

Sampling of Resources on Safety and Risk Assessment of Carbon Capture, Transport, and Storage

This document was prepared by the U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM) to assist stakeholder understanding of carbon capture, transport, and geologic storage. It contains resources for topics of interest—geologic storage risk assessments, co-pollutant analysis of capture systems, and carbon dioxide (CO₂) pipeline safety—and is not designed to be comprehensive for each topic nor cover all carbon management elements.

The first two sections provide links to articles and reports that provide useful overviews and are well-matched to the topics. Note that these references are largely to DOE-funded research and that there is also a large body of complementary literature from academia and international experts. Section 3, CO₂ Pipeline Safety, originated from the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA). Section 4 lists resources that offer additional information as well as a bibliography from one of the included reports to demonstrate the breadth of literature available on carbon capture and storage risk management.

Section 1: Geologic Storage of Carbon Dioxide

The U.S. Department of Energy has supported research on carbon capture and storage for more than two decades—in cooperation with domestic and international partners. A summary of this work is provided here: [https://netl.doe.gov/sites/default/files/Safe Geologic Storage of Captured Carbon Dioxide April 15 2020 FINAL.pdf](https://netl.doe.gov/sites/default/files/Safe_Geologic_Storage_of_Captured_Carbon_Dioxide_April_15_2020_FINAL.pdf)

In 1997, FECM initiated the [Carbon Sequestration Program](#) to build a knowledge base on geologic storage and to develop and validate carbon capture and storage technologies through a diverse portfolio of applied research projects. Building on this initial effort, in 2003 DOE created a nationwide network of seven Regional Carbon Sequestration Partnerships to assess and validate CO₂ geologic storage in different regions of the U.S. and portions of Canada. Under the Regional Carbon Sequestration Partnerships, DOE completed 19 small-scale projects that safely injected over a million tons of CO₂ across different sorts of geologic storage settings, as well as large-scale field projects which safely stored over 11 million tons of CO₂.

To learn more about the field projects, please see pages 32 to 105 of the 2015 atlas: <https://www.netl.doe.gov/sites/default/files/2018-10/ATLAS-V-2015.pdf>

Part of the Regional Carbon Sequestration Partnerships initiative was to identify and capture lessons learned from each of the field projects; these are captured in a series of DOE Carbon Storage Program Best Practice Manuals: <https://www.netl.doe.gov/carbon-management/carbon-storage/strategic-program-support/best-practices-manuals>

Note that these manuals were originally completed in 2011 and were updated in 2017.

Because the injection test projects found no negative impacts to human health or the environment, DOE set up the CarbonSAFE program in 2016 to advance its storage work further, with the goal of ensuring

that CO₂ storage sites will be ready for integrated carbon capture and storage system deployment in the 2025-2030 timeframe.

To learn about the CarbonSAFE phases, please see this infographic:

[https://netl.doe.gov/sites/default/files/2023-03/CarbonSAFE Infographic 20220909.pdf](https://netl.doe.gov/sites/default/files/2023-03/CarbonSAFE%20Infographic%2020220909.pdf)¹

The following list of publications was obtained from the U.S. Department of Energy's Office of Scientific and Technical Information (OSTI) search engine.² OSTI resources were used since published articles summarize activities with DOE participation and/or oversight and therefore have been reviewed by the Department, although to varying degrees.

1. Paper title: Computational Tools and Workflows for Quantitative Risk Assessment and Decision Support for Geologic Carbon Storage Sites: Progress and Insights from the U.S. DOE's National Risk Assessment Partnership

Date of publication: December 2022

Access link: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4298480

This paper contains links to many resources describing the original National Risk Assessment Partnership (NRAP) Carbon capture and storage reservoir modeling capabilities as well as the recent enhancements available in Phase II. NRAP is a research collaboration between five DOE labs initiated in 2010. The authors stress that these tools are generally open access and are available to carbon capture and storage project developers and community stakeholders.

2. Paper title: Physics-informed machine learning for fault-leakage reduced-order modeling

Date of publication: March 2023 (behind the Journal's paywall until March 2024)

Access link: <https://www.osti.gov/biblio/1963647>

The authors describe the performance of a fault-leakage reduced order model for geologic storage reservoirs developed as part of National Risk Assessment Partnership. Using just five parameters, the model performs well at a reduced computation time. The article includes a

¹ Note that DOE is in the process of updating the Carbon Transport & Storage Interactive Project Map that is featured on the CarbonSAFE page linked above.

² OSTI (osti.gov) is mandated by law to "maintain publicly available collections of scientific and technical information resulting from research, development, demonstration, and commercial applications activities supported by the Department" (EPACT 2005). This covers submissions by federal employees and contractors. In 2014, the Department issued a directive that all recipients of Department funding must have submitted a Data Management Plan, which includes safeguards to ensure that any resultant published content is provided to OSTI through data collection mechanisms at the time of publisher acceptance. These stipulations apply regardless of whether the recipient is the lead/corresponding author or one of many coauthors. During a 12-month administrative period immediately following publication, OSTI posts the publisher's version of record. If the article is Open Access, its full text is immediately available through osti.gov, whereas linked paywall articles remain hidden. At the conclusion of the period, OSTI substitutes the full text previously provided by the funding recipient for articles that otherwise remain behind the publisher's subscription requirement, allowing public access through its search engine. Even after access is active, the original publisher retains all copyrights.

series of links for previously published studies on the risks associated with geologic carbon storage and suggests verification processes that do not rely on extensive field data.

3. Paper title: Multi-Layered Systems for Permanent Geologic Storage of CO₂ at the Gigatonne Scale

Date of publication: December 2022

Access link: <https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2022GL100443>

The first section of the manuscript details potential issues with CO₂ storage leakage concerns, linking to several recently published studies. The authors' modeling suggests that diffuse CO₂ will rise no more than 300 meters in the course of one million years, after being injected approximately 1500 meters below the surface, although these estimates are conservative, with caveats explained.

4. Paper title: Inference of Rock Flow and Mechanical Properties from Injection-Induced Microseismic Events During Geologic CO₂ Storage

Date of publication: January 2021

Access link: <https://www.osti.gov/biblio/1849183>

This study describes the application of two stochastic microseismic prediction models on a field scale formation in Farnsworth, Texas, where CO₂ was injected for enhanced oil recovery. Results from the exercise show that the models' use of microseismic data led to improved descriptions of reservoir rock mechanical and flow properties. Such advancements will lead to improved environmental and safety risks associated with geologic storage, including the curtailment of geomechanical deformations, induced seismicity, and potential leakage.

5. Report title: Evaluation of Improvements in Storage Efficiencies, Containment Assurance, CO₂ Plume Movements, and Verification of Storage Technologies

Date of publication: October 2022

Access link: <https://www.osti.gov/biblio/1905536>

This SEACARB report provides a plain language summary of evolving improvements in technical skills that are emerging to facilitate widespread carbon capture and storage adaptation and focuses on novel concepts that have the potential to provide breakthroughs as projects evolve. Topics covered, in prose that can be easily digested by community stakeholders, are evaluation of improvements in storage efficiency estimation, containment assurance methods, CO₂ plume movement and pressure prediction, and monitoring and verification of storage methods. A scientific method workflow is introduced near the end of the report that can initiate a discussion of essential community concerns and how they can be addressed with safety and monitoring assurances.

6. Report title: National Risk Assessment Partnership Recommended Practices for Containment Assurance and Leakage Risk Quantification

Date of publication: December 2022

Access link: <https://www.osti.gov/servlets/purl/1906399>

The National Risk Assessment Partnership report provides detail on how each process of geologic storage should be handled – from site characterization to post-injection monitoring. It stresses the need for quantitative risk reduction with models that can be easily updated with real-world input parameters. As more field data becomes available through specific project development, forecasted values must achieve concordance with observations for the work to continue, in order to minimize unforeseen negative consequences. Phased corrective action is discussed near the report's conclusion.

Section 2: Carbon Capture and Storage and Air Quality / Co-Pollutant Release³

1. Paper title: W.A. Parish Post-Combustion CO₂ Capture and Sequestration Demonstration Project (Final Technical Report)

Date of publication: March 2020

Access link: <https://www.osti.gov/biblio/1608572>

This is a final technical report for large scale demonstration of post combustion capture technology at an operating coal-fueled power plant. It provides a project narrative including a two-year demonstration and monitoring period. The report includes 3-year average annual emission rates for volatile organic compounds and ammonia from the capture system absorber column.

2. Paper title: CO₂ Capture with Monoethanolamine: Solvent Management and Environmental Impacts During Long Term Operation at the Technology Centre Mongstad

Date of publication: March 2019

Access link:

<https://www.sciencedirect.com/science/article/abs/pii/S1750583618307576?via%3Dihub>

This peer-reviewed journal article describes testing campaigns of monoethanolamine solvent-based carbon capture system at Technology Centre Mongstad. The article provides a narrative of long-duration (7,000+ hours) pilot-scale (80-200 ton CO₂ per day) testing over a wide range of operating conditions that provided insights into impacts including but not limited to solvent degradation behavior and emissions to the atmosphere. The article also describes how solvent quality and low emissions can be maintained during long-term operation by appropriate solvent management measurement and monitoring of solvent degradation and emissions.

3. Paper title: Carbon Capture Co-Benefits

Date of publication: August 2023

³ In June 2023, the United States Energy Association (USEA), in cooperation with FECM, organized a workshop in Birmingham, Alabama, on Measurement, Monitoring and Controlling Potential Environmental Impacts from the Installation of Point Source Capture. DOE expects to publish a report detailing the workshop's findings soon.

Access link: <https://carboncaptureready.betterenergy.org/carbon-capture-co-benefits/>

This is a published study by the Great Plains Institute estimating potential health and economic benefits associated with anticipated reductions (i.e., co-benefits) in criteria pollutants (NO_x, SO₂ and PM) associated with deployment of post-combustion carbon capture for reducing point-source CO₂ emissions.

Section 3: Carbon Dioxide Pipeline Safety

All content in this section is courtesy of the Transportation Department's Pipeline and Hazardous Materials Safety Administration

CO₂ incident data online: <https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends>, (Click the link "ALL REPORTED INCIDENT 20 YEAR TREND," about two-thirds of the way down the page. This should then take you to the PHMSA data portal. Since CO₂ is currently regulated as a hazardous liquid, select that in the drop down for "System Type" in the upper left. Once that loads, select "CO₂" from the Commodity drop down (directly below the "System Type" drop down) and the incident data will populate below.)

Additional PHMSA resources:

1. News Release: <https://www.phmsa.dot.gov/news/phmsa-announces-new-safety-measures-protect-americans-carbon-dioxide-pipeline-failures>
2. CO₂ public meeting in Iowa.
 - a. Main landing page: <https://primis.phmsa.dot.gov/meetings/MtgHome.mtg?mtg=165>
 - b. Webcast Day 1: <https://www.onlinevideosevice.com/clients/PHMSA/053123/>
 - c. Webcast Day 2: <https://www.onlinevideosevice.com/clients/PHMSA/060123/>
 - d. Docket with written public comment: <https://www.regulations.gov/document/PHMSA-2023-0013-0001>
3. PHMSA Research and Development Database.
 - a. Main landing page with search capability in the upper left: <https://primis.phmsa.dot.gov/matrix/>
 - b. Active CO₂ Research Projects:
 - i. Determination of Potential Impact Radius for CO₂ Pipelines using Machine Learning Approach: <https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=987>
 - ii. Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO₂: <https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=996>
4. Upcoming CO₂ rulemaking: <https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202304&RIN=2137-AF60>
5. Map of existing CO₂ pipelines: https://www.npms.phmsa.dot.gov/Documents/NPMS_CO2_Pipelines_Map.pdf

6. CO₂ is currently regulated as a hazardous liquid and those regulations can be found here:
<https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-195>

Section 4: Other Resources

Homepage of the National Risk Assessment Partnership:
<https://edx.netl.doe.gov/nrap/>

National Risk Assessment Partnership Publication Database:
<https://app.powerbi.com/view?r=eyJrJoiODUzOGFjNTktNjc0Zi00ZDY3LWJiMjEtNjhkNWNhNWl4NjUyIiwidCI6Ijc4MDA2MmYxLTI1NGMtNDA3MC1hOGIwLWY0ZjdlOWY0NDBhMSIsImMiOiN9>

NETL's Energy Data eXchange:
<https://edx.netl.doe.gov/>

Bibliography from [NRAP's Recommended Practices Report](#) (Carbon Capture and Storage Safety Reference Link #6)

Note: These references have not been reviewed by FECM and are included to show the wide body of literature available on carbon capture and storage. They are not necessarily representative of the state of the industry nor indicative of DOE policies and research priorities.

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