# SSAE Newsletter

JUNE // 2022 VOLUME 2.6



## // 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:

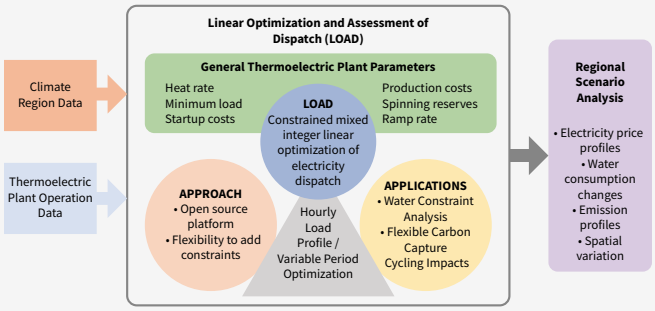
- Process systems engineering research: advanced modeling, simulation and optimization tools for complex dynamic systems
- Process and cost engineering: plant-level synthesis, process modeling and simulation of energy systems with performance estimates
- Resource and subsurface analysis: evaluation of 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

## NETL Paper Highlights LOAD Model and Effects of Short-Term Water Constraints on Electricity Dispatch

NETL researchers used NETL's Linear Optimization and Assessment of Dispatch (LOAD) model to evaluate the effects of short-term water constraints on power generation in two electricity market regions, the Electric Reliability Council of Texas (ERCOT) and the Southwest Power Pool (SPP). The results, published in *ACS ES&T Water*, showed that the imposition of water constraints in the drought-prone ERCOT region in southern Texas and western regions of SPP led to fuel switching, electricity price increments, increased coal plant cycling and localized shifting of generation in the regions. Under low-to-moderately-high water constraints, the total water consumption decreased in SPP (9.7%) and ERCOT (4.4%) as generation shifted from the water-constrained region to other regions. However, under high water constraints (65% in ERCOT and 85% in SPP), total water consumption rebounded as generation shifted to less water-efficient plants outside of the water-constrained regions.




LOAD model framework

## $sCO_2$ Turbine Cooling Modeling Highlighted in Paper

Details of a blade cooling analysis and design process for a 950-megawatt (MW) supercritical carbon dioxide ($sCO_2$) turbine for a direct-fired $sCO_2$ power plant are presented in a recently published paper by **Selcuk Can Uysal***, **Charles White***, Nathan Weiland and **Eric Liese** in *Energy Conversion and Management*. Previous analyses in literature use simplified cooling extractions and additions for analyzing the impact on the overall direct-fired cycle analysis. The detailed model in this study gives greater confidence in an accurate characterization of the cycle performance. The best cooling configurations for a single flow and a double flow turbine were determined by testing in a direct-fired $sCO_2$ power plant performance model in Aspen Plus®. A weighed scoring criteria was developed to help select closely related performance outcomes. Scoring results gave a single flow turbine with a calculated turbine efficiency of 88%, and a resulting cycle lower heating value (LHV) efficiency of 65.73% and plant LHV efficiency of 54.43% for an approximately 602 net MW direct-fired $sCO_2$ power plant (952-MW turbine) as the best option. Direct-fired $sCO_2$ plants are capable of high (≥ 98%) rates of $CO_2$ capture, consistent with the Administration's decarbonization goals.

## NETL Hydrogen Baseline Study Released and Gaining Traction

Levelized costs and life cycle greenhouse gas emissions of commercial, state-of-the-art hydrogen production technologies within plant configurations at scale were assessed in a recently released study by a team led by **Eric Lewis**. SSAE modeled steam methane reforming (SMR), natural gas autothermal reforming (ATR) and gasification using coal and biomass and included carbon capture and storage (CCS).

The lowest levelized cost of hydrogen (LCOH) was associated with SMR without CCS at \$1.06/kg $H_2$, followed by SMR and ATR with CCS at \$1.64/kg $H_2$ and \$1.59/kg $H_2$, respectively. The lowest global warming potentials (cradle to gate) were associated with the coal/biomass co-gasification plant with CCS, at -1.0 lb $CO_2$e/lb $H_2$. The detailed study provides a baseline to which research and development (R&D) progress can be compared and supports the identification of R&D pathways to reduce costs and improve environmental performance. DOE's Hydrogen Energy Earthshot – announced June 7, 2021 – seeks to reduce the cost of clean hydrogen to \$1/kg within one decade.

With the potential of hydrogen as a versatile clean energy fuel, particularly for difficult-to-decarbonize segments of the economy, this study has gained attention. **Eric Lewis** was invited to present this work at an April 2022 Low-Carbon Resources Initiative (LCRI) webcast, which consisted of a group focused on the production of low-carbon hydrogen from hydrocarbon sources, and at the 2022 DOE Hydrogen Program Annual Merit Review and Peer Evaluation Meeting (AMR) on June 8, 2022 during the Systems Analysis/Intra-Agency Activities session. The LCRI, a joint effort between Electric Power Research Institute (EPRI) and Gas Technology Institute, targets advances in a variety of low-carbon electric generation technologies and low-carbon chemical energy carriers to enable economy-wide decarbonization. During the DOE Hydrogen Program AMR, hydrogen and fuel cell projects funded by DOE were presented, and projects and programs were reviewed for their merit.

## SSAE Study Combines Subsurface Modeling Capability, Risk and Cost Evaluation to a $CO_2$ Storage Site

A study comparing potential cost savings associated with reduced post-injection site care (PISC) periods and smaller area of review (AoR) for $CO_2$ storage sites as compared to standard U.S. Environmental Protection Agency (EPA) Underground Injection Control (UIC) Class VI regulatory default approaches was recently published. The study focused on the FutureGen 2.0 site in Illinois. Analyses were conducted to compare the costs of storage (on a first-year break-even dollar per tonne [2018$] basis) at the proposed FutureGen 2.0 site as a case-study storage location by implementing different approaches to determine AoR and PISC given the prevailing geologic conditions, injection volume and injection duration considerations. The approaches included the use of: 1) risk-based methods to define AoR and PISC duration that leverage NETL's National Risk Assessment Partnership tools, 2) EPA-approved AoR and PISC documented in the FutureGen 2.0



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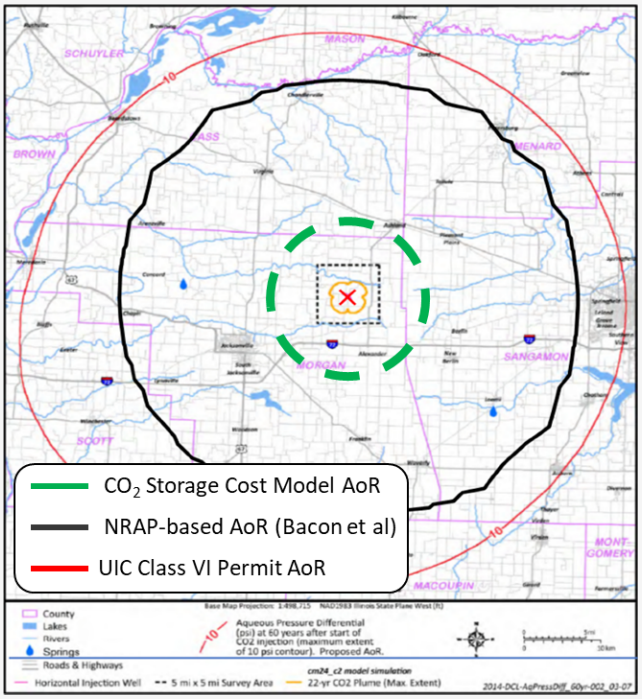
# // HIGHLIGHTS (cont'd)

UIC Class VI permit applications generated from reservoir modeling and 3) FE/NETL $CO_2$ Saline Storage Cost Model (CO2_S_COM) default settings that utilize approximated site geologic conditions and uncertainty multipliers to estimate $CO_2$ plume and pressure front extent as part of AoR determination, as well as rely on a 50-year PISC default.

The pre-determined AoR and PISC specified in the Class VI permit applications for FutureGen 2.0 were found to be the largest and the longest relative to the other two approaches. The study found that as the AoR size and/or PISC duration increased, the break-even cost and total costs for similar projects increased due in part to the need for additional monitoring coverage and surface area access. Results also suggested the stronger influence of AoR size on project cost compared to PISC. However, the combination of shorter PISC with smaller AoR yielded the greatest financial benefit. Overall, the results for this case-study support the notion that risk-based approaches for evaluating AoR and PISC may result in significant project cost savings. However, this notion is contingent upon appropriate determination of non-endangerment to properly set bounds to AoR extent and the needed PISC timeframe.




Risk-based AoR (black circle) compared to EPA UIC Class VI permitted AoR (red circle) and CO2_S_COM default (green circle)

## Staff Spotlight

Since joining the Subsurface Energy Analysis Team almost four years ago, **Alana Sheriff's*** work has included support to NETL's Carbon Storage Program, Gas Hydrate Program and Unconventional Oil and Gas Program. She helped design and assess the economic impacts of multiple integrated CCS networks located in the central United States, developed an Excel-based model that estimates the cost of an unconventional well on a per well and per pad basis and also conducted an analysis using a multi-criteria evaluation methodology to screen the Gulf of Mexico's outer continental shelf for potentially viable $CO_2$ storage and enhanced oil recovery sites. Outside of carbon storage, Alana supports the multi-national lab-to-lab collaboration working to advance methane hydrate production technology by assisting with the design of two production test wells capable of producing methane hydrates for a minimum of one year.

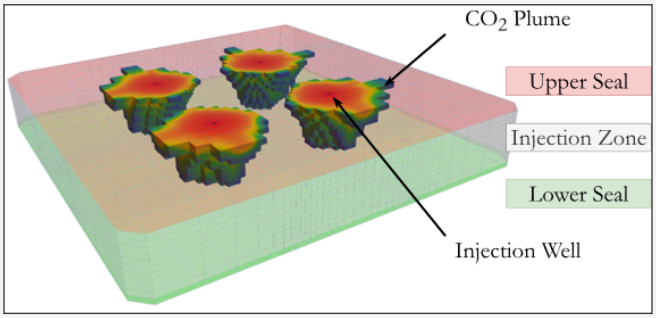
Sheriff graduated from Penn State University with a B.S. in Petroleum and Natural Gas Engineering and a double minor in Energy Business & Finance and Geoscience.

# // NOTICES

### Carbon Conversion Technologies Cost Scaling Library Underway

SSAE is working on a novel spreadsheet-based cost-scaling library designed to support future techno-economic analyses (TEA) of carbon conversion technologies. The library has references to past studies relating to carbon conversion technologies and is divided into three sections: 1) NETL studies with costing, 2) NETL studies without costing and 3) non-NETL TEAs on carbon conversion technologies. For NETL studies with costing, the library documents reference sources, individual items scaled or costed and scaling values used to complete costing. For NETL studies without costing, the library documents potential reference sources for future cost estimation as well as diagrams and/or equipment lists of small-scale systems, if available. Non-NETL TEAs are cataloged with lists of major equipment, equipment costs and potential cost-scaling values as available. The cost-scaling library will have public and internal-only versions, be regularly updated with future TEA work on carbon conversion technologies and be part of the NETL suite of tools for conducting TEA of carbon conversion technologies, which is also in development.

### Subsurface Basin-Scale Modeling Featured at SPE Conference




$CO_2$ plumes from four injection wells at the end of 30-year injection, stored in the injection zone bounded by upper and lower seal layers

Basin management of geologic $CO_2$ storage in regard to the technical analysis on quantification of $CO_2$ plume extents and magnitude of pressure buildup in $CO_2$ storage formations was presented by **Nur Wijaya*** in a paper co-authored with SSAE researchers **Derek Vikara***, **David Morgan** and **Timothy Grant** at the Society of Petroleum Engineers (SPE) Western Regional Meeting in April 2022. Modeling plume extents and pressure buildup in multiple nearby commercial-scale $CO_2$ saline storage projects highlights the importance of coordination among storage project operators and regulatory stakeholders to allow deployment upscaling.

Exploratory analysis of the factors that influence the size of the AoR per Class VI well rules, along with the potential close proximity among injection wells or storage projects, which could result in $CO_2$ plume commingling and pressure buildup and interference, were provided in the presentation. The pressure buildup challenge was especially highlighted given its connection with the current regulatory guidelines set by EPA concerning the maximum allowable pressure buildup in the storage formations to maintain seal/caprock layer integrity. This effort employed numerical reservoir simulation and modeling to quantify $CO_2$ plume and pressure buildup extents using full-physics multi-dimensional TOUGH3-ECO2M simulator, leveraged NETL supercomputer Joule 2.0 and processed the simulation results using in-house Python-based ParaView visualization tools.

Delivered within a dedicated session on "Carbon Capture and Sequestration" at the meeting, the presentation was attended by professionals from industry and academia. Questions from the audience elicited further explanations on the modeling assumptions and potential next steps of the project.

### Brackish Water Treatment Results Discussed at Student Conference

Results of a techno-economic assessment evaluating the potential of brackish water treatment for wet cooling towers at existing thermo-electric generating units (EGUs) was presented at the 18th Annual Rocky Mountain Section of the American Water Works Association (RMSAWWA)/Rocky Mountain Water Environment Association (RMWEA) Student Conference in May 2022. The study, co-authored by NETL and University of Wyoming researchers, addresses current knowledge gaps in support of non-traditional water resources planning and the electric power industry's water decision-making and policymaking. When supporting decision-making in water management and planning, factors like trade-offs among technical, performance, economics and environmental impacts must be considered. Reusing non-traditional water resources is critical for alleviating water stress in the western United States.

The viability of retrofitting reverse osmosis-based brackish water treatment systems to individual existing EGUs and on the fleet level was modeled. The study concluded that brackish water treatment can reduce the freshwater consumption of electric generation but increase the cost of electric generation. Applying zero liquid discharge systems to brackish water treatment significantly increases freshwater consumption savings, the cost of electricity and energy penalty to the power plant.

### Treatment Technology Assessment for Landfill Leachate to be Featured at ASME Power Conference

Combustion of coal results in the creation of solid byproducts (such as fly ash, bottom ash, synthetic gypsum or other solid waste streams) that are typically disposed of in impoundments. When water comes into contact with these solid byproducts, that water becomes a waste stream regulated by EPA emission guidelines and must be treated before discharge. A market assessment to estimate the total volume of wastewater that could be subject to regulation and treatment and an evaluation on the cost to treat will be presented by **Chad Able*** at the ASME Power Conference to be held July 18–19, 2022. Given the trace amounts of heavy metals (such as mercury, selenium and arsenic) present in coal, predicting which pollutants are most likely to appear in the resulting wastewater can be challenging. However, this study also projects those heavy metals that are most likely to be present in combustion

# // NOTICES (cont'd)

residual leachate, based on the type of coal that was burned at the power plant. Given the wide variation in heavy metal concentration in wastewater, characterizing which pollutants are most likely to be present is a critical step to understanding the treatment technology R&D needs. A paper discussing this analysis will be published in Fall 2022.

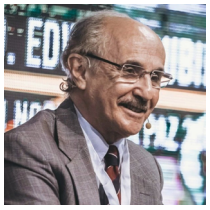
### SSAE Work to be Featured at Clearwater Conference

Recent advances in the analysis of carbon capture and hydrogen production technology by SSAE researchers will be presented at the 46th International Technical Conference on Clean Energy, which brings together representatives from six continents to discuss innovations meeting the challenges to energy utilization. A sampling of SSAE work to be featured at this event, which will be held August 1–4, 2022, includes the following, but other work can be found in the conference program:

- A direct air capture (DAC) case study that examines a solid sorbent-based DAC technology and plant configurations will be presented by **Timothy Fout**.
- Updates to the legacy "Cost of Capturing $CO_2$ from Industrial Sources" report and their impacts on cost and performance, including a capture system update, updated source information and capture rates higher than 90%, will be presented by **Timothy Fout**.
- Information from a study titled "Comparison of Commercial, State-Of-The-Art, Fossil-Based Hydrogen Production Technologies" – an independent assessment of the cost and performance of select hydrogen production plants – will be presented by **Robert Stevens**.
- Updates to the "Technoeconomic and Life Cycle Analysis to Bio-Energy with Carbon Capture and Storage (BECCS) Baseline," which adds 100% biomass cases to existing coal-biomass cofiring cases and includes higher capture rates (95% and 99%), will be presented by **Timothy Fout**.
- Updates to the "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity" that aim to establish performance and cost references for greater than 90% carbon capture rates in fossil-based power systems, with particular emphasis on natural gas combined cycle power plants, will be presented by **Timothy Fout**.

### SSAE Welcomes Amanda Harker Steele

**Amanda Harker Steele** is joining SSAE's Energy Markets Analysis Team after working as an NETL site support contractor since June 2019. As a site support contractor, Amanda conducted economic and market analysis in support of several NETL research programs including carbon storage, carbon ore processing, high-performance materials and sensors and controls. Amanda holds a doctorate in Agricultural and Applied Economics from the University of Georgia and a bachelor's degree in Environmental and Natural Resource Economics from West Virginia University. Her research agenda focuses on the economic efficiency and distributional equity implications of decisions involving the production and consumption of energy resources. In her spare time, Amanda enjoys running, biking, hiking and completing home improvement projects while raising one cat, Toonces, with her husband, Bert.



## Thank You Ed Rubin

Professor Ed Rubin – a long-time collaborator with NETL – announced his retirement from Carnegie Melon University (CMU). Recognized for exploring technical, economic and policy issues related to energy and the environment, including CCS technologies, he has been noted as the world's most prolific and highly-cited author of CCS-related academic publications. Ed has been a mentor, friend and phenomenal colleague to NETL and specifically the SSAE Directorate during his tenure, with many valuable contributions advancing our mission, including, but not limited to:

*Integrated Environmental Control Model (IECM)*

Ed has been the critical driver for the creation, development and maintenance of IECM, a modeling tool that quantifies the thermodynamic performance, environmental emissions, resource requirements and costs of power plant designs and environmental control options for air pollutants, greenhouse gases, water pollutants and solid wastes. First created as a tool to help DOE assess the potential payoffs and risks of its R&D portfolio of advanced technologies for fossil fuel power generation and emissions control, it was a pioneering development in energy technology R&D that helped create the field that is today called TEA.

IECM incorporates several technical and software capabilities including

- Set of engineering-economic models that estimate the capital, operating and overall cost implications of process or system design changes
- Stochastic modeling that provides the ability to perform rigorous probabilistic analyses of uncertainties to quantify risks, which is especially important for the design and analysis of advanced technologies still in their early (pre-commercial) stages of development
- Suite of models for current and advanced CCS technology options
- Graphical user interface to run the model

Dr. Rubin won CMU's College of Engineering 2021 David P. Casasent Outstanding Research Award for developing IECM, which is widely used and cited by individuals and organizations worldwide. It incorporates results from many NETL-sponsored studies in its framework and has allowed several thousand users from all sectors in over 60 countries to employ it for technology design, R&D planning, regulatory compliance, policy analysis, market analysis, research and graduate education.

*CCS Costing Guidelines*

Ed worked with NETL researchers, industrial research institutes, universities and other organizations on a white paper that provided costing guidelines for CCS technologies, which are critical for reducing greenhouse gas emissions from thermal power plants and industrial processes. Understanding CCS technology costs – particularly at earlier stages of development – is essential to successfully guide research activities and inform investment decisions. These guidelines aim to address the challenge of establishing reliable and transparent cost estimates for the breadth of CCS technology options, $CO_2$ source/applications and degree of technological maturity.

Stemming from previous work completed by a group of experts from industry, government, academia and other organizations (including Ed and NETL) in 2013, which laid a foundation for establishing a common costing methodology, this new white paper provides a complementary set of CCS costing guidelines in three areas where further guidelines and better practices are needed: 1) advanced, low-technology readiness level (TRL) $CO_2$ capture technologies, 2) CCS from industry like cement plants and steel mills and 3) uncertainty evaluations and quality assurance of models and data used in CCS cost analysis.

*Dry and Wet Cooling Assessment*

Dr. Rubin worked with NETL and the University of Wyoming on a study featured in the January 2022 issue of *Applied Energy* that investigated the performance, cost and generating capacity impacts of switching from wet to dry cooling systems to reduce the consumptive water use at existing fossil fuel-fired power plants in a water-stressed region. IECM was used for this analysis and as a testament to its ease-of-use, the impact of seasonal variations in ambient conditions (dry bulb temperature and relative humidity) on dry cooling's effectiveness was also incorporated into the study. The results found that although dry cooling retrofits substantially reduce or eliminate fossil power plant water consumption, this reduction comes at a cost of a decrease in net power generation, particularly in summer when ambient temperatures are hottest, and demand for power generation peaks. This study quantified the benefits and tradeoffs associated with development and deployment of advanced technology, which is expected to be of great benefit to policymakers. Ed's knowledge and experience understanding the nexus of technology development and policymaking were instrumental in the successful completion of this project. He also never lost touch with his background as an educator and was always willing to make himself available to mentor and advise others on the project team.

While Ed is transitioning to professor emeritus, he will still be advocating for the environment. He plans to split his time between Pittsburgh, Pennsylvania and Valencia, Spain where he will be advising on a number of energy, climate change and sustainability activities. His expertise and enthusiasm will be greatly missed by NETL.

# // UPCOMING CONFERENCES AND EVENTS

**SSAE Federal staff and NETL support contractor personnel will attend or present at the following conferences and events in June and July 2022:**

- 2022 Advanced Manufacturing and Processing Conference
  Keynote plenary: **David Miller** – Optimizing Decarbonized Industrial and Energy Systems
  Presenter: **Stephen Zitney** – Science-Informed Virtual Digital Twin for an Integrated Energy System with Carbon Capture: Research, Training and Education
  Workshop leaders: **John Eslick***, **Radhakrishna Tumbalam-Gooty*** and **Miguel Zamarripa*** – Workshop: Introduction to the IDAES PSE Framework
  Bethesda, MD, June 1–3, 2022
- 2022 DOE Hydrogen Program AMR
  Presenter: **Eric Lewis** – FE005 Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies
  Participants: **Gregory Hackett** and **Shannon McNaul***
  Virtual, June 6–8, 2022
- Smart Manufacturing Experience 2022
  Presenter: **Jaffer Ghouse*** – IDAES: A Next-Generation, Multi-Scale Process Systems Engineering Framework for Optimizing Energy Systems and Manufacturing Processes
  Pittsburgh, PA, June 7–9, 2022
- NAWI Peer Review Meeting
  Presenter: **Timothy Bartholomew**
  Berkeley, CA, June 13–17, 2022
- EPRI's Water, Land and Ecosystems – Environmental Issues Summer Meeting
  Participant: **Eric Grol**
  Monterey, CA, June 14–16, 2022
- H2IQ Hour: GREET Model for Hydrogen Life Cycle Emissions
  Presenter: **Eric Lewis** – Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies
  Virtual, June 15, 2022
- 14th International Symposium on Process Systems Engineering (PSE 2021+)
  Presenter: **Jinliang Ma***– Dynamic Simulation and Optimization of a Subcritical Coal-Fired Power Plant During Load-Ramping Operations
  Hybrid (Virtual and Kyoto, Japan), June 19–23, 2022
- 2022 ARS & NAL LCA Visioning Workshop (Invite-only)
  Participant: **Timothy Skone**
  Virtual, June 27–28, 2022
- NERC Reliability Assessment Subcommittee Second Quarter Meeting
  Participant: **John Brewer**
  Hybrid (Virtual and Kansas City, MO), July 11–15, 2022
- 2022 IEEE Power & Energy Society General Meeting
  Panelist: **John Brewer** – Panel Session: Future Reliability and Resilience Study of Electrical and Gas Systems under Extreme Weather Events – 22PESGM3806-Natural gas-electric interdependency through 2030
  Denver, CO, July 17–21, 2022
- ASME Power 2022 Conference
  Presenter: **Chad Able*** – Treatment Technology Assessment for Landfill Leachate
  Participant: **Eric Grol**
  Pittsburgh, PA, July 17 (workshops), July 18–19 (conference) and July 20 (tours), 2022
- AIChE-ASEE Chemical Engineering Summer Meeting
  Participant: **Stephen Zitney**
  Golden, CO July 24–July 29, 2022
- 5th Annual Generation Flexibility Conference
  Participants: **Travis Shultz** and **Marc Turner***
  Hybrid (Virtual and Charlotte, NC), July 25–29, 2022
- CACHE Meeting
  Participant: **Stephen Zitney**
  Golden, CO July 29–July 30, 2022



* NETL Support Contractor

# // RECENT PUBLICATIONS

### Articles / Manuscripts

- A.W. Zimmermann, T. Langhorst, S. Moni, J.A. Schaidle, F. Bensebaa and A. Bardow, " Life-Cycle and Techno-Economic Assessment of Early-Stage Carbon Capture and Utilization Technologies—A Discussion of Current Challenges and Best Practices," *Frontiers in Climate*, March 28, 2022.
- G. Faber, A. Ruttinger, T. Strunge, T. Langhorst, A. Zimmermann, M. van der Hulst, F. Bensebaa, S. Moni and L. Tao, "Adapting Technology Learning Curves for Prospective Techno-Economic and Life Cycle Assessments of Emerging Carbon Capture and Utilization Pathways," *Frontiers in Climate*, April 14, 2022.
- R. Boswell, T. Collett, K. Yamamoto, N. Okinaka, R. Hunter, K. Suzuki, M. Tamaki, J. Yoneda, D. Itter, S. Haines, E. Myshakin and G. Moridis, "Scientific Results of the Hydrate-01 Stratigraphic Test Well Program, Western Prudhoe Bay Unit, Alaska North Slope," *Energy & Fuels*, vol. 36, no. 10, pp. 5167-5184, April 27, 2022.
- Y. Kumar, R. Hoesly, A. Venkatesh, E. Shuster and A. Iyengar, "Effects of Short-Term Water Constraints on Electricity Dispatch: A Case Study of ERCOT and SPP Regions," *ACS ES&T Water*, vol. 2, no. 5, pp. 749-758, April 29, 2022.
- S. Can Uysal, C. W. White, N. Weiland and E. A. Liese, "Cooling analysis of an axial turbine for a direct fired $sCO_2$ cycle and impacts of turbine cooling on cycle performance," *Energy Conversion and Management*, vol. 263, article 115701, July 2022.
- A. Wendt, A. Sheriff, C. Shih, D. Vikara and T. Grant, "A multi-criteria CCUS screening evaluation of the Gulf of Mexico, USA," *International Journal of Greenhouse Gas Control*, vol. 118, article 103688, July 2022.

### Conference Proceedings and Events

- E. Lewis, "Overview of Integrated Pathway Analyses to Meet the Hydrogen Energy Earthshot Goal," *Proceedings of the 2022 Bulk Storage of Gaseous Hydrogen Workshop*, Virtual, February 10, 2022.
- S. Can Uysal and E. Liese, "Radial Compressor Design and Off-Design for Trans-critical $CO_2$ Operating Conditions," Paper #161, *Proceedings of the 7th International $sCO_2$ Power Cycles Symposium*, Hybrid (Virtual and San Antonio, TX), February 21–24, 2022.
- S. Pidaparti, "A Performance and Economic Comparison of Partial Cooling and Recompression $sCO_2$ Cycles for Coal-fueled Power Generation," presentation at the 7th International $sCO_2$ Power Cycles Symposium, Hybrid (Virtual and San Antonio, TX), February 21–24, 2022.
- S. Pidaparti, "Cooling System Cost and Performance Models to Minimize Cost of Electricity of Direct $sCO_2$ Power Plants (Paper #113)," presentation at the 7th International $sCO_2$ Power Cycles Symposium, Hybrid (Virtual and San Antonio, TX), February 21–24, 2022.
- S. Can Uysal and E. Liese, "Radial Compressor Design and Off-Design for Trans-critical $CO_2$ Operating Conditions," presentation at the 7th International $sCO_2$ Power Cycles Symposium, Hybrid (Virtual and San Antonio, TX), February 22, 2022.
- E. Grol, "Overview of Emissions Control R&D at NETL," presentation at the FY22 FECM Spring R&D Project Review Meeting – Emissions Control, Virtual, May 3, 2022.
- I. Peña-Cabra, "Integration of Energy Storage in Fossil Energy Power Plants (ES-FE) Market Analysis," presentation at the FY22 FECM Spring R&D Project Review Meeting – Crosscutting Research (Energy Storage), Virtual, May 5, 2022.
- P. Myles, J. Brewer and D. Keairns, "Evaluation of NGCC with Capture for Long Duration Energy Storage (LDES)," presentation at the FY22 FECM Spring R&D Project Review Meeting – Crosscutting Research (Energy Storage), Virtual, May 5, 2022.
- D.C. Miller, "IDAES – Institute for the Design of Advanced Energy Systems," presentation at the FY22 FECM Spring R&D Project Review Meeting – Crosscutting Research (Simulation-Based Engineering), Virtual, May 6, 2022.
- J. Kneifel, P. Gagnon and M. Jamieson, "Times (and the Grid) are A-Changin' – Publicly Available, Forward-Looking Electricity Databases for GHG and LCA Projections," presentation at the ACLCA Webinar, Virtual, May 11, 2022.

# // 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

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Institute for the Design of Advanced Energy Systems webpage

Life Cycle Analysis webpage

$CCSI^2$ webpage

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