Market Pull Commercialization for Industrial Uses of Carbon Capture Technologies Sponsored by the National Energy Technology Laboratory

Introduction

Analyses such as "Carbon Capture and Storage: The solution for deep emissions reductions," (International Energy Agency, 2015) show carbon capture and storage (CCS) plays a critical role in the lowest cost scenarios of meeting global greenhouse gas (GHG) emission reductions. However, there is currently only a limited demand for commercial carbon dioxide (CO_2) capture applications; implementing carbon capture technologies almost always increases the cost of the primary product. In other words, in anticipation of CO_2 emission penalties or future markets for CO_2, carbon capture research is "pushing" technologies toward applications that view the technology as an economic penalty; in general, the current market is not "pulling" on researchers to develop such technologies to satisfy current commercial needs.

There are, however, industries where the barrier for economic entry of carbon capture technology is lower or where the technology can be used in alternative commercial applications. These instances help to drive research from technology applications designed for large point source power generation markets, where CO_2 emissions reduction is maximized, to smaller potential industrial markets, where critical early learning can occur.

The limited opportunities that have significant overlap between immediate industrial interest and federal motivation can and should be fully leveraged. Pulling carbon capture technologies forward into commercial and demonstration projects at industrial facilities has the potential to de-risk the technology on these limited applications in preparation for widespread CO_2 mitigation. These commercial applications and demonstration projects at industrial facilities also lead to comprehensive assessment of CO_2 capture technologies across industry sectors.

Through significant performance improvements and cost reductions, carbon capture research at the U.S. Department of Energy's (DOE) Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) has pushed several technologies over market barriers to the point where market pull is developing. This is now resulting in alternative commercial applications and large-scale demonstration projects at industrial facilities with an emerging economic interest in CO_2 capture.

Background

The NETL Carbon Capture Program's research and development (R&D) portfolio contains CO_2 capture technologies that are projected to provide step-change reductions in both cost and energy penalty compared to currently available technologies. The program sponsors research projects applying various pre- and post-combustion CO_2 control technologies, including advanced solvents, sorbents, membranes, and other novel concepts.

The scale of NETL's Carbon Capture Program research ranges from laboratory/bench-scale testing under simulated operating conditions; to bench/small pilot-scale testing using actual coal-fired flue gas; to large pilot-scale testing; and, eventually, to long-term testing at demonstration scale. Technical-economic analyses are conducted at each step in the technology's progression to refine cost and performance projections and determine the feasibility of the advanced capture technology.

Many NETL-sponsored carbon capture technologies have progressed through numerous cooperative agreements from successful bench-scale testing to small and large pilot-scale testing with actual coal-fired flue gas. Some of these technologies have moved beyond NETL sponsorship and are being used commercially in alternative applications or have been adopted for further development or demonstration in other independent research programs.

For example, NETL has funded a membrane developed by Membrane Technology and Research, Inc. (MTR) to decrease the economic penalty of large-scale CO_2 capture from power plant flue gases. MTR leveraged federal programs established to mitigate CO_2 emissions from power generation to lay claim to approximately 10 percent of the commercial market for membrane-based fuel gas conditioning. As another example, a polybenzimidazole (PBI) membrane developed by SRI International (SRI) is garnering significant interest in a variety of potential applications, such as water purification and key chemical industries. As a final example, NETL supported development of a solid sorbent through the lab scale. With continued support from the Norwegian government, RTI International (RTI) and Norcem, part of HeidelbergCement Group, are partnering to carry out a pilot-scale carbon capture technology test project in Norcem's cement plant in Brevik, Norway.

MTR – Polaris CO_2 Capture Membrane

The Polaris post-combustion CO_2 capture membrane was developed by MTR with funding support from NETL that began in 2007. Over a series of NETL projects, the membrane was scaled-up from concept to commercial production in 1,000-ft rolls. Although principally intended to capture CO_2 from the flue gas of coal-fired power plants, the technology has found commercial application for industrial use in fuel gas conditioning. Fuel gas conditioning involves removing CO_2, hydrogen sulfide (H_2S), and water vapor from raw natural gas so that the gas can be used as fuel in generators or compressors.

MTR small-pilot (1 MWe) membrane capture system
Source: MTR

Fuel Gas Conditioning Membrane Installations

Raw, unprocessed natural gas is widely used to power field engines and turbines that drive compressors or generate power. However, unprocessed gas can be very rich in heavy hydrocarbons, which can lead to corrosion and carbon build-up in the gas engine. Moreover, CO_2 and nitrogen (N_2) diluents lower the heat content of the fuel. These impurities can compromise engine operation, increase downtime, or increase emissions.

The MTR technology is used in systems that purify raw gas to premium quality fuel gas. Although membrane systems to remove CO_2 have been used in the natural gas processing industry since the mid-1980s, the MTR membrane technology sponsored by NETL uses differences in gas solubility to permeate both heavy hydrocarbons and CO_2. The MTR membrane removes H_2S, C_3+, CO_2, N_2 and water from fuel gas at moderate pressure providing an economic advantage. These units also have the advantages of no moving parts, simple installation, and unattended operation. MTR notes that because these impurities are taken out of the fuel gas and returned to the compressor suction, effluent stream disposal is not required. Any C_3+ removed from the fuel gas goes back into the main gas stream, so all natural gas liquids in the raw gas stream are made available for downstream recovery.

There are currently more than 100 fuel gas conditioning membrane installations in various North American shale plays. Most of these installations use a hydrocarbon-selective membrane to recover C_3+ from the gas. Of these 100 current installations, approximately 10 percent use the MTR Polaris membrane for polar gas removal. Success in this market has been driven by attractive economics made possible by NETL investment in developing this technology.

SRI International Pre-Combustion CO_2 Capture Process Using High-Temperature PBI Hollow-Fiber Membranes

In research conducted with NETL funding that began in 2007, SRI developed a pre-combustion CO_2 capture process that uses high-temperature PBI hollow-fiber membranes (HFMs). SRI is currently developing a technically and economically viable bench-scale PBI membrane CO_2 capture system and optimizing the process for integration into an integrated gasification combined cycle (IGCC) plant.

SRI's membranes are asymmetric hollow-fiber PBI, which is chemically and thermally stable at temperatures up to 450°C and pressures up to 55 atm. Tolerance to these relatively aggressive conditions permits use of the PBI membrane for CO_2 capture downstream of a water gas shift (WGS) reactor without aggressive, prerequisite gas cooling and water knockout. Retaining high temperatures in the synthesis gas (syngas) promotes greater power generation in the Brayton cycle. In addition, the CO_2 is recovered at high pressure, decreasing CO_2 compression requirements. The combination of increased output and reduced auxiliary load significantly increases low-carbon power generation efficiency. However, the improvements in membrane characteristics that lead to these benefits are also appreciated in other applications.

Industrial Uses for PBI Hollow-Fiber Membranes

Industrial users are actively pursuing the SRI PBI HFM technology for a variety of separations. High-potential uses for PBI membranes include desalination and brackish water purification and alcohol dehydration, with growing interest from other potential users as well.

PBI hollow-fiber membranes
Source: SRI

Manufacturers of organic chemicals and solvents can benefit from the water selectivity and solvent resistant nature of PBI-based pervaporation dehydration membranes to produce very pure chemicals at a fraction of distillation costs. As a result, PBI-based membranes have immediate commercial potential for producing and recycling organic chemicals and solvents like tetrafluoropropanol, ethylene glycol, and acetic acid, which are characterized by hard-to-distill, aggressive chemistries.

Successful introduction into additional markets, such as desalination and brackish water purification and alcohol dehydration, is expected to generate supporting capital investments in commercially economic production of HFMs, which will further decrease production costs and lead to wider market deployment.

RTI's Advanced Solid Sorbent Project

Through a cooperative agreement, NETL supported the development of a solid sorbent-based CO_2 capture technology in collaboration with Pennsylvania State University (PSU) and RTI. This technology uses a molecular basket sorbent (MBS) from PSU combined with RTI's circulating, fluidized, moving-bed reactor (FMBR) process design concept. Laboratory- and bench-scale testing was conducted from 2011 through 2015 to characterize and develop the sorbent for CO_2 capture from power plant flue gas. As a result of this development, reduced costs and parasitic loads are projected for the advanced, MBS-based CO_2 capture process.

Development of this technology was primarily supported through a cooperative agreement with NETL. Co-funding was provided by Masdar in the United Arab Emirates, which is interested in the potential application of this technology for natural gas-fired power plants. In addition to Masdar involvement, the success of this technology has pulled future development and demonstration of the RTI sorbent into other independent, international R&D programs.

Brevik, Norway, CO_2 Capture Test Facility

RTI is currently conducting a pilot-scale demonstration of the MBS CO_2 capture technology in an operating cement plant in Brevik, Norway. The demonstration project was initiated in 2013. Under terms of the project, RTI will adapt and integrate its solid sorbent-based process technology, currently developed for coal-fired power plants, into the cement plant. Because the operating experience of cement plants is largely based on solids handling, the solid sorbent technology is anticipated to match the general operational expertise and experience of the cement industry. The project is part of a larger effort by Norcem to construct and operate a CO_2 capture test facility at its Brevik plant for new CO_2 capture technologies that are suitable for the cement industry.

RTI's pilot-scale test unit, Brevik, Norway
Source: RTI International

Financial support for the facility is being provided by Gassnova, the Norwegian state enterprise for CCS. Leaning on prior successes of the NETL MBS project, Gassnova's goal is to develop ways to reduce the costs linked to CCS by establishing successful forms of cooperation between industry and research to enable efficient CCS technology.

The RTI Brevik project is structured into two phases. Phase I focused on proving the viability of the solid sorbent CO_2 capture process for cement plants through detailed economic analyses and sorbent exposure testing using cement flue gas. Phase II is the actual pilot demonstration of RTI's process at the Brevik cement plant.

As is anticipated for power plants, RTI's process technology has similar potential to substantially reduce the energy load and capital and operating costs compared to conventional aqueous amine CO_2 scrubbing in cement plants as well. The cement plant demonstration and future scale-up are expected to prove the technology's economic competitiveness. If these efforts are successful, RTI will develop a commercial design of the solid sorbent CO_2 capture technology for application within the cement industry.

Conclusions

Supporting the introduction of a technology into commercial use can greatly accelerate learning-by-doing, driving down costs and reducing operational risk for future commercial applications. Early deployment in multiple applications with varying operational conditions will develop a virtuous cycle of reduced costs, leading to additional deployments, additional technology improvements, and still lower costs. Successes of the R&D efforts at NETL-sponsored projects focused on power generation have already led to several of these technologies being pulled into promising industrial applications.

The application of MTR's membrane technology, targeted principally for use in post-combustion CO_2 capture, is a striking example of NETL-funded technology that has been pulled into commercial industrial use. SRI's membrane technology, focused on pre-combustion CO_2 capture in NETL-sponsored projects, is showing similar potential for use in a variety of commercial applications.

While few direct economic drivers for reducing carbon emissions from cement plants currently exist, translation of the RTI technology in Norway represents a different type of success toward commercialization. Understanding the potential requirements to implement CCS technology for CO_2 reduction, international stakeholders have expressed advocacy for NETL-developed technologies in alternative applications through continued development and demonstration in their own R&D programs. For example, industrial emissions of carbon are recognized as a significant source of global emissions, yet the sector is not large enough to "push" technology research toward such applications. However, operators of industrial CO_2 sources understand that preparing for restrictions on emissions must be part of prudent business planning. This is because most alternative pathways for production of a given product, if any exist, have relatively similar CO_2 footprints. Reducing carbon emissions cannot be achieved by simply switching to lower carbon-intensive production. Therefore, most industrial interest in CO_2 capture technology development is indeed motivated by economics, even if only as a safeguard to sustain economic competitiveness in a future where carbon emission may be penalized.

NETL investment focuses on reducing power plant CO_2 emissions. However, due to advancements made possible by NETL funding, decision-makers from broader markets – including alternative commercial uses and industrial CO_2 emissions controls – are increasingly willing to "pull" innovative NETL technologies into their own applications. These growing markets for NETL-funded capture technologies are creating more diverse opportunities for testing and development. Technology "pull" from such markets promotes robust, accelerated, and lower-risk commercialization in multiple markets relevant to new carbon capture technologies.

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