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ENVIRONMENT

PAPER

CHILLED AMMONIA PROCESS FOR CO_2 CAPTURE

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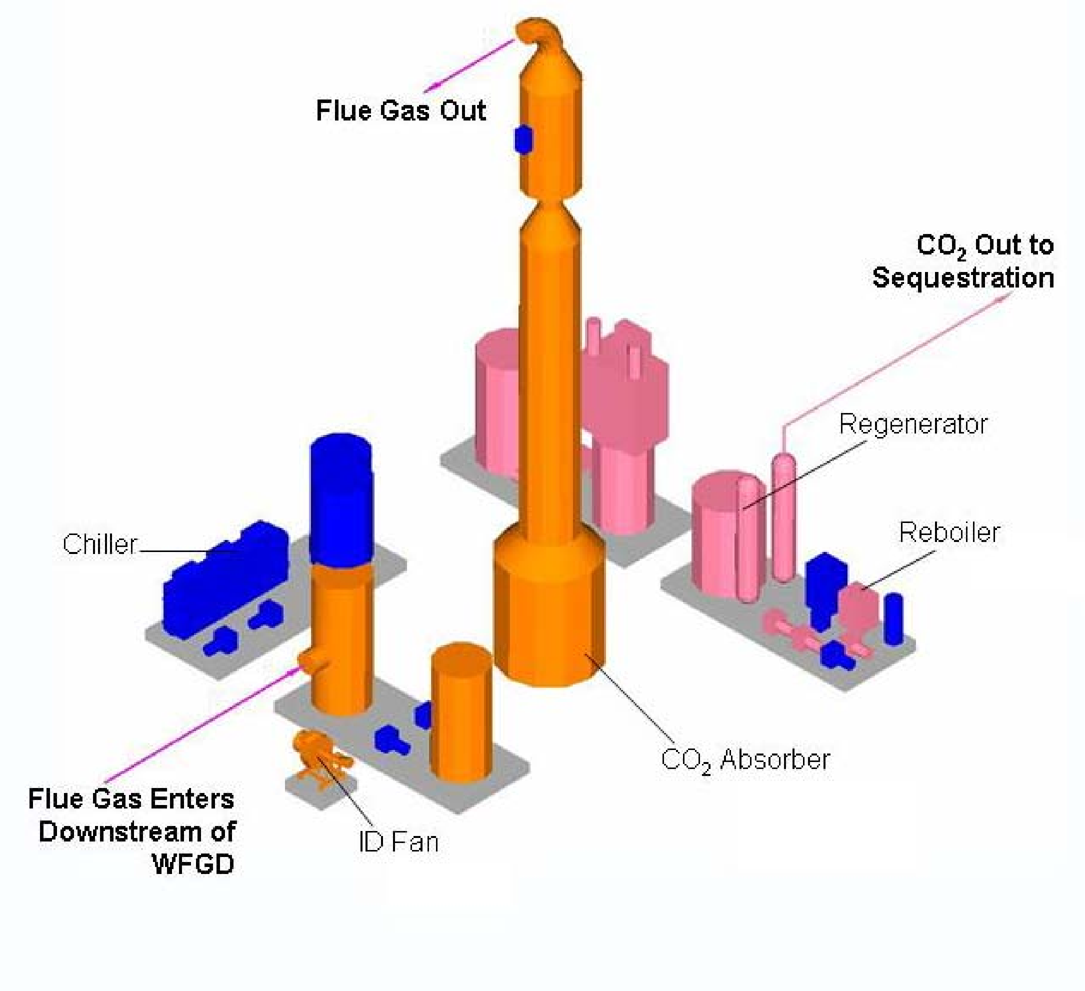

CONCEPT FOR COMMERCIAL SCALE SYSTEM

ALSTOM has licensed the exclusive, world-wide rights to market and sell the patented process described below from EIG, Inc. ALSTOM is now engaged in an extensive development and commercialization program with the objective of offering a commercial product for selected market segments before the end of 2011. The process has the potential to be applied to capture CO_2 from flue gases exhausted from coal-fired boilers and natural gas combined cycle (NGCC) systems, as well as a wide variety of industrial applications.

The concept described below will be constructed and tested in a 5 MW pilot plant to be built at the We Energies' Pleasant Prairie Power Plant (see further details below). Optimization and improvements based on the proposed pilot will impact the final design for commercialization. This description captures the main features and advantages of the process. The process is designed to take advantage of the very attractive characteristics of the ammoniated solution while preventing the ammonia escape from the system. The feasibility of the key features described herein has been confirmed in small and large bench scale tests.

A schematic of the integrated process is shown in *Figure 1* below. The system is expected to achieve 90% removal of CO_2 and high removal of residual SO_2, HCl, HF, SO_3, and $PM_{2.5}$.

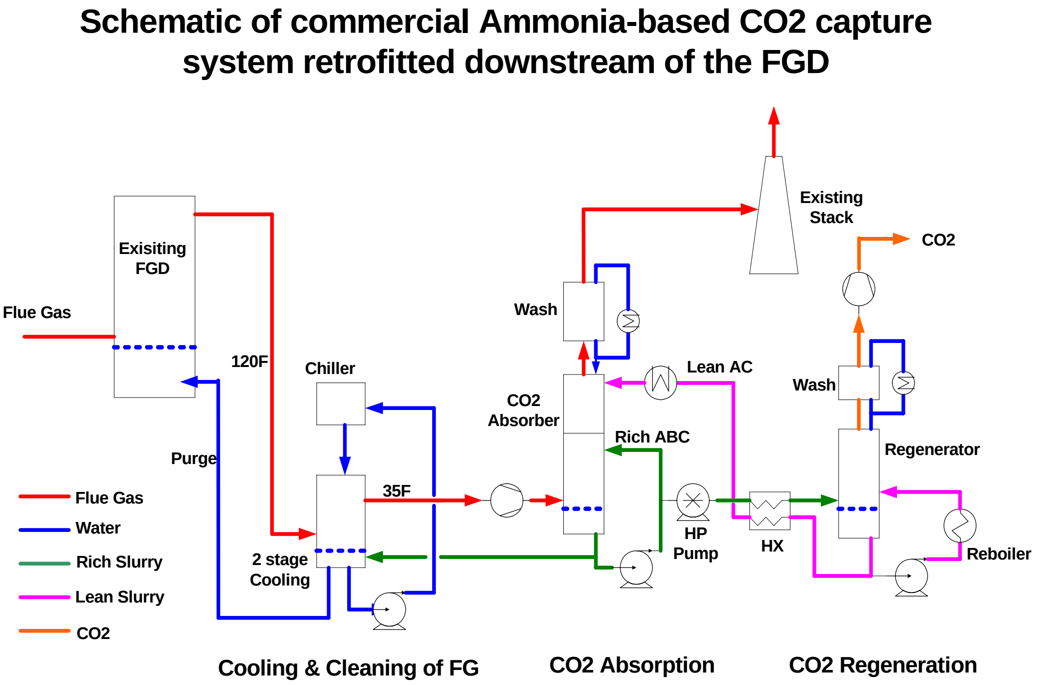
Schematic of commercial Ammonia-based CO2 capture system retrofitted downstream of the FGD

Figure 1

The CO_2 capture system has the following main subsystems:

1. Flue Gas Cooling.
2. CO_2 absorption.
3. High-Pressure Regeneration.

FLUE GAS COOLING

The flue gas exiting the FGD is typically at 120-140°F. The gas is water saturated and it contains residual contaminants such as SO_2, NO_x, HCl, sulfuric acid mist, filterable particulate matter (PM) and condensable particulate matter ($PM_{2.5}$). In order to cool the saturated flue gas, both sensible heat and latent heat for water vapor condensation has to be removed. Direct cooling with no heat exchangers using cooling towers and mechanical chillers is the most efficient and low cost cooling method. Direct cooling of the saturated flue gas results in massive condensation of water and in the capture of residual contaminants from the flue gas. The pH of the water in the flue gas cooling subsystem will be controlled by alkaline reagent.

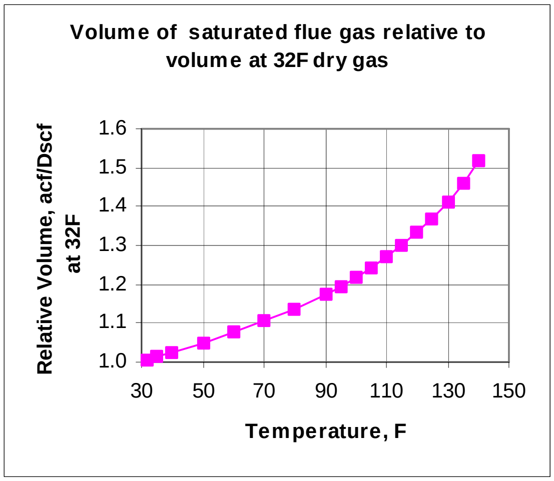

Figure 2

The net water balance around the flue gas coolers, with moisture condensing in the direct coolers and evaporating in the cooling towers is close to being even. Cooling the flue gas to 35°F is estimated to consume 1-2% of the power output of the plant (depending on ambient conditions), a small power penalty relative to the huge gains elsewhere in the system.

The low temperature and the elimination of most of the moisture from the flue gas results in a substantial reduction in volume and mass of the flue gas reducing the size of downstream equipment.

The impact of the cooling-condensing operation on the volume of the flue gas is given in *Figure 2* above. It shows that **the volume of the saturated flue gas is 33% smaller at 32°F compared to the volume at 140°F.** The ID fan will be installed downstream of the cooling subsystem minimizing its size and power consumption.

CO_2 ABSORPTION

The flue gas entering the CO_2 absorber is cooled, it is relatively dry with less than 1% moisture, and it contains low concentrations of SO_2, SO_3, HCl and PM.

The CO_2 absorber is similar to SO_2 absorbers and is designed to operate with slurry. The flue gas flows upwards in counter current to the slurry containing dissolved and suspended mix of ammonium carbonate and ammonium bicarbonate. More than 90% of the CO_2 from the flue gas is captured in the absorber. The low concentration of ammonia in the clean flue gas will be captured by cold-water wash and returned to the absorber. The clean flue gas, containing mainly nitrogen, excess oxygen and low concentration of CO_2 flows to the stack.

HIGH-PRESSURE REGENERATION

The CO_2-rich slurry from the absorber contains mainly ammonium bicarbonate. The CO_2 rich slurry is pumped through a heat exchanger to the high-pressure regenerator. The pressure required for the CO_2 gas at the plant boundary limits is in the range of 1200-1500 psi representing a pressure ratio of about 80-100 relative to the ambient conditions. The proposed process generates the CO_2 at higher pressures, thus reducing the pressure ratio for mechanical compression and consuming less power.

The ammonium bicarbonate in the CO_2 rich slurry dissolves as the temperature increases in the heat exchanger and it turns into a clear solution at about 80°C (175°F). The hot solution is injected into the regenerator, which is a high-pressure vessel. Additional heat for stripping the CO_2 is provided in a reboiler. Both ammonia and water vapor, about 5% of the total CO_2 gas stream, are captured in a cold-water wash at the top of the absorber.

PERFORMANCE EVALUATION OF COMMERCIAL SYSTEM

A study to evaluate the energy consumption and the cost of a full-scale CO_2 capture system was conducted and compared to a study on a MEA system performed by Parsons in 2000 and 2002. The base power plant is a supercritical PC boiler firing 333,542 lb/hr Illinois #6 coal operating at 40.5% net efficiency (HHV) and generating 462 MWe of net power. Plant energy performance with and without CO_2 capture is summarized in the Table below.

	Supercritical PC Without CO_2 Removal	SCPC With MEA CO_2 Removal Parsons Study	SCPC With NH_3 CO_2 Removal Current Study
Coal Feed rate, lb/hr	333,542	333,542	333,542
Coal heating value, Btu/lb (HHV)	11,666	11,666	11,666
Boiler heat input, MMBtu	3,891	3,891	3,891
LP Steam extraction, lb/hr for reboiler	0	1,215,641	179,500
Steam Turbine Power, kWe	498,319	408,089	484,995
Generator loss, kWe	(7,211)	(5,835)	(7,018)
Gross plant, kWe	491,108	402,254	471,301
Plant Auxiliary Load (IDF, FGD, BFW pumps, Water pumps, Cooling Towers, CO2 unit, Chillers, CO2 compressor, BOP), kWe	(29,050)	(72,730)	(53,950)
Net Power Output	462,058	329,524	421,717
Net efficiency, % HHV	40.5	28.9	37.0
Avoided Cost, $/ton CO2	Base	51.1	19.7

As shown, the biggest saving by far, compared to the MEA system, is the steam extraction for absorbent regeneration. The steam consumption in the reboiler of the ammonia-based system is less than 15% of the consumption of the MEA system mainly due to the lower heat of reaction and the lower steam fraction in the regenerated CO_2 stream. The main auxiliary power saving relative to a MEA system is the much smaller CO_2 compressor and ID fan. Additional power is required for cooling. However, the saving is significantly greater than the additional power consumption to yield a net saving of almost 91 MWe compared to the MEA system.

DEVELOPMENT AND COMMERCIALIZATION OF THE CHILLED AMMONIA PROCESS

ALSTOM is currently engaged in an extensive development program to commercialize the chilled ammonia process for post-combustion capture of CO_2 emissions from power plants before the end of 2011. Subsequent releases of the proposed technology will enable the technology to be applied to capture CO_2 from other applications in both power generation and industry.

Over the past 24 months, bench scale testing funded by ALSTOM, EPRI, and other third-parties confirmed the potential of the process to cost-effectively capture CO_2 emissions. The second step in development was the construction of a 0.25 MWe large bench scale CO_2 absorber, with the following objectives:

1. Demonstrate greater than 90% CO_2 removal efficiency with low ammonia emission;
2. Measure CO_2 mass transfer for various operating conditions;
3. Improve the understanding and database of the fundamental system parameters;
4. Identify and evaluate key components for future phases of development.

The large bench scale pilot commenced operation in October, 2006 and will be operated throughout 2007.

ALSTOM, EPRI and We Energies have recently announced the development of a 5 MWe field pilot to be installed and operated at the We Energies Pleasant Prairie Power Plant, located in Pleasant Prairie, Wisconsin, US.

As the technology developer, ALSTOM will design, construct and operate the carbon capture facility. This pilot will capture CO_2 emissions from a slipstream of less than one percent from one of the two boilers operating at the We Energies' Pleasant Prairie Power Plant. The absorbed CO_2 is separated from the flue gas. Once the CO_2 is isolated from the flue gas, it is considered captured.

The main objectives of this project are the following:

- Demonstrate full system operation on actual flue gas, including but not limited to: flue gas cooling using heat recovery/exchange and chilling, removal of residual pollutants, CO_2 absorption and regeneration;
- Evaluate energy consumption relative to calculated values and to other CO_2 capture technologies;
- Operate the system long-term to identify O&M issues and establish system reliability;
- Conduct field tests to gather operating data from the system and develop objective, third-party techno-economic analyses to refine current estimates for the performance and lifetime costs of a commercial system;

The construction of the carbon capture facility will begin in early 2007, with start-up anticipated in mid-2007. The project will remain operational for at least one year. During this time, EPRI will conduct an extensive test program to collect data and evaluate technology performance. ALSTOM expects that results from the pilot plant will be published before the end of 2008.

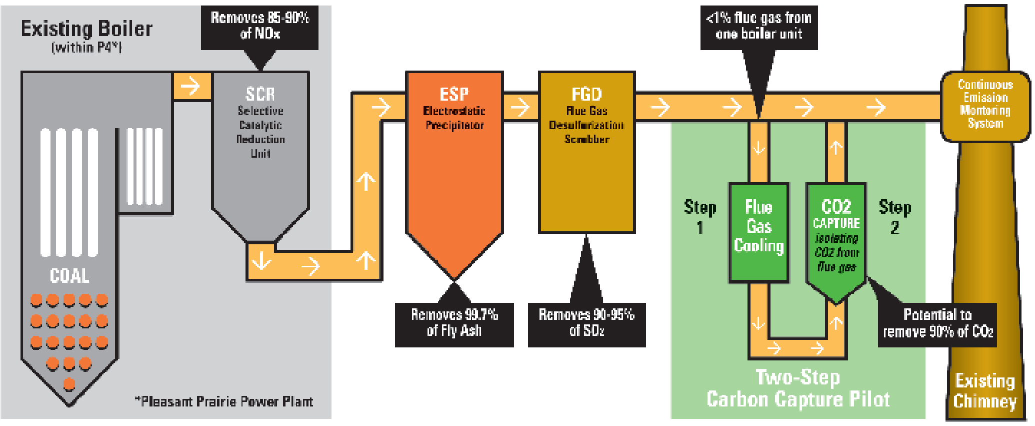

Photo courtesy of We Energies

In addition, ALSTOM is planning the development of a similar pilot project, to be located in the European Union.

Following successful operation of these field pilot units, ALSTOM anticipates the final stage of development and commercialization will involve the design, construction and operation of a larger scale commercial demonstration project.