaluation of the technologies
(5) Capture-ready design of new power stations as a first step toward enabling future CCS addition and sustained operation in a carbon-constrained world

## ADVANCED ULTRASUPERCRITICAL POWER PLANT

To offset the expected loss in efficiency resulting from carbon capture, further improvement of the power plant is necessary. The most effective way to increase power plant efficiency is to increase the live steam temperature. The state-of-the-art boiler materials of today limit the boiler outlet steam temperature to approximately 600°C. A step change is required to further increase the steam temperature. That is, the 700°C boiler of the future will need to use nickel-based alloys for the superheaters, turbine, and some parts of the waterwall. Hitachi has been involved in the associated R&D (research and development) and manufacturing testing since the beginning of this 700°C power plant concept in the 1990s in Europe. Similar development efforts were started in Japan years ago and Hitachi together with other suppliers and utilities is driving forward the development.

Fig. 1[1] shows the key R&D programs performed since the mid-90s. In numerous publicly sponsored and privately financed programs all of the important components of the steam generator were qualified. Feasibility studies and basic engineering for 700°C power plants were carried out based on different steam generator types and different pressure ranges (THERMIE 1+2, NRW PP 700). Semi-finished products such as tubes and pipes were manufactured, welding procedures were tested, and laboratory testing of mechanical properties was performed. Superheater test loops exposed to real flue gas atmospheres have provided information about corrosion and oxidation behavior. Components such as superheater wall panels, superheater surfaces, headers, piping, and different types of welds were tested in the COMTES 700 Component Test Facility. Components with original

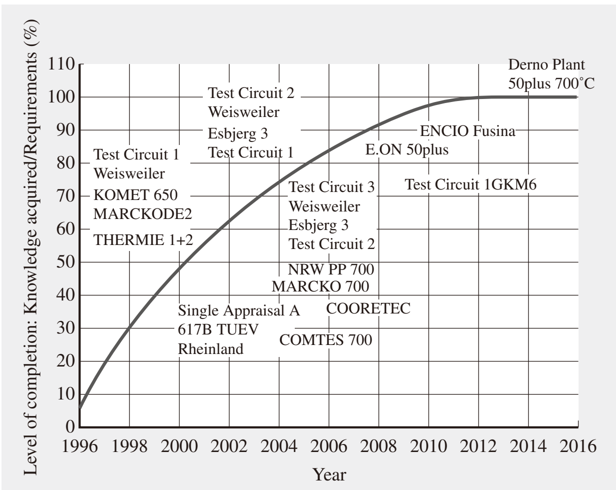


*Fig. 1—Road to 700°C Technology in Europe.*
*The know-how to construct demonstration plants will be available in the near future.*

dimensions for a 500-MW demonstration plant such as membrane walls, superheater tubes with high wall thicknesses, HP (high pressure)-pipes, RH (reheat)-pipes, and different welds have been designed and fabricated using various manufacturing technologies. Even though there are still some open problems among the lessons learnt from the COMTES 700 test facility, sufficient knowledge of the manufacturing process has been gained and sufficient investigations into material qualifications have been completed that a demonstration plant could be ordered in the near future.

Hitachi Power Europe GmbH (HPE) actively participated in most of the projects, taking a leading role in material and manufacturing development for the nickel-based materials. These materials are needed in the upper part of the furnace walls and for superheater and reheater surfaces. Examples are given in Fig. 2. The photograph on the left shows an A617 membrane wall successfully welded and bended in HPE's workshop. Through this work, HPE gained the know-how to fabricate membrane walls for 700°C boilers. The photograph on the right of Fig. 2 shows a full-scale superheater bundle for a 700°C application. The bundle consists of Alloy 617B, Alloy 740, Sanicro 25, and HR3C tubes and was successfully tested for 30,000 hours in the COMTES 700 test plant. It represents an important part of HPE's experience in the manufacturing of pressure parts for the forthcoming 700°C technology.


*Fig. 2—Membrane Wall (a) and Superheater Panel Using Nickel-based Alloy (Alloy 617B)(b).*
*Hitachi Power Europe GmbH is working on the development of technologies required to construct 700°C-class boilers.*

*Fig. 3—Pilot Plant for PCC (post-combustion capture) Testing in Europe.*
*Testing is being undertaken in Europe using the flue gas from power plants.*

## PCC

Amine-based $CO_2$ separation is a leading technology expected to be available commercially within the next decade for large fossil-fueled power stations. However, the traditional $CO_2$ capture process utilizing conventional amine solvents is very energy intensive and is also susceptible to solvent degradation by $O_2$ (oxygen), $SO_x$ (sulfur oxides), and $NO_x$ (nitrogen oxides) in coal-fired flue gas, resulting in large operating costs. Therefore, concepts for improved AQCS have to be developed and proven. The development of amine systems that consume less energy and the recovery of waste heat are the most essential measures for further decreasing the efficiency penalty. These measures already have to be defined for new power stations, and the changed heat balance and necessary equipment for retrofits has to be pre-designed in advance as per the definition of capture-readiness because all new power stations in the EU must be capture-ready. Additionally, the technology has to be proven in pilot and demonstration scale plants to be commercially available for new builds and retrofits in 2020.

For the PCC process, HPE has completed a 5-MWth pilot facility (see Fig. 3) for $CO_2$ capture based on amine absorption. It will be set up in cooperation with E.ON AG and GDF SUEZ at a power plant site in the Netherlands in mid-2010 and be subject to tests involving various scrubbing agents up to 2015. One of the pilot plant's assets is its transportability which allows it to be deployed to various plant sites. Moreover, because it is not limited to any specific scrubbing or amine solution, the operator is free to use their reagent of choice. In conjunction with German power companies and universities, HPE is also supporting the construction of a second mobile pilot plant for testing $CO_2$ scrubbing agents, which are not subject to protective rights, at a power plant in Duisburg.

Thanks to the system integration capabilities within the group (power plant boilers, turbines, air quality control systems, and $CO_2$ compression), HPE has developed overall plant technology which

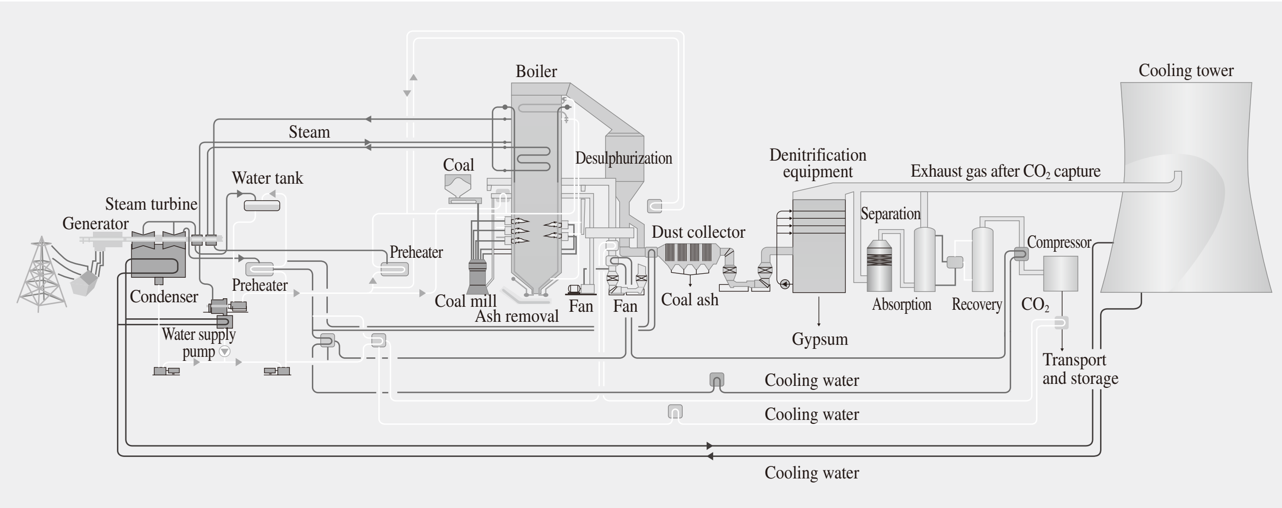


*Fig. 4—Heat Integration of PCC.*
*It is anticipated that the thermal losses in 600°C-class boilers will be able to be reduced to 8% or less.*

for future plants can cut the total efficiency loss from $CO_2$ capture to under 8% compared to 11% to 14% for today's commercial amine solvents with minimum integration. Fig. 4 shows the design of the heat integration and optimized flow scheme which can achieve an efficiency loss as low as 7.8% points for a 600°C power plant[(2)].

As a part of the commercialization effort, Hitachi is actively pursuing opportunities for demonstration of CCS technologies, partnering with industry and government. In October 2009, the US DOE (Department of Energy) selected a CCS demonstration project run by Wolverine Power Supply Cooperative, Inc. (WPSCI) to be one of the ICCS (Industrial Carbon Capture and Storage) Phase 1 Projects. The project plans to demonstrate Hitachi's technology to capture 300,000 t of $CO_2$ per year (1,000 t/d on a 50-MWe slipstream) from a 600-MW power plant to be built near Rogers City, Michigan. The captured $CO_2$ will be sequestered through EOR (enhanced oil recovery) operations near the project site. The Wolverine project team includes WPSCI (the owner), Hitachi Power Systems America, Ltd. ($CO_2$ capture technology provider), Core Energy Group (EOR host), Burns and Roe (owner's engineer), and Western Michigan University (geology evaluation for $CO_2$ storage). Hitachi will provide an integrated $CO_2$ capture system and the advanced H3-1 amine-based solvent for the project.

In February 2010, Hitachi and SaskPower in Canada agreed to long-term cooperation in developing low-carbon energy technology including CCS. Hitachi was also selected to supply the steam turbine for the SaskPower Boundary Dam Integrated Carbon Capture

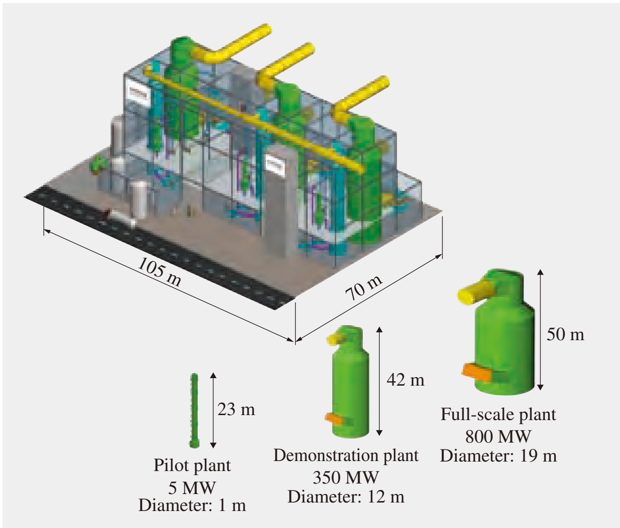


*Fig. 5—Relative Sizes of Commercial-scale $CO_2$ Scrubbers.*[(2)]
*The technology has already progressed to the demonstration plant stage and Hitachi is working on scaling this up for full commercial use.*

and Sequestration Demonstration Project, which will retrofit an existing unit to produce 115 MW of clean base-load electricity, while enhancing local oil production and reducing $CO_2$ emissions.

Scaling-up of the $CO_2$ capture system components has been investigated in detail under several ongoing projects for engineering and design study. Fig. 5 shows the absorber dimensions of different sizes and the layout of an 800-MWe $CO_2$ capture system.

## OXYFUEL COMBUSTION

Oxyfuel combustion is another promising technology to enable $CO_2$ capture and sequestration for new and existing coal-fired power plants where the

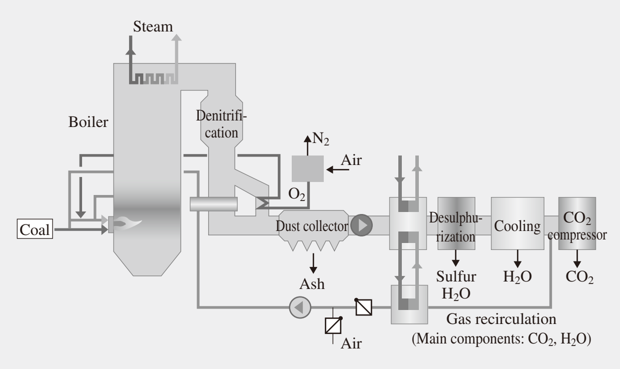


*Fig. 6—Optimized Oxyfuel Process.*[3]
*Pilot testing is planned in Europe to verify the underlying performance of oxyfuel boilers.*

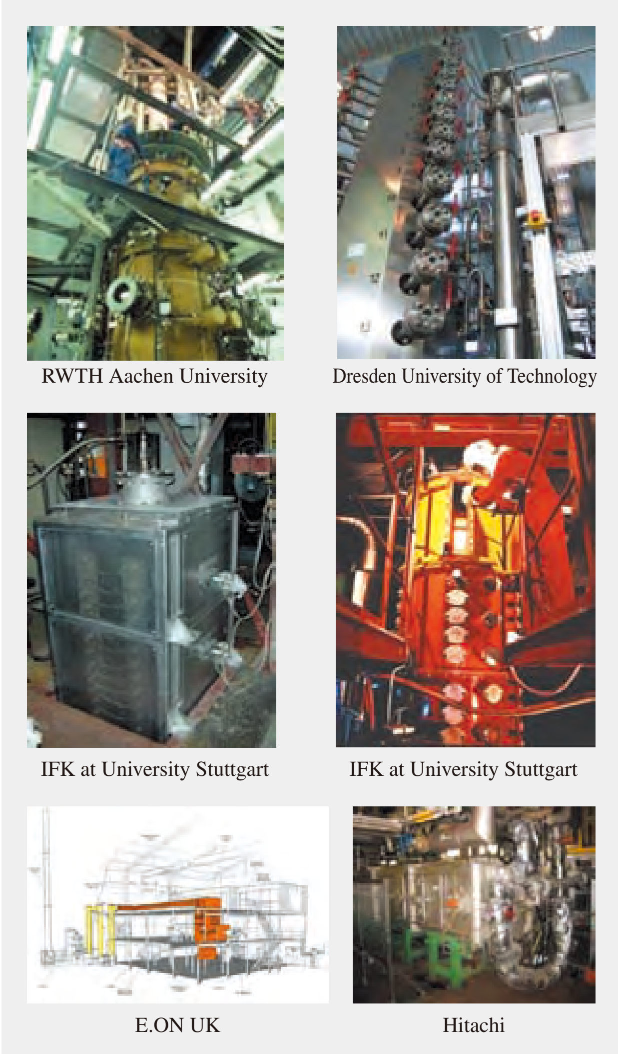


*Fig. 7—Oxyfuel Test Rigs Used for Basic Investigations.*
*Hitachi is working on basic research in conjunction with European universities and industry partners. (Images courtesy of P. Winandy, RWTH Aachen University, IFK (formerly IVD) at University Stuttgart, and E.ON UK.)*

coal is burned with pure oxygen diluted by recycled flue gas resulting in highly concentrated $CO_2$ and some $H_2O$ in the flue gas. Fig. 6 shows a block diagram of the oxyfuel process. To determine the impact on the process of using a totally different flue gas composition, Hitachi and others have been working on extensive development programs to commercialize oxyfuel combustion technology through design studies, laboratory scale experiments, CFD (computational fluid dynamics) modeling, as well as small and large pilot plant tests.

As for PCC, the immediate focus is to ensure that the coal-fired power stations commissioned in recent years and in the near future can be easily converted to oxyfuel for CCS operation. The development work to date has shown that existing state-of-the-art coal-fired power stations can be converted to oxyfuel combustion with minor changes to the plant water-steam cycle and other equipment, as shown in Fig. 6. The most important issue is to have space available inside and around the power station for the new equipment required for a CCS retrofit.

On the R&D side, studies of the basic technologies for oxyfuel combustion have been conducted over many years by Hitachi and others at various pilot-scale plants. In cooperation with universities and industrial partners, small- and medium-scale experiments have been performed to prove design models and correlations for combustion systems (see Fig. 7)[4], [5].

Valuable findings from the experimental studies have been implemented into the design models and programs for a variety of plant components that will be adopted to meet the new requirements under oxyfuel conditions. These findings have been applied to, for instance, the design of a new DS-T burner for firing dry fuels. This burner was successfully tested in a 30-MWth experimental combustion facility under air combustion conditions in 2009 and 2010 in Europe. The fuels used were dry lignite, bituminous coal, and biomass (saw dust). The fact that stable combustion was maintained while meeting all relevant emission limits for all fuels tested is proof of the high flexibility of Hitachi's technology (see Fig. 8).

Under a technology partnership with Vattenfall AB, the DS-T burner was successfully installed and commissioned at the Schwarze Pumpe oxyfuel pilot plant in Brandenburg, Germany in April 2010 and will be tested under various air and oxyfuel conditions[6]. The results from this testing will be used for the validation of the burner and firing system design by CFD (see Fig. 9) as well as for the further optimization

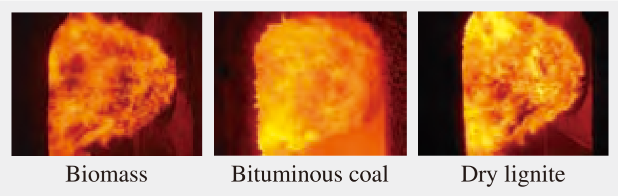


*Fig. 8—DS-T Burner Flames for Different Fuels (Air Combustion).*
*Stable combustion is being achieved that complies with appropriate flue gas standards.*

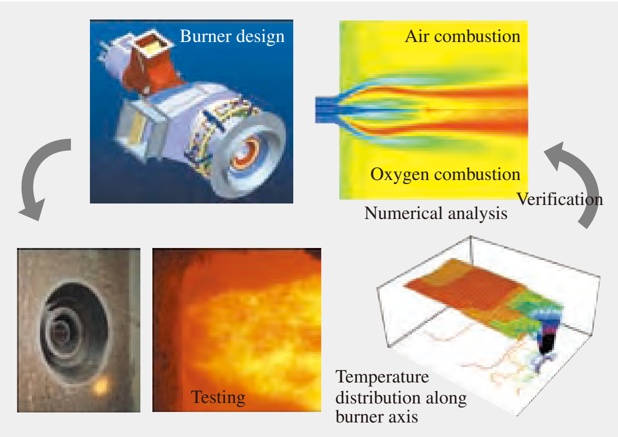


*Fig. 9—Design and Validation of Firing System and Burner.*
*The overall process will be optimized by numeric-analysis-based design and by validation through testing.*

of the overall process to achieve lower emissions and higher efficiencies.

In conjunction with sister companies in the Hitachi Group, HPE has also been validating the design fundamentals and materials (including catalysts) for other major components such as the desulphurization and denitrification equipment for the oxyfuel flue gas, the boiler, and the $CO_2$ compressor. The findings will be implemented into the design of an oxyfuel demonstration plant which is currently being planned.

## CONCLUSIONS

As an all-round provider of power generation technologies and equipment, Hitachi's aim is to find the optimum total-system solution for the highly efficient power stations of the future, both with and without $CO_2$ capture. By developing in parallel the technologies for improving efficiency through higher steam temperatures and for $CO_2$ capture processes such as post-combustion capture and oxyfuel combustion, Hitachi's next generation ultrasupercritical power plants with CCS will enable carbon storage and near-zero emissions within the next decade.

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