

## **Overview of ECO<sub>2</sub><sup>TM</sup> for CO<sub>2</sub> Capture**

In May 2004, Powerspan Corp. and the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) entered into a cooperative research and development agreement to develop a cost effective CO<sub>2</sub> removal process for coal-fired power plants. The regenerative process, called "ECO<sub>2</sub><sup>TM</sup>", is readily integrated with Powerspan's ECO<sup>®</sup> process for multi-pollutant control, and uses an ammonia-based solution to capture CO<sub>2</sub> in flue gas and release it for enhanced oil recovery or other form of geological sequestration. The process can be applied to both existing and new coal-fired power plants and is particularly advantageous for sites where ammonia-based scrubbing of power plant emissions is employed.

ECO<sub>2</sub> is a scrubbing process that uses an ammonia-based (not an amine) solution to capture CO<sub>2</sub> from the flue gas. The CO<sub>2</sub> capture takes place after the NO<sub>x</sub> and SO<sub>2</sub> capture in Powerspan's ECO multi-pollutant control technology. Once the CO<sub>2</sub> is captured, the ammonium bicarbonate solution is regenerated to release CO<sub>2</sub> and ammonia (NH<sub>3</sub>). The NH<sub>3</sub> is recovered and sent back to the scrubbing process, and the CO<sub>2</sub> is in a form that is sequestration ready. Ammonia is not consumed in the scrubbing process, and no separate by-product is created.

## **ECO<sub>2</sub> Commercialization Plan**

Both Powerspan and the DOE have conducted laboratory testing of the CO<sub>2</sub> capture process, and Powerspan is preparing for pilot testing, which is scheduled to begin in early 2008. Powerspan laboratory testing of the CO<sub>2</sub> absorption process has demonstrated 90 percent CO<sub>2</sub> removal under conditions comparable to a commercial-scale absorber, confirming test results previously obtained by the DOE under similar conditions.

### **Pilot Test Program**

In September 2005, Powerspan and FirstEnergy announced plans to pilot test the ECO<sub>2</sub> technology at FirstEnergy's R.E. Burger Plant in Shadyside, Ohio. In May 2006, FirstEnergy announced that its Burger Plant was selected as a carbon sequestration test site by the Midwest Regional Carbon Sequestration Partnership, one of seven regional partnerships set up by the U.S. DOE to research carbon sequestration projects throughout the country. These combined projects provide a first-time opportunity to demonstrate both CO<sub>2</sub> capture and sequestration at a conventional pulverized coal-fired power plant.

The ECO<sub>2</sub> pilot unit will process a 1-MW slipstream (20 ton CO<sub>2</sub>/day) from the 50-MW Burger Plant ECO unit. The pilot program will demonstrate the ability of the CO<sub>2</sub> capture process to be integrated with the ECO multi-pollutant control process and will confirm process design and cost estimates.

- 1 MW equivalent, designed to capture 90% of incoming CO<sub>2</sub> (~20 tons/day)
- Purified CO<sub>2</sub> stream will be provided to Battelle/EPRI for pressurization and sequestration on site as part of the Midwest Regional Carbon Sequestration Partnership project, sponsored by U.S. DOE.

- Construction of ECO<sub>2</sub> pilot scheduled for completion by the end of 2007 with pilot testing beginning early in 2008.

### **Commercial Demonstration Program Plans**

The following highlights the major aspects of the Company's plans to commercially demonstrate the ECO<sub>2</sub> process, based upon successful completion of the pilot scale testing in 2008-09:

- The ECO<sub>2</sub> commercial demonstration would nominally be a 100 MW system, capturing 90% CO<sub>2</sub> (2,000 tons/day, or 500,000 tons/year at 70% capacity factor), making this system among the largest CO<sub>2</sub> capture systems in the world.
- Design of the commercial demonstration would begin in 2009 with operations commencing in 2011.
- The commercial demonstration would preferably be installed where an ECO unit is located and also within close proximity to an enhanced oil recovery (EOR) site. CO<sub>2</sub> sold for EOR is worth up to \$30/ton with \$50/barrel oil prices.

### **Plans for Full-Scale Commercial ECO<sub>2</sub> Systems**

With success of the pilot and commercial demonstration phases, it is reasonable to project availability of full-scale ECO<sub>2</sub> systems beginning in 2015 (assuming a design start in 2012).

### **Projected ECO<sub>2</sub> Capital Cost**

Today, Powerspan would target full-scale ECO<sub>2</sub> system capital costs in the \$300-\$500/kW range, or \$150-\$250 million for a 500-MW plant (assuming ECO is already installed).

## **Background on CO<sub>2</sub> Capture Economics & Research**

### **CO<sub>2</sub> Capture Economics**

In February 2005, DOE published *An Economic Scoping Study for CO<sub>2</sub> Capture Using Aqueous Ammonia* that compared the cost of CO<sub>2</sub> capture and sequestration for a new super-critical pulverized coal-fired power plant using conventional air pollution control equipment and amine (MEA, monoethanolamine) based CO<sub>2</sub> absorption, versus a multi-pollutant control system such as ECO and CO<sub>2</sub> removal using ammonia (i.e. ECO<sub>2</sub>). Their economic analysis projects that 90% CO<sub>2</sub> capture and sequestration with the conventional pollution control systems and MEA would cost \$47/ton of CO<sub>2</sub> removed, and the cost of electricity would be 7.6 cents/kWh. By comparison, the estimated costs for the ECO system with ammonia-based CO<sub>2</sub> capture and sequestration were \$14/ton of CO<sub>2</sub> removed and 5.5 cents/kWh for electricity. Thus the projected incremental costs of CO<sub>2</sub> removal with ECO are less than one-third of the costs for conventional technology on pulverized coal-fired plants.

### **CO<sub>2</sub> Capture Research**

NETL researchers authored a paper entitled *Aqua ammonia process for simultaneous removal of CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>x</sub>*. This paper documents research conducted at NETL labs on the use of aqua ammonia for absorption of CO<sub>2</sub>. The paper reaches the following conclusions:

1. The traditional monoethanolamine (MEA) process for CO<sub>2</sub> removal suffers the disadvantages of low CO<sub>2</sub> loading capacity (kg CO<sub>2</sub> absorbed per kg absorbent), high equipment corrosion rate, amine degradation by SO<sub>2</sub>, NO<sub>2</sub>, HCl, HF and O<sub>2</sub> in the flue gas (which requires a high absorbent makeup rate), and high energy consumption during absorbent regeneration.
2. By comparison, aqua ammonia, which Powerspan uses in the ECO<sub>2</sub> process, has higher loading capacity, does not pose a corrosion problem, does not suffer degradation in a flue gas environment (minimizing absorbent makeup), requires much less energy to regenerate, and costs much less than MEA.
3. Specifically, the aqua ammonia process compared to MEA:
  - a. Has CO<sub>2</sub> absorption capacity up to two times greater;
  - b. Requires 49% to 64% less heat to release CO<sub>2</sub> and regenerate absorbent; and
  - c. Has reagent makeup costs of approximately one sixth.
4. Another major benefit is that removal of other pollutants (principally SO<sub>2</sub> and NO<sub>x</sub>) could be integrated with the aqua ammonia process for CO<sub>2</sub> removal (i.e. using the ECO multi-pollutant control technology).

Both NETL and Powerspan have research teams assigned to conduct bench-scale testing of the process to optimize parameters for CO<sub>2</sub> capture and regeneration of the ammonium carbonate solution to release CO<sub>2</sub> for enhanced oil recovery or sequestration.