

## LIFECYCLE CO<sub>2</sub> EMISSIONS FROM US BIOETHANOL PRODUCTION WITH CCS

Sean T. McCoy, Lawrence Livermore National Laboratory  
mccoy24@llnl.gov  
Kimberley A. Mullins, University of Minnesota  
Ines L. Azevedo, Carnegie Mellon University

Key Words: Biofuel, carbon capture and storage, carbon intensity, lifecycle assessment

There is growing consensus that carbon dioxide removal (CDR) technologies – also referred to as “negative emissions” technologies (NETs) – will be part of the portfolio of strategies and technologies needed to hold the increase in the global average temperature to “well below 2 °C” (1), as agreed by parties to the Paris Agreement. The production of bioenergy with carbon capture and sequestration (BECCS) is one class of CDR technology (2), involving the capture and geologic storage of CO<sub>2</sub> (CCS) that would otherwise be emitted to the atmosphere from use of biomass as a fuel for electricity generation or feedstock for production of liquid fuels. Use of CCS typically imposes two energy penalties that can diminish its benefits: energy is needed to separate CO<sub>2</sub> from dilute CO<sub>2</sub>-containing mixtures (e.g. flue gas), and to liquefy CO<sub>2</sub> so that it can be transported and injected into geologic formations. The predominant biofuel production pathway in the United States (U.S.) today is conversion of corn starch to ethanol, which generates relatively high-concentration CO<sub>2</sub> from fermentation and dilute-CO<sub>2</sub> from fuel combustion for process heat. In 2015, the U.S. produced approximately 53 billion liters of bioethanol from nearly 200 facilities (3) releasing approximately 40 MtCO<sub>2</sub> of CO<sub>2</sub> from fermentation and a further 20 MtCO<sub>2</sub> from process heat (4).

The climate benefit of applying CCS to biofuel production – and BECCS more generally – can only be accurately assessed in the context of emissions over the entire fuel production pathway, including the biomass supply chain. Few prior studies have quantified the carbon intensity of biofuels, such as ethanol, produced from processes including CCS (5–8). While previous studies consider a range of feedstocks (i.e., sugar cane, beets, and corn), none consider the emissions from direct and indirect land-use change associated with feedstock production and some use dated assumptions for key parameters, such as corn and ethanol yields (7,8). However, all conclude that, with the addition of CCS, GHG intensity of produced fuels decreases and can become negative (even without credit for displacement). In this paper, we quantify the life-cycle emissions of several corn-ethanol production pathways coupled with CCS at different process steps. Specifically, we assess the lifecycle emissions for dry-mill ethanol production with and without CCS for fermentation process emissions and for onsite boiler or cogeneration emissions. We run these scenarios for representative U.S. corn ethanol plants, and include recent estimates of indirect land use change. Finally, we do a detailed parametric sensitivity analysis of our results.

1. Sanderson BM, O'Neill BC, Tebaldi C. What would it take to achieve the Paris temperature targets? *Geophys Res Lett.* 2016 Jul 16;43(13):7133–42.
2. The Royal Society. *Geoengineering the climate: science, governance and uncertainty* [Internet]. London, UK: The Royal Society; 2009. Available from: <https://royalsociety.org/topics-policy/publications/2009/geoengineering-climate/>
3. U.S. DOE. *Renewable & Alternative Fuels - Data* [Internet]. U.S. Energy Information Administration (EIA). [cited 2017 Jan 14]. Available from: <http://www.eia.gov/renewable/data.cfm#alternative>
4. U.S. EPA. *EPA Facility Level GHG Emissions Data* [Internet]. [cited 2017 Jan 14]. Available from: <https://ghgdata.epa.gov/ghgp/main.do>
5. Lindfeldt EG, Westermarck MO. System study of carbon dioxide (CO<sub>2</sub>) capture in bio-based motor fuel production. *19th Int Conf Effic Cost Optim Simul Environ Impactof Energy Syst* 2006. 2008 Feb;33(2):352–61.
6. Laude A, Ricci O, Bureau G, Royer-Adnot J, Fabbri A. CO<sub>2</sub> capture and storage from a bioethanol plant: Carbon and energy footprint and economic assessment. *Int J Greenh Gas Control.* 2011;5(5):1220–31.
7. Möllersten K, Yan J, R. Moreira J. Potential market niches for biomass energy with CO<sub>2</sub> capture and storage--Opportunities for energy supply with negative CO<sub>2</sub> emissions. *Biomass Bioenergy.* 2003;25(3):273–85.
8. Kheshgi HS, Prince RC. Sequestration of fermentation CO<sub>2</sub> from ethanol production. *Energy.* 2005 Jul;30(10):1865–71.