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Review

# Recent developments in carbon dioxide capture technologies for gas turbine power generation

Miguel Angel González-Salazar*

*Energy Systems Lab, GE Global Research, Freisinger Landstrasse 50, D-85748 Garching b. München, Germany*

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ABSTRACT

This paper describes the status of various carbon capture technologies investigated and outlines challenges and opportunities of carbon capture in gas turbine power generation for enhanced oil recovery (EOR). Technical achievements, maturity, drivers, barriers and gaps in knowledge are described for four technologies: novel chemical solvents and processes, low temperature separation, membranes and exhaust gas recirculation (EGR) in gas turbines. As a near-term application, carbon capture in gas turbine power generation for enhanced oil recovery (EOR) is analyzed and drivers, requirements and challenges are outlined. The paper is structured as follows: the first section describes the current global status of carbon capture and storage (CCS), second section explains the approach followed in the paper, third section presents a literature review, fourth section provides a technical analysis of the focus technologies, fifth section describes challenges and opportunities of carbon capture from gas turbines for $CO_2$-EOR applications and finally sixth section provides conclusions.



**Contents**



*Abbreviations:* ARPA-E, Advanced Research Projects Agency Energy; BIT, Best Integrated Technology; CCS, carbon capture and storage; CDM, Clean Development Mechanism; DLN, dry low $NO_x$; DOE, Department of Energy; EGR, exhaust gas recirculation; EOR, enhanced oil recovery; HRSG, heat recovery steam generator; IEA, International Energy Agency; IGCC, integrated gasification combined cycle; IRCC, integrated reforming combined cycle; MEA, monoethanolamine; NETL, National Energy Technology Laboratory; NGCC, natural gas combined cycle; $NO_x$, nitrogen oxides; R&D, research and development; TEG, triethylene glycol; TRL, technology readiness level; UNFCCC, United Nations Framework Convention on Climate Change.

* Tel.: +49 89 5528 3549.
*E-mail address:* gonzalez@ge.com

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## 1. Current global status

Most energy scenarios suggest carbon capture and storage (CCS) from power generation might contribute to reduce the carbon emissions necessary to limit long-term temperature increase to 2 °C. While renewables would likely keep growing worldwide in the future, CCS from power plants would still be required to respond to an increasing energy demand while meeting emission targets. In fact, one sixth of the cumulative emissions reduction to limit long-term temperature increase to 2 °C by 2050 is expected to come from CCS (IEA, 2013). CCS comprises technologies to capture, purify, compress, transport and store $CO_2$ underground in depleted oil and gas fields and deep saline formations. Individual CCS technologies are well understood and mature, but integration into large-scale projects remains a challenge. Demonstrations of CCS technologies have been successful but limited. To date, four-large scale CCS projects have been demonstrated, accounting for 50 million tons of captured and stored $CO_2$ (IEA, 2013). Nine projects are under construction with an additional potential of 13 million tons of $CO_2$ (IEA, 2013). However, uncertainties around permanent storage, lack of public acceptance of large-scale demonstration and high cost of CCS have slowed down or even stopped various projects.

While most of the existing CCS projects address coal-fired power generation, the use of CCS can also be extended to other applications. In fact, half of the $CO_2$ that can potentially be captured worldwide could come from industrial applications (IEA, 2013). These applications include cement, iron and steel, chemicals production, oil refining, biofuels and paper industries. Despite having a great potential for $CO_2$ capture, currently there are only two demonstration projects in planning phase (IEA, 2013). An alternative to permanent $CO_2$ storage is $CO_2$ utilization. Uses of $CO_2$ are numerous and many remain unexplored. Current and proposed uses for $CO_2$ include injecting it as a fluid in enhanced hydrocarbon recovery, in particular enhanced oil recovery (EOR), using it as a photosynthesis enhancer in greenhouses, employing it as a solvent in the chemical industry as well as using it for carbonation in the beverage industry and for production of plastics, chemicals and fuels.

While $CO_2$ emissions continue to grow, the need for CCS technology is becoming more urgent. Actual deployment of CCS technologies is far below the requirements to stabilize global temperature (IEA, 2013). In the last decade, CCS progressed on various fronts such as accumulating experience through large-scale demonstration projects, increasing understanding of $CO_2$ storage, creating regulatory frameworks in many countries and including CCS under the United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM). However, progress has been slower than expected and CCS technologies have lost momentum in many regions, particularly in continental Europe. A complex combination of factors including the financial crisis, lack of political commitment to create effective binding policies, low $CO_2$ prices, lack of public acceptance and a significant cost of CCS technologies contributed to this slow pace of deployment. Today, the future deployment of CCS technologies and $CO_2$ utilization looks uncertain and subject to regional politics, availability of resources and economic development.

## 2. Approach

This paper has two main purposes. The first purpose is to describe the status and maturity of the most relevant technologies investigated at GE Global Research. Various routes with potentially lower energy requirements and environmental impact than state-of-the-art processes have been investigated including post-combustion capture (e.g. novel chemical solvents, low temperature separation, membranes, exhaust gas recirculation), pre-combustion capture (e.g. IGCC, IRCC, hydrogen membranes) and Oxyfuel. Therefore, technologies with the largest numbers of published documents (e.g. technical papers, patents, patent applications, theses, etc.) are considered the most relevant and selected for further analysis. While the number of published documents is an imperfect measure of relevance, it can give an indication of resources, funding and business interest associated with a particular technology. Following this criterion, a thorough literature search was performed. Technologies were ranked according to their number of published documents and those dominating the list were selected for further analysis. Then, a technical analysis was performed to examine, discuss and compare the technical characteristics, maturity, drivers, barriers and gaps in knowledge associated with the selected technologies. The second purpose of this paper is to provide an analysis of a $CO_2$ utilization option to complement the discussion on carbon capture technologies. Concretely, the use of carbon capture in gas turbine power generation for enhanced oil recovery (EOR) was analyzed and drivers, requirements, challenges and opportunities were outlined.

## 3. Literature review

A literature search of papers, patents and theses associated with GE Global Research was performed. In total 81 documents were found: 28 published papers (Hoffmann et al., 2008, 2009a; Finkenrath et al., 2006, 2007, 2009; Ku et al., 2011; Shilling et al., 2011; Yan et al., 2011; York et al., 2013; Botero et al., 2009a,b,c; Sipöcz et al., 2013; Xie et al., 2011; Gonzalez-Salazar et al., 2012; Perry and O'Brien, 2011; O'Brien et al., 2013; Perry et al., 2010, 2012; Perry and Davis, 2012; An et al., 2011; Barillas et al., 2011;