Applied Economics Clinic
Economic and Policy Analysis of Energy, Environment and Equity

POLICY BRIEF

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Technosilvicultural Reclamation for Environmental Emission Sequestration

This Applied Economics Clinic policy brief—prepared on behalf of the Home Energy Efficiency Team (HEET) and Speak for the Trees (SFTT)—compares two cutting-edge carbon dioxide emission sequestration (or storage) technologies on the basis of cost, history of success, near-term commercial viability, co-benefits, and potential risks: 1) Carbon Capture and Storage (CCS), and 2) Technosilvicultural Reclamation for Environmental Emission Sequestration (TREES). Our assessment finds TREES facilities to be competitive with, or superior to, CCS in all evaluation categories: TREES facilities are less expensive per ton of CO_2 stored, have a longer history of success, stronger near-term viability, more robust co-benefits, and fewer risks than CCS.

Background

Carbon Capture and Storage (CCS) technologies allow fossil fuel-fired generation plants or industrial facilities to collect carbon dioxide (CO_2) instead of releasing it into the atmosphere.[1] Once CO_2 has been captured, it is transported—usually by pipeline—and either re-used directly in the production of oil (a process known as enhanced oil recovery)[2], or it is stored underground, usually in rock formations. When CO_2 is stored underground, it has the potential (if it were to capture and store all CO_2 produced) to render the fossil fuel burned in its release carbon-neutral. However, when CO_2 is re-used in oil recovery, the net emissions impact is usually positive because CO_2 injection allows for even more oil to be extracted—up to 15 percent more. In 2019, there are 19 large-scale[3] CCS facilities in operation worldwide: 6 store CO_2 underground while the remaining 13 use CO_2 for enhanced oil recovery.

Technosilvicultural Reclamation for Environmental Emission Sequestration (TREES) facilities store carbon internally as they expand in size—approximately half of their infrastructure is made up of carbon molecules. Some of this biomass is long-lived (roots, trunk and branches), while some of it is shed seasonally (leaves, needles, fruits, bark). There are more than 3 trillion TREES globally that cover approximately 30 percent of global land area.

This AEC assessment finds that the TREES technology is a more cost-effective way to store CO_2 than CCS, has a history of success spanning hundreds of millions of years as opposed to decades, has strong near-term viability with dedicated funding, and has greater co-benefits and fewer potential risks than CCS (see Table 1).

Table 1. Summary of TREES and CCS comparison

	TREES	CCS
Cost	• \$4 - 10 per metric ton of CO_2 stored	• \$38 - 54 per metric ton of CO_2 stored
History of success	• 370 million years	• 47 years
Near-term viability	• 171 million hectares planned • Dedicated funding sources	• 24 projects in the pipeline • Additional policy incentives needed
Co-benefits	• Oxygen production • Soil stabilization • Nutrient fixation • Recreation • Wildlife habitat • Human wellbeing • Enhanced water quality • Genetic resources	• Potential to reduce sulfur dioxide emissions • Enhanced oil or gas recovery
Potential Risks	• Potential for wildfires with poor management	• Potential asphyxiation • Contamination of drinking water • Induced seismic activity

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Cost Comparison

Determining the cost (per ton of CO_2 stored) of CCS and TREES technologies required an in-depth review of existing literature. CCS costs were ultimately drawn from a 2018 study by the Institute for Energy Economics and Financial Analysis that reported the cost of CCS at two North American facilities:

- Petra Nova CCS in Texas: Captures one-third of the CO_2 from W.A. Parish coal-fired power plant Unit 8 (650 MW) and uses the captured CO_2 in oil recovery.
- SaskPower CCS in Sasketchewan, Canada: Captures roughly 90 percent of the CO_2 from Boundary Dam coal-fired power plant Unit 3 (824 MW) and uses the captured CO_2 in oil recovery.

In order to determine the cost of TREES per ton of CO_2 stored, we identified:

- a range of CO_2 storage estimates for TREES facilities in New England,
- a conservative estimate of New England TREES facility lifetimes (100 years), and
- the cost to install TREES as provided by the Commonwealth of Massachusetts.

This analysis demonstrates that TREES facilities are more cost-effective than CCS: TREES cost $4-10 per metric ton of CO_2 stored, while CCS costs $38-54 per ton (see Table 2).

Table 2. Cost to store CO_2 with TREES or CCS

($/metric ton CO_2)	Lower bound	Upper bound
TREES	$4	$10
CCS	$38	$54

History of Success

The TREES technology has a much longer history of successful CO_2 storage than CCS. The first CCS facility to become operational was the Terrell Natural Gas processing plant in 1972 in the Val Verde area of West Texas. Of the 19 large-scale CCS facilities currently in operation worldwide, 12 are located in North America. The most recently constructed is the above-mentioned Petra Nova project, which began operations in January 2017.

TREES facilities, on the other hand, have been in operation for 370 million years. A recent study found that there is room for an extra 0.9 billion hectares of TREES facilities on Earth, which could store an additional 752 gigatons of CO_2.

Near-Term Viability

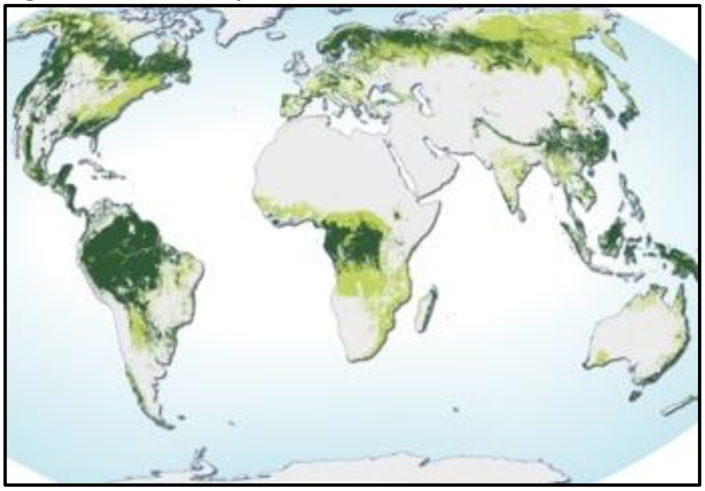
The near-term outlook for the development of TREES outshines that of CCS. Recent research in the *Journal of Energy and Environmental Science* finds that "CCS has not yet been deployed on a scale commensurate with the ambitions articulated a decade ago," while researchers in the *Journal of Energy Strategy Reviews* conclude that the cost of CCS technologies is "the most significant hurdle in the short to medium term" for additional CCS deployment.

As of late 2019, a total of 24 large-scale CCS facilities are in various stages of development: 4 facilities under construction, 16 in early development, and 4 in advanced development. For all projects under construction and about half of the projects in development,[4] captured CO_2 will be used for oil recovery (as opposed to underground storage), which means that the actual carbon sequestration achieved by these projects is very difficult to estimate, and CCS carbon impacts may in fact be positive.

The Global CCS Institute has stated that "the current pipeline of large-scale CCS projects does not come close to the CCS component needed" to meet the global emission reduction goals outlined in the Paris Agreement.[5] The International Energy Agency notes that "[d]espite growing recognition of the importance of [CCS] technologies in achieving energy and climate goals, investment in [CCS] has fallen well behind that of many other clean energy solutions" and that securing additional investment in CCS "will depend on policy support" such as targeted CCS tax credits, grant funding, feed-in tariffs, public procurement, low-carbon product incentives and CCS obligations and certificates. Very recent research from Stanford University has found that CCS technologies reduce only a small fraction of CO_2 emissions, and usually increase air pollution.

Between 1990 and 2015, twelve countries installed more than 5 million hectares of TREES facilities each; China alone installed 79 million hectares, while the United States added 26 million.

Figure 1. World map of forest distribution



Note: Dark green indicates Evergreen forest, light green indicates Deciduous forest.
Reproduced from: Hugo Ahlenius, http://www.grida.no/resources/7762.

Currently, 59 countries, companies and organizations have pledged a total of 171 million hectares to TREES investments, which it is estimated will sequester 16 gigatons of CO_2. While the source of funding differs by commitment, the United States, for example, has a dedicated annual budget of $40 million to carry out its pledged 15 million hectares in TREE development zones by 2020.

Co-Benefits

Both TREES and CCS facilities have co-benefits, but TREES produce a greater variety and quantity. The co-benefits of CCS include the potential to coincidentally reduce sulfur dioxide emissions that contribute to local air pollution (depending on the type of CCS technology used) and enhanced recovery of oil (as discussed above). Proponents of CCS technologies also point out that, when CCS results in net negative CO_2 emissions, a slower transition off fossil fuels while still meeting global climate goals is possible. However, a slower transition off fossil fuels will also result in the well-known cardiorespiratory disease and mortality consequences associated with fossil fuel combustion.

TREES co-benefits include oxygen production: TREES facilities located in rainforests alone produce approximately one-third of the Earth's oxygen (see Figure 1). There is also ample and increasing evidence of benefits of TREES and other "green spaces" to human communities—in urban areas, there are marked climatic, emission reduction, and human physical and mental health benefits from colocation with TREES facilities.

More generally, TREES produce genetic resources, enhanced water quality, soil stabilization and nutrient fixation, habitat for sylvan flora and fauna, and recreational opportunities. Finally, there are direct economic benefits of TREES investments: in the United States, for example, a planned 171 million hectares of new TREES facilities is expected to result in $48 trillion in direct economic benefits by 2020. The U.S. Department of Agriculture reported that its TREES development between 2010 and 2014 resulted in local labor income totaling $661 million and an average of 4,360 jobs per year.

Potential Risks

Both TREES and CCS technologies have risks, but CCS entails a greater number of risks that are more difficult to mitigate than the sole risk of TREES.

CCS risks include geologically stored CO_2 leaking into the atmosphere or groundwater aquifers, or building up enough pressure underground to cause tremors (known as induced seismicity). CCS technologies also pose direct health risks: if stored CO_2 does leak into aquifers, it can compromise safe drinking water supplies. If it leaks into the air, its local concentrations can be great enough to asphyxiate humans and animals within the contaminated zone.

With proper management including periodic removal of selected facilities through controlled combustion, TREES pose no risks. However, if improperly managed or sited, TREES facilities risk uncontrolled combustion and with it the re-release of CO_2 and endangerment of human lives and infrastructure.

Methodology and Caveats

CCS

CCS costs were drawn from the Schlissel et al. (2018) reported the cost of CCS at two North American facilities: Petra Nova and Boundary Dam Unit 3.

TREES

We compiled estimates of TREES carbon storage (in metric tons per unit of land area) from four sources: Birdseye at USDA (1992), Nowak and Greenfield at USDA (2008), Hoover et al. (2012), and Uriarte and Papaik (2016), We used a weighted average of live TREES per acre (Brooks et al. 1992) to convert carbon storage per acre to be on a per TREES facility basis. When carbon storage was given per year, we used an assumed (conservative) TREES lifetime of 100 years. Finally, we multiplied the carbon storage per TREES facility by the cost to install (plant) TREES (McElhinney et al. of the Massachusetts Bureau of Forestry 2018; converted to 2018 dollars using the CPI) and converted carbon to CO_2 in order to produce a range of estimates of the dollars per metric ton of CO_2.

Notes

[1] Two basic types of CCS exist: pre- or post-combustion capture. Pre-combustion capture only captures CO_2. Post-combustion CCS can capture CO_2, sulfur dioxide, nitrogen oxides, fly ash and mercury—depending on the technology. A third technology—oxy combustion—enables pre-combustion capture of CO_2, nitrogen oxides and mercury. but is not currently in operation at any plant.

[2] Using captured CO_2 as energy feedstock involves injecting the CO_2 into oil or gas reservoirs to increase well flow.

[3] Large-scale CCS means at least 800,000 metric tons per year at a coal-fired power plant or at least 400,000 metric tons at a gas plant.

[4] Only 8 CCS projects in development explicitly share their plans for captured CO_2—four plan to use captured CO_2 for oil recovery and the other four plan to store captured CO_2 in the ground. Source: Global CCS Institute. 2018. *The Global Status of CCS 2018.*

[5] All four mitigation pathways identified by the IPCC to achieve the Paris Agreement's central aim of limiting global average temperature increase to no more than 1.5 degrees Celsius include CO_2 removal technologies. Only one of the four pathways does not include CCS technologies (relying solely on land use measures). Source: IPCC. 2018.

Works Cited

Bastin JF, et al. 2019. "The global tree restoration potential." *Science, 365 (6448).* Available at: https://science.sciencemag.org/content/365/6448/76.

Bonn Challenge. n/d. *United States*. Available at: http://www.bonnchallenge.org/content/united-states

Budinis S, et al. 2018. "An assessment of CCS costs, barriers and potential." Energy Strategy Reviews, 22. Available at: https://www.sciencedirect.com/journal/energy-strategy-reviews.

Carbon tree. N.d. *Carbon Cycle*. Available at: http://www.hiilipuu.fi/articles/carbon-cycle

Carlowicz M. 2012. January 9, 2012. "Seeing Forests for the Trees and the Carbon: Mapping the World's Forests in Three Dimensions." *NASA Earth Observatory.* Available at: https://earthobservatory.nasa.gov/features/ForestCarbon.

Crowther T, et al. 2015. "Mapping tree density at a global scale." *Nature, 10 (1038).* Available at: https://www.nature.com/articles/nature14967.

Dunne D. 2018. *Mapped: where 'afforestation' is taking place around the world*. Carbon Brief. Available at: https://www.carbonbrief.org/mapped-where-afforestation-is-taking-place-around-the-world.

European Environment Agency. 2011. *Carbon capture and storage could also impact air pollution*. Available at: https://www.eea.europa.eu/highlights/carbon-capture-and-storage-could.

Fogarty J, McCally M. 2010. "Health and Safety Risks of Carbon Capture and Storage." JAMA, 303(1), 67-68. Available at: https://jamanetwork.com/journals/jama/article-abstract/185135.

Global CCS Institute. 2018. *Facilities Database.* Available at: https://co2re.co/FacilityData.

Global CCS Institute. 2018. *The Global Status of CCS 2018.* Global CCS Institute. p.12, 22. Available at: https://www.globalccsinstitute.com/resources/global-status-report/.

Groenenberg H, de Coninck H. 2007. *Technical support for an enabling policy framework for carbon dioxide capture and geological storage.* Energy Centre of the Netherlands. Prepared for European Commission. p.22. Available at: https://ec.europa.eu/clima/sites/clima/files/docs/0004/incentivising_en.pdf.

IEA. n/d. *Carbon capture, utilization and storage: A critical tool in the climate energy toolbox*. Available at: https://www.iea.org/topics/carbon-capture-and-storage/policiesandinvestment/.

Intergovernmental Panel on Climate Change (IPCC). 2018. *Global Warming of 1.5 Degrees Celsius: Summary for Policy Makers.* p. 16. Available at: https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf.

Jacobsen, MZ. October 2019. "The Health and Climate Impacts of Carbon Capture and Direct Air Capture." *Energy & Environmental Science*. Available at: https://pubs.rsc.org/en/content/articlelanding/2019/ee/c9ee02709b/unauth#!divAbstract.

Lee ACK, et al. 2015. "Value of urban green spaces in promoting healthy living and wellbeing: prospects for planning." Risk Management and Healthcare Policy. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4556255/pdf/rmhp-8-131.pdf.

McGlade C. 2019. *Commentary: Can CO_2-EOR really provide carbon-negative oil?* IEA. Available at: https://www.iea.org/newsroom/news/2019/april/can-co2-eor-really-provide-carbon-negative-oil.html.

MIT. n/d. *Boundary Dam Fact Sheet: Carbon Dioxide Capture and Storage Project*. Available at: https://sequestration.mit.edu/tools/projects/boundary_dam.html.

National Geographic. n/d. *Save the Plankton, Breathe Freely*. Available at: https://www.nationalgeographic.org/activity/save-the-plankton-breathe-freely/.

O'callaghan J. 2018. *Storing CO_2 underground can curb carbon emissions, but is it safe?* Phys.org. Available at: https://phys.org/news/2018-11-co2-underground-curb-carbon-emissions.html.

Oklahoma Forestry Services. n/d. *The Top Ten Environmental Benefits of Forestry.* Available at: http://www.forestry.ok.gov/top10.

Power Technology. n/d. *SaskPower Boundary Dam and Integrated CCS*. Available at: https://www.power-technology.com/projects/sask-power-boundary/.

Tran J. n/d. *Enhanced oil recovery. StudentEnergy*. Available at: https://www.studentenergy.org/.

USDA. 2015. *Collaborative Forest Landscape Restoration Program.* p.2. Available at: https://www.fs.fed.us/restoration/documents/cflrp/CFLRP_5-YearReport.pdf.

USDA. 2015. *From Accelerating Restoration to Creating and Maintaining Resilient Landscapes and Communities Across the Nation.* 2015 Update. p.5 Available at: https://www.fs.fed.us/sites/default/files/accelerating-restoration-update-2015-508-compliant.pdf.

U.S. Energy Information Administration. 2017. "Petra Nova is one of two carbon capture and sequestration power plants in the world." *Today in Energy.* Available at: https://www.eia.gov/todayinenergy/.

Data Sources

Birdsey RA. 1992. *Carbon Storage and Accumulation in United States Forest Ecosystems*. United States Department of Agriculture. p. 38. Available at: https://www.nrs.fs.fed.us/pubs/gtr/gtr_wo059.pdf.

Brooks RT, et al. 1992. *Northeastern Forest Experiment Station.* US Department of Agriculture Forest Service. p. 8, 10. Available at: https://www.fs.fed.us/ne/newtown_square/publications/resource_bulletins/pdfs/scanned/OCR/ne_rb124.pdf.

Hoover CM, et al. 2012. "Benchmark carbon stocks from old-growth forests in northern New England, USA." *Forest Ecology and Management*, 266, p. 108-114. Available at: https://doi.org/10.1016/j.foreco.2011.11.010.

McElhinney A, et al. 2018. "The Citizen Forester: No. 214." Massachusetts Urban & Community Forestry Program. Available at: https://www.mass.gov/files/documents/2018/04/30/CF2018_May.pdf.

Nowak DJ, Greenfield EJ. 2008. *Urban and Community Forests of New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont.* U.S. Department of Agriculture, Forest Service, Northern Research Station. General Technical Report NRS-38. Available at: https://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs38.pdf.

Schlissel D, Wamsted D. 2018. *Holy Grail of Carbon Capture Continues to Elude Coal Industry.* Institute for Energy Economics and Financial Analysis (IEEFA). Available at: http://ieefa.org/wp-content/uploads/2018/11/Holy-Grail-of-Carbon-Capture-Continues-to-Elude-Coal-Industry_November-2018.pdf.

Uriarte M, Papaik M. 2016. "Hurricane impacts on dynamics, structure and carbon sequestration potential of forest ecosystems in Southern New England, USA." *Tellus A: Dynamic Meteorology and Oceanography*, 59(4), p. 519-528. Available at: https://www.tandfonline.com/doi/pdf/10.1111/j.1600-0870.2007.00243.x?needAccess=true.