Advanced 800+ MW Steam Power Plants and Future CCS Options

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Abstract

More than ever clean and cost-effective power generation is a key to cope with the challenges imposed by the financial crisis and the increasing concerns about global warming. Investment cost and fuel costs have been the main contributors to the cost of electricity for many years. With the climate change package sealed by the European parliament in December 2008, cost associated with CO$_2$ allowances will become a relevant expense factor for power producers in Europe. Power plant suppliers will have to respond to the changed market needs by offering highly efficient power plant concepts considering future options for CO$_2$ capture.

Ultra supercritical (USC) steam power plants meet notably the requirements for high efficiencies to reduce both fuel costs and emissions as well as for a reliable supply of electric energy at low cost. Siemens has extensive experience with ultra supercritical steam turbines and continues to optimize associated designs and technologies in order to achieve highest efficiency and to fulfill CO$_2$ requirements.

Modularized reference power plants are responsive to the need for cost-effective solutions while providing flexibility to suit specific customer and site requirements. Marketed as SSP5-6000 (50 Hz) and SSP6-6000 (60 Hz) series these reference plants have been successfully built worldwide and now provide an intelligent response to needs of the European coal-fired power plant market. An advanced ultra supercritical 800 MW steam power plant based on the SSP5-6000 (1x800 USC) reference plant is currently under construction in Lünen/Germany.

The paper will discuss the major innovations considering plant economics and plant operability evaluations. In addition details of the water/steam cycle optimization process, single-line configurations and the general plant layout will be discussed. Advanced steam parameters (280 bar / 600 °C / 610 °C), a net efficiency of ~46 % (LHV basis, hard coal, inland location), and specific CO$_2$ emissions well below 800 g/kWh are characteristic features of this plant concept which reflects the state-of-the-art in USC power plant technology.

Carbon capture and storage (CCS) and capture ready power plant designs (CCR) are becoming increasingly important for the evaluation of investments into new power plants and in addition retrofit solutions for the existing power plants are required. Besides a brief overview of the capture technologies which will be applied in the first mover demonstration projects, the paper will focus on the enhancement potential for the post-combustion capture technology. The major development efforts are directed towards the selection and improvement of solvents, process design and the integration of the capture unit into the power plant. As defined in the EU climate change package a capture ready assessment is mandatory for all new fossil power plants > 300 MW. The investor has to provide information and documents whether storage sites are available, transportation is viable and retrofit of the capture unit is economically and technically feasible. For the SSP5-6000 a capture ready design has been developed, the options to cope with the capture ready requirements in different retrofitting scenarios will be presented.
**Introduction**

Coal-based power generation is still a fundamental part of energy supply throughout the world. Reliability, security of supply, low fuel costs, and competitive cost of electricity make a good case for coal-fired steam power plants. Requests for sustainable use of existing resources and concerns about the effect of CO₂ emissions on global warming have strengthened the focus of plant engineers and the power industry on more efficient energy conversion processes and systems.

Applying proven state-of-the-art technology while striving for cost-optimal efficiencies are key customer requirements in any new power plant project. Optimizing the combustion process, increasing the steam parameters, reducing the condenser pressure and improving the internal efficiency of the steam turbines are some of the well known levers for raising the overall plant efficiency. Due to the efficiency penalties associated with carbon capture and storage (CCS) such improvements are more than ever needed to ensure a sustainable generation of electricity based on coal. Siemens steam plants SSP5-6000 are designed to meet these challenges with today’s technology.

This paper describes technical features and customer benefits of Siemens advanced coal-fired steam power plants. Solutions to current challenges in plant design are presented and technical options to cope with future carbon capture requirements are discussed in detail.

**SSP-6000 Reference Power Plants**

**Power Plant Design**

**Scope of Supply**

Siemens scope of supply for steam power plants covers the full range from component packages to engineering, procurement and construction (EPC) of turnkey Siemens Steam Plants (SSP™, Figure 1). This paper focuses on the turbine island and some aspects of the power block for large coal-fired units >800 MW_{el} with ultrasupercritical (USC) steam parameters. However, smaller supercritical or subcritical steam power plants (>300 MW_{gross}) can also be provided. The SSP™ Turbine Island relies on a reasonable scope split and clearly defined interfaces with the Boiler Island and balance of plant (BOP).
Figure 1 Siemens scopes of supply for steam power plants

In addition to the supply of systems for advanced air quality control (advanced burners, flue gas desulphurization units, NOx systems (SNCR), fabric filters and electrostatic precipitators) and instrumentation & control, the product portfolio already includes CO₂ capture process know-how as well as CO₂ compressors to perfectly meet future carbon capture requirements.

State-of-the-Art Technology
Since the early 1990s Siemens has been working on reference power plant (RPP) concepts both for steam power plants and combined cycle power plants. Reducing investment costs by making use of modular pre-engineered RPP designs and at the same time providing sufficient flexibility to accommodate specific needs arising from customer requirements are major driving forces for all these development efforts. Recent examples of putting reference power plant concepts into practice are the coal-fired steam power plants Trianel Lünen/Germany (50 Hz, 813 MWgr, 280 bar/600°C/610°C) [1], CS Energy Kogan Creek/Australia (50 Hz, 744 MWgr, 250 bar/540 °C/560 °C) and Genpower Long View/USA (60 Hz, 775 MWgr, 248 bar/566 °C/566 °C).

The main focus of the SSP5-6000 series is the turbine building, where all mechanical components of the water steam cycle as well as all electrical equipments are optimized around the steam turbine generator set. The design is based on materials and technology that are available today and have proven reliability in use. In general, only a few modifications are
required to adapt the RPP design to the specific customer needs. Optimized for cost-effectiveness and environmental performance, the RPP turbine island with ultrasupercritical steam parameters for the 800+ MW market (50 Hz, bituminous coal) shows the technical features summarized in Table 1. A single train concept for both the air and flue gas path is applied to minimize investment costs.

Table 1 SSP5-6000 (1x800 USC) reference power plant - key technical features

<table>
<thead>
<tr>
<th>Scope of supply:</th>
<th>Turbine island</th>
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<tbody>
<tr>
<td>Gross power output:</td>
<td>800+ MW (rated output; 50 Hz); single unit</td>
</tr>
<tr>
<td>Net efficiency (LHV basis) of the overall plant</td>
<td>45.5-46.0 % (@ design point), depending on the coal, the steam generator design and the cooling conditions</td>
</tr>
<tr>
<td>Steam parameters</td>
<td>280 bar/600°C/610°C steam parameters at boiler outlet</td>
</tr>
<tr>
<td>Steam turbine</td>
<td>SST5-6000 with single reheat and double-flow LP turbines (5…12.5 m² exhaust annular area)</td>
</tr>
<tr>
<td>Generator</td>
<td>SGen5-3000W, water/hydrogen-cooled</td>
</tr>
<tr>
<td>Feedwater preheating</td>
<td>9-stages: 3 high-pressure header-type feedwater preheaters (FWPH) with one external desuperheater, 5 plate-type low-pressure FWPH; feedwater heaters A1 &amp; A2 are located in the condenser neck as a duplex heater</td>
</tr>
<tr>
<td>Feedwater pump concept</td>
<td>2 x 50 % electric motor-driven feedwater pumps</td>
</tr>
<tr>
<td>Condenser</td>
<td>Parallel or serial (dual-pressure) condenser configuration</td>
</tr>
<tr>
<td>Flue gas discharge:</td>
<td>via the natural-draft wet cooling tower</td>
</tr>
<tr>
<td>Distributed control system</td>
<td>SPPA-T3000 power plant automation system</td>
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Large gross power outputs for USC units in the range from 800 to 1000 MW are preferred by many customers to provide electricity at low cost. Maximizing the use of single-train designs is a key issue to take advantage of economies of scale (i.e., lower specific capital expenditures in €/kW at larger unit sizes). Some limitations need to be taken into account before the final unit size is fixed. Although Siemens can even supply USC steam turbine packages for 1000+ MW gross power output (see references in [1] and [4] for details), the size of some plant components available at the market is a limiting factor for cost-effective single train designs (Figure 2). For example, only a few air preheater suppliers exist for single-train air paths in >900 MW_\text{el} coal-fired power plants. Less competition might reduce the effect of economy of scale.
To ensure a flexible operation, header-type high-pressure feedwater heaters are preferred in this power range since the plate in U-type FWH gets too thick for a single-train design. Two feedwater trains result in higher capital expenditures.

Electric-driven boiler feedwater pump (BFP) configurations are affected by the stability requirements of the grid and the auxiliary power supply during startup. A standard configuration consists of 2x50% pumps. For larger units, either a 3x33% configuration or a steam turbine driven pump might be required. Again, both solutions increase the total capital investment.

High-energy piping (main steam, hot/cold reheat, and feedwater) has a significant share in the total capital expenditures for the overall plant. The price for the piping material P92 is still rising and emphasizes the need to optimize the piping design. Higher steam parameters (e.g., 620 °C instead of 610°C) cause thick piping walls and higher cost. Increasing the steam mass flow rate (= power output) for a given wall thickness generates excessive pressure losses deteriorating the performance. Evaluating the trade-off between capital expenditures and efficiency shows that: (a) steam parameters up to 610 °C are an economic reasonable choice, (b) two main steam lines are sufficient even for 900+ MW, and (c) a second cold reheat line needs to be added when the gross power output is raised from 800 to 900 MW.
Unit sizes should be carefully evaluated. Based on comprehensive expertise and a broad product portfolio, Siemens can provide guidance in this task.

**Plant Layout**

Lünen is a good example of the SSP5-6000 (1x800) concept in practice. General layout planning attached particular importance to a compact and economic design (Figure 3). The arrangement of the steam turbine and the boiler results in short steam lines and a short electrical run to the switchyard. The side arrangement of the cooling tower in relation to the electrostatic precipitators allows efficient routing of the flue-gas exhaust system through the cooling tower, while at the same time optimizing the circulating water system. The SSP™ design incorporates highly efficient components and systems which lead to low emissions. A high efficiency due to ultrasupercritical steam parameters further reduces these emissions thus simplifying the permitting process.

![Diagram showing plant layout](image)

**Emissions**

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<table>
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<tbody>
<tr>
<td>NOx</td>
<td>200</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>SOx</td>
<td>200</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>CO</td>
<td>&lt;200</td>
<td>g/kWh</td>
</tr>
<tr>
<td>PM</td>
<td>20</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>CO₂</td>
<td>&lt;800</td>
<td>g/kWh</td>
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**Figure 3 General arrangement drawing (Example: Trianel Lünen / Germany [1])**

Figure 4 illustrates the compact cost-effective plant design in the turbine building which also allows for good accessibility during maintenance. Header-type high-pressure feedwater heaters and the separate desuperheater are located in-front of the high-pressure steam turbine. The turbine floor level is on 17 m. No basement exists in the turbine building to minimize construction efforts. Lünen is also adopting the heater bay concept with the main components of the high and low pressure feedwater preheating line (including the feedwater tank and boiler feed pumps) arranged within an annex of the turbine hall.
The annex is located between the turbine building and the boiler island and forms an integral part of the main structure. The central switchgear building is nearby the turbine building and accommodates the central control room.

**Steam Turbine**

The modular steam turbine portfolio of Siemens enables full speed tandem compound turbo-sets for ultrasupercritical steam power plants (gross power output: 600 to 1200 MW per unit). A typical steam turbine set SST5-6000 for an 800-1000 MW unit with cooling tower consists of a four-casing arrangement with separate HP, IP, and two LP turbines (Figure 5).
Main product requirements are highest efficiency and flexibility without limiting reliability, availability and lifetime at high steam parameters of 270 bar/600°C (main steam) and 60 bar/610°C (reheat steam) at the steam turbine inlet. Figure 5 shows some important design features addressing these requirements.

The HP cylinder is designed as a barrel-type turbine and has an inner casing. This rotation-symmetric design has minimum deformation during steady-state and transient operation and as a consequence minimum clearances i.e. minimum leakage losses are achieved. Advanced sealing technologies like brush seals and abradable coatings reduce steam leakages even further (i.e. the inner efficiency is further increased).

A general key criterion for turbine efficiency is blading design. Siemens proven advanced 3DV™ technology (3-dimensional design with variable reaction levels) is applied for HP and IP blades. With 3DV™ blades the stage reaction and stage loading for each row is optimized to gain highest HP and IP efficiencies. Stage reaction describes the split of pressure drop and velocity increase between stationary and moving blades, and is defined by the ratio of the enthalpy drop through the moving blade row to the enthalpy drop through the whole stage. For increased steam temperatures of the first stages the use of Nimonic material has proven to be an adequate solution.

Another HP turbine design feature for USC applications is the internal bypass cooling system. Basically a small amount of cooling steam passes through radial bores into the small annulus between the inner and outer HP casing. The cooling steam is lead through the inner casing towards the thrust balancing piston. Thus the surface temperature is reduced, creep stresses are reduced and customers’ lifetime requirements are met. The internal bypass cooling also effectively protects the inner surface of the outer casing (which would be exposed to main steam temperature without the internal bypass cooling). As a consequence it was possible to reduce the wall-thickness of the outer casing enabling faster heat-up of the casing. Thus, an improved starting performance is another customer benefit of this innovative concept.

In addition, the IP turbine is equipped with an internal cooling system to reduce the rotor surface temperature in the inlet section. This cooling principle called vortex cooling results in a temperature decrease due to reduced relative steam velocities at the rotor surface. The patented push rod concept permits parallel axial thermal expansion of LP rotor and inner
casing by directly coupling the IP outer casing with the LP inner casing. This reduces clearances between rotor and casing and improves the efficiency. The low-pressure turbines are double-flow designs. Different available exhaust areas between 5 m$^2$ and 12.5 m$^2$ provide optimum steam flow for all existing types of condenser cooling. A comprehensive technical description of specific features is given in references [1]-[4].

Siemens has many years of operating experience with large scale USC steam turbines. Isogo (Japan) being the first unit was in put in commercial operation in 2001. After 48000 operating hours, the inspection of the 500 MW turbo set in 2008 showed a very good condition of all relevant components and revealed an outstanding suitability of the selected design concept. Since this first application steam parameters have increased only slightly but gross power output capacity has risen considerably. Chinese power suppliers favor 1000 MW, European customers nowadays very often consider 800-900 MW an optimum unit size. In addition to the Isogo steam turbine set six other units delivered by Siemens are currently in commercial operation. Another six units are awarded and these projects are processed now [4].

**Generator**

The mechanical power released by the steam turbine set is converted into electrical power in a highly efficient manner by a 2-pole synchronous generator of the SGen5-3000W class shown in Figure 6. The efficiency of such a generator reaches values of up to 99 %.

![Figure 6 SGen5-3000W generator.](image-url)
Although the shaft power is almost completely transferred to the grid, the loss must be removed by sophisticated cooling concepts. Concerning the stator winding, machines of this power-class utilize direct water cooling of the conductors because of the high specific heat and heat transfer coefficient of water. For practically all types of machines the conductive parts of the stator bars are made of insulated, single copper strands which are guided through the whole conductive cross-section in a position changing manner. This means twisting around a vertical central plane and forming two or a multiple of two columns, a design basically known as the Roebel bar.

In a direct water-cooled stator winding, the cooling water is supplied to some hollow strands which provide direct transfer of generated heat to the coolant. These hollow strands are made of copper in machines with a rated power of 1300 MVA and above. However, hollow copper strands require great effort concerning the primary water conditioning. Alkalization and restrictive oxygen control is needed as a protection against corrosion and the accumulation of corrosion products in the strands with the risk of blockage. It is therefore advantageous to replace hollow copper strands in the bar design by stainless steel tubes for coolant transport. The risks associated with corrosion are eliminated thereby and chemical requirements for the primary water are significantly reduced. A simple deionization of the water is sufficient.

From the electrical point of view, bar designs based on stainless steel tubes are less efficient compared to mere copper designs only to a very small and practically almost negligible extent. Directly water-cooled machines equipped with stainless steel tubes in the stator bars are available with a rated power of up to 1150 MVA. However, this limit will be exceeded by the new harmonized product line of Siemens water cooled generators the development of which has recently started.

The rotor winding is cooled by compressed hydrogen gas (e.g. to 600 kPa) which improves cooling performance by a factor of approximately 14 compared to air at atmospheric pressure. In the direct cooling design the gas flows along axial ducts inside the copper conductors from both sides providing direct heat transfer from the copper winding to the gaseous coolant, which is finally exhausted through radial vents into the air gap in the central region of the rotor body. From there it is fed back via the air gap and through vertically arranged hydrogen coolers before again entering the winding under the retaining ring as shown in Figure 7.
The necessary differential pressure for keeping the inside gas atmosphere in motion is generated by a multi-staged, optimized on-shaft blower. The laminated stator core is also equipped with axial ducts and cooled in the same fashion allowing for a uniform temperature distribution in all core components.

These design features, in combination with many other well established and proven concepts, make the Siemens SGen5-3000W product line some of the most highly reliable and efficient energy converters for coal-fired power plants throughout Europe and the whole world. The proven design features of Siemens water-cooled generators are based on experience from hundreds of generators in commercial operation worldwide. The generators are designed for daily start-stop operation with high reliability.

**Water/steam cycle**

The simplified process flow diagram is shown in Figure 8. Important features of the water/steam cycle include (see Table 1):

- Frequency control through condensate throttling,
- Condensate polishing in bypass loop; separate 1 x 100% condensate polishing pump,
- Steam bypass system including a 4x25 % HP bypass station with safety function and a 2x50 % LP bypass station.
Figure 8 Water/Steam cycle (Example: SSP5-6000 (1x800 USC))

**Thermodynamic Performance**

The SSP5-6000 (1x800 USC) reference power plant is designed for an overall plant net efficiency of 45.5-46.0%. Depending on the quality of the coal and on the cooling conditions, the performance data of coal-fired power plants can vary in a certain range. In addition, the efficiency of the plant is determined by the selected technical systems and components.

Figure 9 illustrates the impact of some design parameters on the overall plant efficiency of a bituminous coal-fired steam power plant without CO\(_2\) capture. The temperature and pressure of the steam supplied to the turbine are key design variables that affect both the cost and the efficiency of the overall plant. The availability of new materials pushed forward the efficient conversion of coal energy into electricity by allowing higher steam parameters. A conservative approach was chosen for the maximum steam temperatures in the ultrasupercritical SSP5-6000 series to ensure a high availability and to improve the economic lifetime of the power plant. Raising the reheating temperature from 610 to 620°C slightly improves the net efficiency. However, the additional costs due to the increased material thickness outweigh this effect. For future applications, net efficiencies above 50% at coastal sites (once-through seawater cooling) might be achieved if nickel-based alloys prove their economic readiness for use. Even higher fuel utilization factors can be attained in combined heat and power applications.
Future CCS Options

Requirements for Carbon Capture Readiness

Carbon capture and storage (CCS) and carbon capture ready power plant designs (CCR) are becoming increasingly important for the evaluation of investments into new power plants. Highly efficient power generation is the key to keep the carbon capture cost as low as possible. For that reason, “best available technology” for the steam power plants, as described in the previous sections, is a prerequisite for the later retrofit. Capture readiness should not result in an inefficient plant operation in the period of time before the retrofit.

A power plant in the capture ready design will be able to integrate the CO\(_2\) capture unit when the necessary regulatory or economic drivers are in place. In the EU a capture ready assessment is mandatory for all new fossil power plants > 300 MW\(_{el}\), in other regions capture ready programs are already implemented or still under discussion. The aim of building power plants that are capture ready is to reduce the risk of stranded assets or “carbon lock-in”. Service companies such as the “Technischen Überwachungsvereine” (TÜV) in Germany offer their expertise to certify capture ready power plant projects considering all aspects of CO\(_2\) transportation and storage.
In the capture ready assessment the following topics have to be addressed:

- Evaluation of viable CO$_2$ transportation and accessible CO$_2$ storage options
- Reservation of sufficient area on the site for the later retrofit of the CO$_2$ capture unit including CO$_2$ compression and all plant integration measures.
- Assessment of the economic and technical aspects for the later retrofit and integration of the CO$_2$ capture unit.

**Design Options**

Developing cost-effective capture-ready design solutions consists of finding an appropriate balance between the additional investment in the early capture ready design and the later investment for the retrofit. Environmental aspects during the different planning and project execution periods also have to be considered.

![Diagram of capture ready requirements for the steam power plant](image)

Figure 10 Capture ready requirements for the steam power plant

Siemens has already developed capture-ready design options for the advanced SSP5-6000 reference power plant series (Figure 10). The measures are focused on four main topics:

- **Water supply and cooling water**: These systems need to be adapted. Later capacity extensions have to be considered in civil and in the plant layout from the outset.
- **Auxiliary power consumption**: The electrical auxiliary load will be doubled after retrofit of the capture unit, mainly caused by the CO$_2$ compression. Sufficient space, additional auxiliary transformers, switchyard and cable routes need to be considered.
• **Steam extraction:** A significant amount of the available LP steam (approx. 40 %) needs to be extracted from the steam turbine and has to be supplied to the capture unit for solvent regeneration. Siemens has evaluated more than 10 different options considering technical and economic aspects. Avoiding thermodynamic inefficiencies associated with throttling at full and partial load as well as keeping the capital expenditures low are the main challenges. In addition, the different solvents and capture processes under competition vary in demand and properties of LP steam.

• **Flue gas path:** Additional space need to be reserved for the connection of the flue gas duct with the capture unit (T-Branch), for the installation of the additional flue gas fan and for the adaptation of the FGD unit. The maximum allowed SO\(_2\) content in the flue gas at the inlet of the capture unit is reported to be in the range of 5 to 30 mg/Nm\(^3\) for amine based solvents, compared to the current limit 200 mg/Nm\(^3\) (13. BImSchV).

**Interactions with the Power Plant**

Several interactions among the power plant and the CO\(_2\) capture unit exist (Figure 11). The capture process consumes low-pressure steam for solvent regeneration and electrical energy for the solvent pumps and the CO\(_2\) compressors. Cooling water is needed as well. The mass and energy flow rates at the interfaces depend on the capture process. Optimizing the heat integration between the power plant and the CO\(_2\) capture unit including CO\(_2\) compression will be a decisive factor for the competitiveness of a steam power plant with CO\(_2\) capture.

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![Figure 11 Interfaces between the power plant and the CO\(_2\) capture unit](image)

*Cooling demand can also influence condenser pressure indirectly*

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**Siemens CO₂ Capture Process**

Following an intensive screening of possible chemical and physical solvents including all major first generation solvents (alkanolamines), Siemens selected an amino acid salts as the basis for the capture process. The molecular structure is illustrated in Figure 12. Amino-acid salts have the advantage of negligible vapor pressure so that no solvent emissions by evaporation are expected. Given an appropriate demister on top of the absorption column, which enhances the removal of liquid droplets entrained in the gas stream, the solvent emissions will be nearly zero. No additional washing unit on top of the absorber or desorber is expected to be required in this process.

Having no vapor pressure gives several advantages for HSE aspects too. The amino acid salt solvent is not inflammable, not explosive (only gases can be inflamed), it is odorless as it stays in the liquid phase and there are no inhalation risks too.

Amino acid salts have an ionic structure and are thus less sensitive to oxygen degradation. Oxygen dissolved in water tends to negative loading too and is thus hindered in degrading the dissolved anion of the amino acid salt. This results in a high chemical stability. Furthermore, the solvent exhibits low thermal sensitivity, so that refill requirements are expected to be very low, which has a direct impact on the operating costs of the CO₂ capture plant. Thermal stability of the solvent also gives more flexibility to the process design, i.e. the absorption and desorption process can be run at a wide range of temperatures and pressures. This second-generation solvent is well-adapted to operational needs of a power plant. Handling for operation and storage is easy.
Figure 12 illustrates fundamental principles of the CO₂ capture process. A detailed description can be found in [6]. In the course of process optimization studies, approximately 50 different options were identified and rated according qualitative criteria. About 30 promising process variants were selected and analyzed in detail using a verified simulation model. As a preliminary result, the energy consumption of the process could be decreased from 3.5 GJ/ton to 2.7 GJ/ton of separated CO₂ by using an advanced process configuration, as indicated in the grey box (confidential process features).

**General Plant Layout**

![Diagram of General Plant Layout](image)

Figure 13 Steam power plant with a post-combustion capture unit

Figure 13 shows an example how the carbon capture plant in a two train arrangement is integrated into the power plant and gives an indication of the area requirements for the capture plant. Potentials for reducing the space requirements are currently being evaluated. Preliminary estimates for the capital expenditures associated with a carbon capture plant for a ultrasupercritical SSP5-6000 (1x800 USC) steam power plant including CO₂ compression and plant integration are in the range of 300 to 400 million €, depending on the train concept selected (price base 2009).
From Pilot Plants to Full Scale Applications

Close collaboration between process development and equipment design and manufacturing is needed for upscaling the absorber columns in postcombustion CO$_2$-capture demonstration projects (Figure 14). Selecting a two-train concept for the capture unit in a SSP5-6000 (1x800 USC) steam power plant would require absorber diameters in the range of 16 to 18 m. However, the technology has to be validated in “slip stream” demonstration units first. Due to limited experiences in the chemical and in the oil & gas industry with absorber diameters above 12 m, Siemens recommends to limit the absorber diameter in demonstration units to approx. 12 m. Based on this absorber size an equivalent flue gas stream of about 200 MW$_{el}$ could be treated in single train or 400 MW$_{el}$ in a two train concept.

![Figure 14 Absorber scale-up steps from lab to prototype](image)

**Conclusions**

- Ultrasupercritical steam parameters, optimized key plant components and processes are prerequisites for high overall plant efficiencies, low emissions and the sustainable use of energy resources.
- Siemens SSP5-6000 reference power plant series for advanced steam power plants rely on proven technology, result in high efficiencies, and ensure low life-cycle cost.
- Extensive knowledge of an experienced power plant supplier is required to select the most cost-effective design options for the given project-specific boundary conditions.
- Siemens develops a proprietary CO$_2$ capture process.
- Measures for capture ready steam power plants are already defined.
The efficiency penalty associated with CO₂ capture based on Siemens advanced process is -9.2 %-pts (validated with the lab piloting unit).

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References


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