## SSAE

# Newsletter

FEBRUARY // 2023 VOLUME 3.1


2 HIGHLIGHTS

5 NOTICES

6 PERSPECTIVES

7 UPCOMING CONFERENCES AND EVENTS

8 RECENT PUBLICATIONS


## // ABOUT

The Strategic Systems Analysis and Engineering (SSAE) directorate provides the decision science and analysis capabilities necessary to evaluate complex energy systems. The directorate's capabilities address technical, economic, resource, policy, environmental and market aspects of the energy industry. These capabilities are critical to strategic planning, direction and goals for technology R&D programs and the generation of market, regulatory and technical intelligence for NETL senior management and DOE. SSAE offers a range of multi-criteria and multi-scale decision tools and approaches for this support:

- Process systems engineering research: advanced modeling, simulation and optimization tools for complex dynamic systems
- Process and cost engineering: plant-level synthesis, process modeling and simulation of energy systems with performance estimates
- Resource and subsurface analysis: evaluation of technologies, approaches and regulations for subsurface energy systems and storage
- Market and infrastructure analysis: economic impacts and program benefits
- Environmental life cycle analysis: cradle-to-grave emissions and impacts

These tools and approaches provide insights into new energy concepts and support the analysis of energy system interactions at the plant, regional, national and global scales.

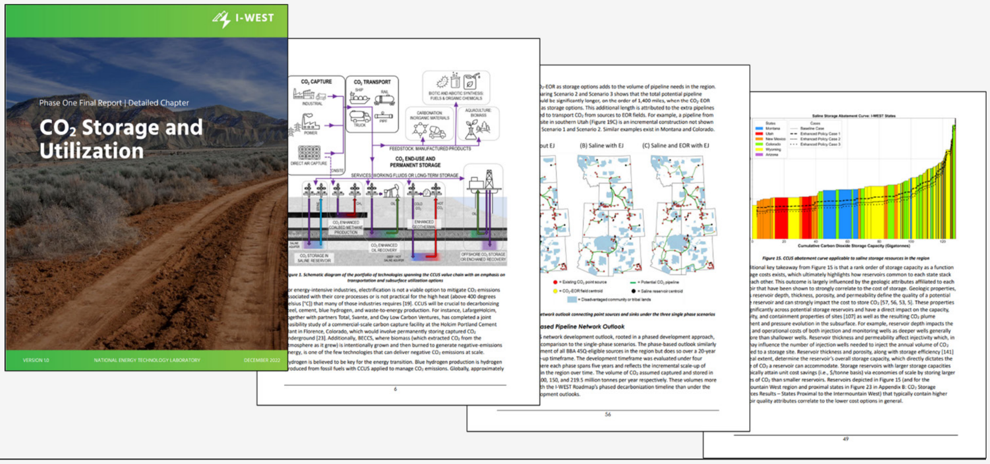
# // HIGHLIGHTS

### SSAE Contributes $CO_2$ Storage and Utilization Expertise to Report on Impact of CCUS for Net-Zero Emissions in Intermountain West

SSAE performed a detailed review of $CO_2$ storage and utilization contributing to a chapter in a summary report that analyzed and modeled various carbon mitigation strategies and low-carbon energy technologies in the context of the Intermountain West region. Funded by DOE and led by Los Alamos National Laboratory (LANL), the [Intermountain West Energy Sustainability & Transition (I-WEST)] initiative targets development of a regional, stakeholder-informed technology roadmap for transitioning the Intermountain West region (Arizona, Colorado, Montana, New Mexico, Utah and Wyoming) into a carbon neutral and economically sustainable energy system. It plans to implement and deploy the roadmap by 2035.

The $CO_2$ storage and utilization review leveraged discussions with regional stakeholders and subject matter experts including a workshop with roundtable discussion on technical, socio-economic and policy issues regarding carbon capture, utilization and storage (CCUS). An opportunity case for CCUS in the region was outlined using strengths, weaknesses, opportunities and threats analysis and gap analysis. Carbon transport and storage modeling was performed using mature CCUS analysis tools developed by SSAE (FECM/NETL $CO_2$ Transport Cost Model [CO2_T_COM], FECM/NETL $CO_2$ Saline Storage Cost Model [CO2_S_COM] and FECM/NETL $CO_2$-EOR Evaluation System) and LANL (Sequestration of $CO_2$ Tool [S$CO_2$T] and SimCCS).

It was determined that the Intermountain West contains ample storage resource potential sufficient to store all the existing point-sourced $CO_2$ emissions in the region that are eligible for the Bipartisan Budget Act of 2018's (BBA) section 45Q carbon oxide sequestration tax credit. With approximately 40 identified projects either proposed or already in operation in the Intermountain West, the region seems poised to take advantage of newly enhanced tax credits under the Inflation Reduction Act of 2022 (IRA). Regional attributes afford early-mover project opportunities, most notably in the form of $CO_2$-enhanced oil recovery (EOR) expansion in Wyoming and Montana, as well as $CO_2$ separation and storage associated with oil and gas processing in New Mexico. Though several enabling technical, workforce and policy needs still exist and must be addressed, the Intermountain West appears well suited to meet I-WEST's emissions goals with CCUS being an early and essential contributor.




The [I-WEST Phase One Final Report] gathers and summarizes all technology pathways and considers a holistic and equitable approach to leveraging them toward an energy transition with net-zero emissions. Information on [modeling and example results] discussed in SSAE's [detailed $CO_2$ storage and utilization chapter] can be found on NETL's Energy Data eXchange.

### Techno-economic Model for Evaluating the Economics of an Unconventional Well Released

A techno-economic model for evaluating the economics of unconventional shale wells was recently developed by SSAE under DOE's Science-informed Machine Learning for Accelerating Real-Time Decisions in Subsurface Applications Initiative Phase I Task 7 efforts. This model is used to analyze the effect of managed pressure drawdown strategies on the production and economics of fractured shale wells.

The [FECM/NETL Unconventional Shale Well Economic Model] (also known as UShWEM) is an Excel-based model that enables an effective, multi-faceted evaluation of both the technical and economic aspects associated with an unconventional shale well on a per-well and per-pad basis. UShWEM can be integrated with any oil and gas production forecasting tool to help inform operators and industry stakeholders on oil and gas productivity performance, associated cost drivers and potential business case viability and/or limitations. The model calculates several financial metrics including the net cash flow, internal rate of return, net present value (NPV) and break-even price for either oil or gas wells. It can be used to estimate the economics of a well or pad over its lifetime (development through site reclamation) based on: 1) capital and operating costs associated with well/pad development and operations; 2) revenue associated with oil, gas and condensate production streams; and 3) relevant tax policies and asset depreciation applicable for oil and gas operations.

The main input for the model is production data. Key financial considerations in the model include oil, gas and condensate market prices, tax-related settings, royalty rates, discount rate and project contingency. As a result, the model can be used to generate a multitude of scenario cases for sensitivity analysis of the various financial considerations, as well as production and cost profiles. Along with the model, a [user's manual] and [production data] were also publicly released.

# // HIGHLIGHTS cont'd

## Study Examines Performance and Cost Potential for Direct $sCO_2$ Power Plants

Direct-fired supercritical carbon dioxide ($sCO_2$) power cycles, which have a high inherent carbon capture rate potential (>98%), are being explored as an alternative to natural gas combined cycle (NGCC) plants with carbon capture and storage (CCS). Commercialization of this technology is being pursued by NET Power, 8 Rivers Capital and their collaborators, who built a 25 MWe demonstration plant in Laporte, Texas. The direct-fired $sCO_2$ cycle is a semi-closed cycle where a hydrocarbon fuel is combusted with oxygen in a recycled $CO_2$ diluent to produce primarily $CO_2$ and water. Thus, after water is condensed, a high-pressure $CO_2$ stream is left for sequestration or some other end use.

Understanding the performance and cost potential of advanced technologies is important to inform research and development (R&D). A report by Sandeep Pidaparti*, Charles White*, Selcuk Can Uysal*, Eric Liese, Nate Weiland and Travis Shultz presents the results of a techno-economic optimization of natural gas-fired, utility-scale power plants based on the direct $sCO_2$ power cycle – data that is lacking in public literature. These results will be presented by Sandeep Pidaparti* at the 5th European $sCO_2$ Conference for Energy Systems to be held March 14–16, 2023 in Prague, Czech Republic. To identify the optimum plant configuration and design operating parameters, the study considered multiple cases with varying levels of thermal integration with the plant air separation unit (ASU). Several design variables for each power cycle configuration were identified and optimized to minimize the levelized cost of electricity (LCOE) for each case.

The optimization design variables include the $sCO_2$ cooler outlet temperatures, recuperator approach temperatures and pressure drops. High fidelity models for recuperators, coolers and turbines were developed and used to capture the impact of design variables on plant efficiency and capital costs. The optimization was conducted using a combination of manual sensitivity analyses and automated derivative-free optimization algorithms available under NETL's Framework for Optimization and Quantification of Uncertainty and Sensitivity (FOQUS) platform developed under the Carbon Capture Simulation Initiative (CCSI). When compared to the baseline best case, use of the optimization tool reduced the LCOE by at least 5%.

To identify the optimum plant configuration, the study considered three different cases with varying levels of thermal integration with the plant ASU (Case A with none, Case B some and Case C with the most). A fourth case (Case D), which is based on a patent from 8 Rivers, was also considered and includes thermal integration with the ASU, as well as compressed recycle $CO_2$ gas. The table to the right shows the plant efficiency (higher heating value [HHV] basis) and LCOE for all the optimized direct $sCO_2$ power plants along with the reference NGCC plants with CCS. The results show that the thermal integration with the ASU is necessary to achieve high plant efficiencies and reduce LCOE.

As can be seen from the table below, Case C offers the lowest LCOE out of all the cases considered in the study. Despite offering higher plant efficiency, Case D has higher LCOE due to additional components needed.

| | Cases | | | | | |
|---|---|---|---|---|---|---|
| | Reference F-Class NGCC with 90% CCS | Reference F-Class NGCC with 97% CCS | Case A | Case B | Case C | Case D |
| Plant Efficiency (HHV basis) (%) | 47.6 | 47.0 | 46.4 | 47.3 | 47.7 | 48.2 |
| LCOE with Transport and Storage (2018$/MWh) | 68.7 | 70.9 | 82.1 | 80.9 | 80.5 | 82.4 |

Plant efficiency and LCOE of optimized direct $sCO_2$ power plants

In summary, the optimized direct $sCO_2$ power plants offered similar or slightly higher plant efficiencies than the reference NGCC plants based on the F-class gas turbine with CCS. The LCOE of the optimized direct $sCO_2$ plants is 13–17% higher than the reference NGCC plants with CCS due to high capital costs associated with the ASU and $sCO_2$ power block, though there may be significant room for improvement due to the high uncertainty in component capital costs for these new plants, as well as from ongoing R&D. Recuperators make up over 50% of the $sCO_2$ power block costs. Consequently, any R&D efforts to reduce the recuperator capital costs will benefit the technology's commercialization. The study also presents preliminary results showing the impact of co-firing landfill gas and natural gas on plant efficiency, LCOE and $CO_2$ emissions.

## SSAE Water Analysis Considers Impact of Non-Steady State Operation on Cooling Water Consumption at Coal- and Natural Gas-Fired Power Plants

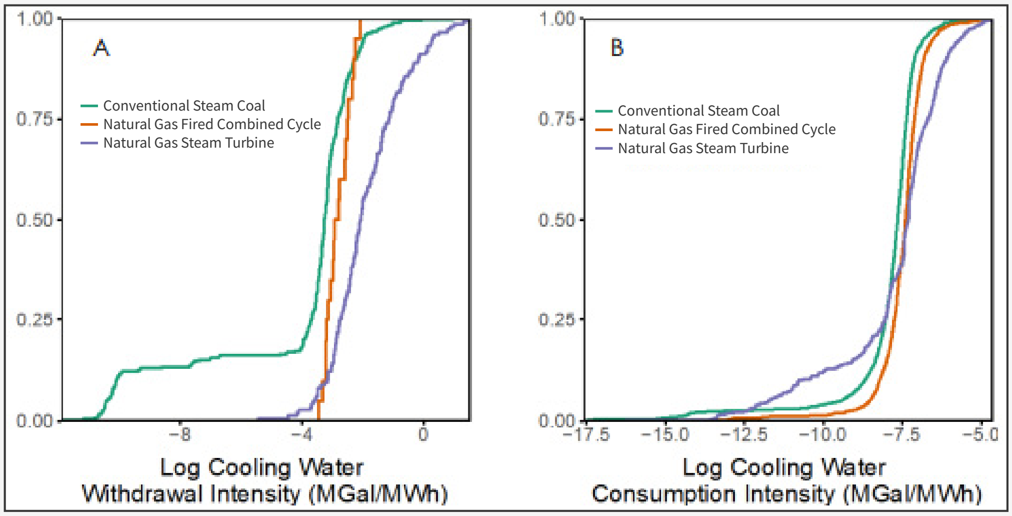
Increased renewable energy penetration in the electricity grid in coming decades will result in more frequent cycling at thermal power plants. Simultaneously, thermal power plants may face water scarcity with declining availability of cooling water. Therefore, to enhance thermal power plants' resiliency to water shortages it is important to understand how non-steady conditions due to cycling will impact cooling water consumption and withdrawal intensity. Non-steady operation at power plants has been previously shown to decrease power plant thermal efficiency. Energy balance models have also demonstrated that a decrease in thermal efficiency is expected to increase cooling water consumption intensity. Furthermore, past work has used operating hours data to show idling and cycling gaps where cooling systems operate more than corresponding generators. As a result, an increase in cycling behavior may impact cooling water consumption and withdrawal intensity.



* NETL Support Contractor

# // HIGHLIGHTS cont'd

A recently released study by SSAE used data from the Energy Information Administration and Environmental Protection Agency to quantify the impact of cycling cooling water consumption intensity for recirculating cooling systems and withdrawal intensity for once-through cooling systems using energy balance and statistical approaches. In a novel application of a fixed effects model to study the effect of temperature on cooling water consumption and withdrawal intensity, the study finds temperature was consistently expected to increase consumption intensity and withdrawal intensity. Non-steady state conditions do not increase cooling water consumption intensity with statistical significance across unit types. However, additional validation of cooling water data is required to confirm these observed trends due to the sensitivity of these findings to model form and concerns with data quality of the dependent variables, cooling water consumption and withdrawal.




Cumulative distribution function for monthly cooling water withdrawal (A) and consumption (B) intensities (MGal/MWh) across 2017 fleet by unit type

---

**Staff Spotlight**

Since becoming a member of the Subsurface Resource Analysis Team in November 2021, Taylor Vactor* has primarily supported NETL's carbon storage and unconventional oil and gas programs. In this role, Taylor has performed geological evaluations and storage resource assessments to determine viability of potential carbon storage sites in the shallow offshore Gulf of Mexico. Taylor recently contributed to the analysis of potential supply chain impacts resulting from a substantial carbon storage infrastructure buildout necessary to achieve the U.S.'s goal of net-zero emissions by 2050 as well as to building a technological roadmap to net-zero for the Intermountain West region of the United States. Prior to his contributions at NETL, Taylor worked for over 10 years as a geologist and petrophysicist in the oil and gas industry performing operations, development and acquisition/divestiture work in unconventional resource plays across the lower 48 states.

Originally from the Pittsburgh area, Taylor graduated from the University of Pittsburgh with a B.S. in Geology. Taylor enjoys hiking and bicycling with his family, as well as playing with his four-year-old son.

# // NOTICES

## SSAE Research Featured at AIChE Conference

Work done by SSAE researchers was featured at the American Institute of Chemical Engineers (AIChE) Annual Meeting in November 2022.

This meeting provided presentations from academic and industry experts on emerging research, technologies and growth areas in chemical engineering. Listed below are the SSAE presentations. Each presenter fielded questions during their session. Publication is pending for the presentations, but links to the sessions and abstracts are provided. Several SSAE researchers were also co-authors on studies presented by other organizations, but information on those efforts is not provided below.

- Novel computational approaches to co-optimize the design and operation of integrated energy systems (IES) while explicitly capturing market interactions was discussed by Jaffer Ghouse*.
- Development of two rigorous first-principles models for gas/solid contactors for a new tetraamine-appended metal organic framework for $CO_2$ capture and techno-economic optimization performed using these models was presented by Ryan Hughes*.
- Overview of the NETL CO2U LCA Guidance Toolkit was provided by Sheikh Moni*. This toolkit aims to create informative and consistent life cycle analyses (LCA) of $CO_2$ utilization (CO2U) projects, which transform captured $CO_2$ emitted from power and industrial sources into valuable products for various applications. Moni described each part of the toolkit including the Guidance Document, 45Q Addendum presenting LCA guidance for tax applicants and openLCA Life Cycle Inventory. He also described the toolkit's utility in assessing emerging technologies.
- Evaluation of the NPV of retrofitting an existing NGCC unit with a flexible post-combustion carbon capture system while incorporating market signals from a high variable renewable energy grid was discussed by Radhakrishna Tumbalam Gooty*. Radhakrishna also presented a techno-economic assessment of coupling an existing nuclear power plant with a low-temperature electrolysis unit and chaired the "Design, Analysis and Optimization of Sustainable Energy Systems and Supply Chains I" and "Design, Analysis and Optimization of Sustainable Energy Systems and Supply Chains II" sessions.
- Determination of the optimal design for an IES involving a thermal power generator, thermal energy storage system and $CO_2$ capture system using historical electricity price signals with a price taker assumption and equation-oriented rigorous process models and advanced design optimization methods was presented by Naresh Susarla*.
- Exploration of combining a natural gas turbine, steam methane reforming process and carbon capture to create an IES capable of generating nearly carbon-free hydrogen and power was provided by Maojian Wang*.

## Key SSAE Products Focus of USEA Webinars

Three of SSAE's key products were featured in webinars hosted by the United States Energy Association (USEA) in January and February 2023. Consisting of over 100 domestic and international organizations (e.g., government agencies and educational institutions), USEA gathers, educates and provides a forum for stakeholders to encourage advancement of the energy sector. Also, in partnership with the U.S. government, it supports energy development internationally by increasing access to safe, affordable, sustainable and environmentally acceptable energy. A description on the SSAE products discussed during the webinars are provided below.

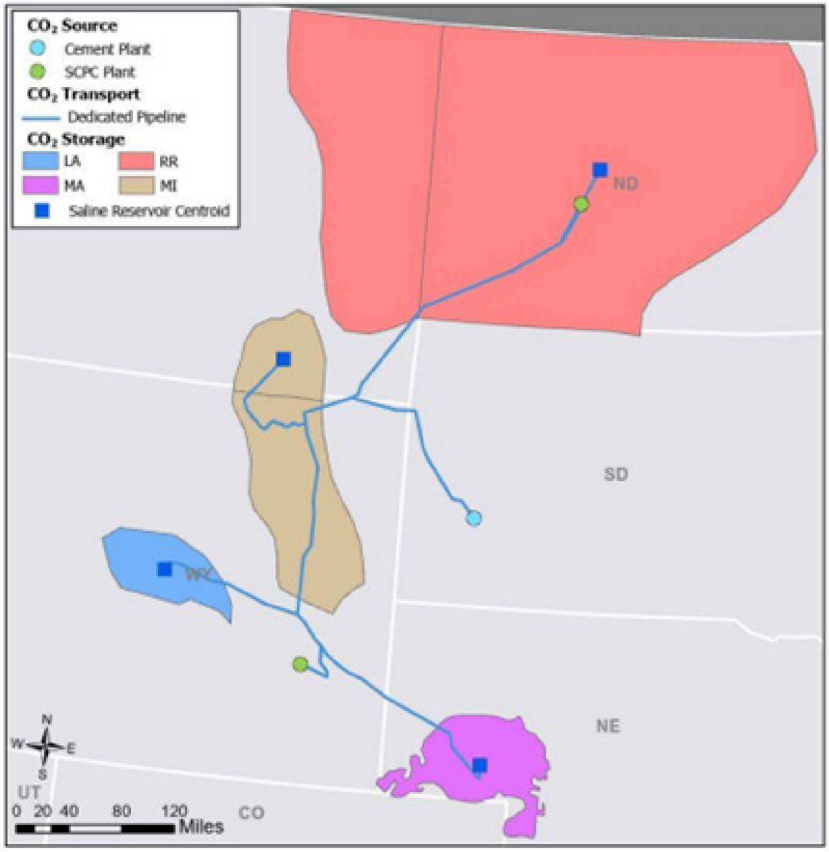
- Overview of the recently updated "Cost of Capturing $CO_2$ from Industrial Sources," which evaluated $CO_2$ capture costs at nine representative industrial plants (e.g., ammonia, ethanol, natural gas processing and cement), was presented by Sydney Hughes*. These processes involve relatively high $CO_2$ effluent concentrations which make them prime targets for decarbonization by carbon capture. In each case, the capture cost considered equipment required for state-of-the-art solvent-based $CO_2$ capture, where applicable, along with compression, dehydration and balance-of-plant equipment. Also, sensitivity analyses considered the cost implications associated with changes to financial assumptions and plant size. Greenfield and retrofit cost implications were both considered for most cases. Cost and performance estimate methodologies and data from the study was used to create a revised "Industrial Carbon Capture Retrofit Database," which was also discussed during the session. This Microsoft Excel tool allows users to estimate $CO_2$ capture retrofit costs for specific ammonia, ethanol, natural gas processing, cement and hydrogen production facilities based on user-provided plant specifications and financial assumptions.
- Discussion of the recently revised "Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 4A," which updated the performance and cost assumptions for the solvent-based post-combustion capture systems used with NGCC and pulverized coal (PC) plants, was provided by Marc Turner*. Using a systematic, transparent technical and economic approach, this study provided an independent assessment of the performance and cost for state-of-the-art fossil energy power systems with and without carbon capture. Historically, performance and cost for 90% capture systems only have been reported for this study, but the recent update included 95% capture cases for both NGCC and PC plants equipped with carbon capture and an appendix with 97% capture for NGCC and 99% for PC. In addition to the F-class combustion turbines considered in previous editions, H-class NGCCs were also included in this update. The results of this study can be used to address the anticipated demands of future decarbonized power markets, provide a perspective for regulators and policy makers, assess goals and metrics and provide a consistent basis for evaluating carbon capture technology development.

# // PERSPECTIVES

### Study Demonstrates Impact of BBA 45Q Tax Credits on CCS Costs

To meet the U.S. goal of achieving net-zero $CO_2$ emissions by 2050, CCS deployment will be required. CCS is a leading carbon management strategy toward decarbonization for the fossil energy and industrial sectors; however, its costs can be high. Policies and options, like the previous BBA and current IRA 45Q tax credits, have been implemented to help reduce CCS costs, so understanding the cost impacts of these options is important when evaluating CCS costs.

SSAE evaluated the impact of the BBA 45Q tax credit on CCS costs in a recently published study that provides a framework for understanding the importance of specific 45Q amendments in the IRA (signed into law just prior to the release of this study), which improved 45Q's ability to reduce the cost of CCS by increasing its face value and easing transferability restrictions. The influence of the 45Q tax credit from a $CO_2$ source's perspective was calculated as the difference between the overall break-even CCS management cost (the sum of capture, transport and storage costs, on a normalized nominal 2018$ per metric ton of $CO_2$ [2018$/t$CO_2$] basis) for the source with and without 45Q credits applied. Results indicated that the BBA-amended 45Q tax credits only marginally lowered levelized CCS management costs and did not close the finance gap between revenues generated and the additional costs associated with CCS, and that other incentives and/or amendments to 45Q may be needed to further reduce the gap.




For $CO_2$ storage reservoirs - MI = Minnelusa 2 reservoir; LA = the Lance 1 reservoir; RR = the Red River 1 reservoir; and MA = Maha 1 reservoir.

Figure 1. $CO_2$ source and storage option locations within the Central U.S. study's Northwest Impact Area

The CCS networks evaluated in this study were replicated from a forthcoming SSAE study that divided the Central United States into three regional impact areas to explore CCS cost options for $CO_2$ sources (hereafter referred to as the Central U.S. study). For the 45Q analysis study, the Northwest Impact Area, which covered portions of Montana, Nebraska, North Dakota, South Dakota and Wyoming, was used. The Northwest Impact Area consisted of three $CO_2$ sources connected to various saline storage options within the Williston, Wind River, Powder River and Denver basins through a dedicated pipeline thus modeling integrated CCS networks. The sources consisted of a cement plant in South Dakota that produces 0.99 million metric tons per annum (Mtpa) of Portland cement and captures 0.97 Mtpa of $CO_2$ and two 650 MW supercritical pulverized coal (SCPC) plants, one in North Dakota and the other in Wyoming, each capturing 4.33 Mtpa of $CO_2$. Saline storage options represent both dome and regional dip structural geologies specific to four different reservoirs in the Northwest United States (see Figure 1).

When $CO_2$ is captured and securely stored in a saline aquifer, 45Q, as amended by BBA, is valued at $50/t$CO_2$ (in 2026$). However, BBA-amended 45Q is a nonrefundable "general business" tax credit and can only be claimed by carbon capture equipment (CCE) owners, with an option for transfer only to associated $CO_2$ storage operators. Therefore, it cannot be modeled as a one-to-one revenue equivalent. In this study, 45Q tax credits were assumed to be used to lower the $CO_2$ source and associated storage project federal income tax liability to the maximum extent allowable for general business credits, using tax credit carryforward mechanisms (referred to as self-sheltering). All excess 45Q tax credits were assumed to be monetized by the $CO_2$ source though a tax equity partnership at a $0.54 after-tax revenue to $1.00 of 45Q credit ratio, based on an Enchant Energy assessment of the San Juan Generating Station CCS project.

Study results indicated that the BBA-amended 45Q tax credits claimed by the $CO_2$ sources modeled only marginally lower levelized CCS management costs by an average of 9.7% for a typical cement plant, and an average of 21% for a typical SCPC power plant, corresponding to a range of cost savings that average $17.79/t$CO_2$ to $19.61/t$CO_2$, respectively (see Figure 2). The study

# // PERSPECTIVES (cont'd)

concluded that other financial strategies, including tax equity partnership structures that also monetize non-45Q tax benefits (e.g., negative income and accelerated depreciation of CCE) and the use of other CCS-related incentives (e.g., early transfer of storage liability to the state), may be needed to close discrepancies between revenues generated and the additional costs associated with CCS. These discrepancies might also be reduced by increasing the per metric ton value of 45Q and making the tax credit fully refundable and/or more easily transferable.

The IRA was signed into law as this study was being finalized. It increased 45Q's per metric ton value (to $85/tCO$_2$ in 2023), made 45Q fully refundable for the first five years it is claimed (allowing taxpayers to reduce their tax liability below zero and claim a refund) and allowed 45Q to be transferrable to any taxpayer for the remaining seven years it is claimed, regardless of their association with CCS projects. – Contributed by Travis Warner* in support of SSAE's Energy Systems Analysis Team

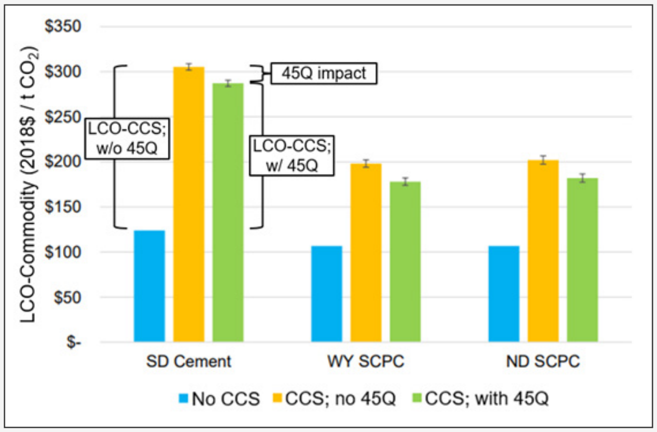



Figure 2. Impact of CCS and 45Q on average levelized cost of (LCO)-commodity (2018$/tCO$_2$) basis for each CO$_2$ source modeled

# // UPCOMING CONFERENCES AND EVENTS

**SSAE Federal staff and NETL support contractor personnel will attend or present at the following conferences and events in February 2023:**

- 6th Ammonia as Fuel World Summit 2023
  Participant: Robert Stevens
  Virtual, January 30–February 2, 2023
- EPRI Generation Advisory Meetings (Virtual) – February 2023
  Participant: Alison Fritz – Program 238 Water Treatment Technologies (February 1)
  Virtual, January 30–February 7, 2023
- Magnetics Conference & Exhibition
  Participant: W. Morgan Summers
  Orlando, FL, February 1–3, 2023
- USEA Webinar: NETL's Updated Performance and Cost Estimates for Power Generation Facilities Equipped with Carbon Capture
  Presenter: Marc Turner*
  Virtual, February 2, 2023
- Hydrogen and Fuel Cell Seminar
  Presenter: Gregory Hackett – Techno-Economic Analysis of a Solid Oxide Fuel Cell Hybrid Carbon Conversion Concept
  Long Beach, CA, February 7–9, 2023
- Produced Water Society Annual Seminar 2023
  Presenter: Markus Drouven
  Hybrid (Virtual and Houston, TX), February 7–9, 2023
- OHI/GTI Workshop: The Future of Hydrogen Markets (Invite only)
  Panelist: Timothy Skone
  Stanford, CA, February 20–23, 2023
- PowerGen International 2023
  Participant: Robert James
  Orlando, FL, February 21–23, 2023
- 2023 Permian Basin Water in Energy Conference
  Presenter: Markus Drouven
  Midland, TX, February 28–March 2, 2023
- National Petroleum Council GHG Study February Meeting
  Participant: Timothy Skone
  Fort Collins, CO, February 28–March 3, 2023



* NETL Support Contractor

# // RECENT PUBLICATIONS

### Article

- G. Pickenpaugh and J. Adder, "Jobs, jobs, jobs: what's an analyst to do?," *Monthly Labor Review*, U.S. Bureau of Labor Statistics, December 2022.

### Models/Tools/Databases

- National Energy Technology Laboratory, "FECM/NETL Unconventional Shale Well Economic Model (UShWEM) (Version 1)," National Energy Technology Laboratory, DOE/NETL-2023/4371, Pittsburgh, PA, October 31, 2022.
- National Energy Technology Laboratory, "Industrial $CO_2$ Capture Retrofit Database (IND CCRD)," National Energy Technology Laboratory, Pittsburgh, PA, December 21, 2022.

### Reports/Supporting Documentation

- S. Pidaparti, C. White, C. Uysal, E. Liese, N. Weiland and T. Shultz, "Performance and Cost Potential for Exemplar Direct Supercritical Carbon Dioxide Natural Gas Plants," National Energy Technology Laboratory, DOE/NETL-2022/3350, Pittsburgh, PA, June 20, 2022.
- A. Sheriff, K. Bello, D. Vikara, M. Wallace and L. Cunha, "FECM/NETL Unconventional Shale Well Economic Model (2022): User's Manual," National Energy Technology Laboratory, DOE/NETL-2023/4370, Pittsburgh, PA, October 31, 2022.
- A. Sheriff, K. Bello, D. Vikara, M. Wallace and L. Cunha, "FECM/NETL Unconventional Shale Well Economic Model (UShWEM): Production Data for UShWEM," National Energy Technology Laboratory, Pittsburgh, PA, October 31, 2022.
- I-WEST Partners, "I-WEST: On the road to carbon neutrality in the Intermountain West – Phase One Final Report," Intermountain West Energy Sustainability & Transitions (I-WEST) initiative, U.S. Department of Energy, December 2022.
- D. Vikara, J. Eppink, R. T. Vactor, T. Warner, B. Chen, S. Matthews, D. Morgan, A. Guinan, M. Marquis, M. Ma, A. Bulbul, R. Pawar and L. Cunha, "I-WEST Phase One Final Report – Detailed Chapter: $CO_2$ Storage and Utilization (Version 1.0)," Intermountain West Energy Sustainability & Transitions (I-WEST) initiative, U.S. Department of Energy, National Energy Technology Laboratory, December 2022.
- National Energy Technology Laboratory, "User Guide for the Public Industrial $CO_2$ Capture Retrofit Database Models," National Energy Technology Laboratory, Pittsburgh, PA, December 20, 2022.
- S. McNaul, C. White, R. Wallace, T. Warner, H. S. Matthews, J. Ma, M. Ramezan and E. Lewis, "Strategies for Achieving the DOE Hydrogen Shot Goal: Thermal Conversion Approaches," National Energy Technology Laboratory, DOE-NETL/2023/3824, Pittsburgh, PA, January 10, 2023.

### Conference Proceedings and Events

- B. Chen, D. Vikara, Z. Ma, D. Morgan, B. Ahmed, R. Vactor, L. Cunha, T. Grant, G. Guthrie, D. Livingston, M. Mehana, R. Pratt, J. van Wijk and R. Pawar, "$CO_2$ Transport Infrastructure Modeling in the Intermountain West Region, USA," *Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16)*, Lyon, France, October 23–27, 2022.
- S. Hughes, "NETL's Cost of Capturing $CO_2$ from Industrial Sources and Industrial Carbon Capture Retrofit Database," presentation (video) at USEA Webinar, Virtual, January 24, 2023.

# // REFERENCE SECTION

**Models / Tools / Databases**

Carbon Capture Simulation Initiative (CCSI) Toolset

FECM/NETL $CO_2$ Transport Cost Model

FE/NETL $CO_2$ Saline Storage Cost Model

FE/NETL $CO_2$ Prophet Model

FE/NETL Onshore $CO_2$ EOR Cost Model

Life Cycle Analysis Models

NETL LCA CO2U toolkit

IDAES Integrated Platform

IDAES Power Generation Model Library

Pulverized Coal Carbon Capture Retrofit Database (CCRD)

Natural Gas Combined Cycle CCRD

Industrial Sources CCRD

**Key Reports**

Baseline Studies for Fossil Energy Plants

Cost of Capturing $CO_2$ from Industrial Sources

Quality Guidelines for Energy System Studies

Life Cycle Analysis

SSAE website

Search for other SSAE products

Institute for the Design of Advanced Energy Systems webpage

Life Cycle Analysis webpage

$CCSI^2$ webpage


U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Visit us: **www.NETL.DOE.gov**

@NationalEnergyTechnologyLaboratory

@netl_doe

@netl_doe