SSAE Newsletter

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NATIONAL ENERGY TECHNOLOGY LABORATORY

// 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

New Version of IDAES Integrated Platform Released

SSAE's capabilities to design and optimize next-generation energy and process systems continue to be enhanced by the Institute for the Design of Advanced Energy Systems (IDAES) with the release of Version 2.0 of the IDAES® Integrated Platform in February 2023. In the four years since Version 1.0 was released, the IDAES toolset has undergone significant growth in both capability and user base. The IDAES team has focused on making state-of-the-art tools and models available to the process systems engineering community. However, with a growing user base comes the need to ensure stability and continuity in the tools and their interfaces so that users can trust that updates to the code will not break their existing models and workflows.

With the second major update to the IDAES toolset, the IDAES team is moving from the concept of rapid growth to sustainable development with an increased focus on backward compatibility. As part of this shift, the entire codebase was reviewed to classify existing tools based on maturity and stability of the code and clearly separate them so that users of the tools are aware of what tools can be considered stable and backward compatible and which tools may be still undergoing development. To support this capability, the IDAES team has also begun testing the code for backward compatibility and performance profiling to ensure that the tools continue to function as expected.

In addition to this change, Version 2.0 also brings several improvements and new features. A new interface for Helmholtz Equations of States, which allows users to define new chemical components to their models, and pre-defined examples for several common refrigerants have been added. A new interface for initializing models has also been added. It aims to increase performance and flexibility for users by supporting multiple initialization schemes for each model, thus allowing users to choose the best approach for their given applications. The new interface also leverages a number of new solver techniques developed in previous years, which apply automatic decomposition tools to break large problems up into smaller, more manageable sub-problems, that can be solved sequentially.

Optimization Papers Highlight PSE Contributions

Collaborations with West Virginia University (WVU), Svante Inc., Los Angeles Department of Water and Power, Susteon Inc., Carnegie Mellon University and the National Renewable Energy Laboratory (NREL) resulted in three papers co-authored by SSAE's Process Systems Engineering Research Team (PSE). These papers focused on various research areas and were recently published in several journals.

An optimization methodology to determine the optimal design and assess the economic viability of deploying flexible carbon capture and storage (CCS) technologies with fossil generators in the context of the bulk power market was the focus of one paper, "Incorporation of market signals for the optimal design of post combustion carbon capture systems," published in *Applied Energy*. The optimal design and economic assessments were determined by incorporating synthetic locational marginal price signals from a future decarbonized grid with a high variable renewable energy (VRE) penetration. The approach removed the high-capacity factor assumption as is standard in the conventional techno-economic analysis (TEA) and instead determined the capacity factor that maximizes the net present value for a given market. The problem, formulated as a mixed-integer nonlinear programming problem, was implemented and solved in the open-source IDAES Integrated Platform. The methodology proposed in this study was applied to determine the profitability of retrofitting an existing natural gas combined cycle system with Svante's proprietary temperature-swing adsorption technology. Results show that the decision to build or not build the capture system is highly dependent on the electricity price signals, which rely on the generation mix of the grid and carbon prices. This methodology can be applied to assess different capture technologies and can help answer questions about the flexibility needs in a capture technology to be deployed in a high VRE grid. It can also address questions about the threshold carbon prices that determine the point at which building a capture system is viable. This effort was funded by the Advanced Research Projects Agency-Energy's FLExible Carbon Capture and Storage (FLECCS) program. The paper is available for free until April 20, 2023, after which a subscription may be required for access.

Another paper, "A complementarity-based vapor-liquid equilibrium formulation for equation-oriented simulation and optimization," built upon work done in 2018 and eliminated the need for expensive bubble and dew point calculations as part of the smooth vapor-liquid equilibrium (VLE) formulation, which speeds up initialization of property packages that have VLE calculations while also improving overall solution robustness. Published in the *AIChE Journal*, the study used the IDAES Integrated Platform to implement the new formulation and demonstrate its effectiveness on different multi-component systems for simulating/optimizing flash and distillation unit models with cubic equations of state. This novel approach to VLE calculations was completed with funding support from the Simulation-based Engineering and Solid Oxide Fuel Cell programs within DOE's Office of Fossil Energy and Carbon Management (FECM).

A study that leveraged the Water treatment Technoeconomic Assessment Platform (WaterTAP) to simulate and optimize a model of low-salt-rejection reverse osmosis (LSRRO) was discussed in the last paper, "Cost optimization of low-salt-rejection reverse osmosis." LSSRO is a novel, conceptual technology that targets high-salinity and high-recovery desalination applications. Published in *Desalination*, results show that LSRRO may be cost-competitive with mechanical vapor compression and osmotically assisted RO, particularly at feed concentrations below 125 g/L total dissolved solids. Moreover, the study also provides guidelines for cost-optimal design and operation and explores the full application space, optimizing across an extensive range of feedwater salinity and water recovery values. WaterTAP is an open-source Python-based software tool for assessing the performance and economic viability of water treatment trains. Its development is led by NETL in collaboration with other national laboratories including Lawrence Berkeley National Laboratory, NREL and Oak Ridge National Laboratory.

// HIGHLIGHTS cont'd

SSAE Prepares Report for APEC on Best Coal Plants

A key element of the global energy transition is retiring low-efficiency, highly polluting coal plants as quickly as possible. Around the world, most retiring coal units are not replaced by new, more efficient and cleaner coal technology but by alternative lower-carbon energy sources, including natural gas and renewables, especially wind and solar.

However, another reality is that a few economies in the Asia-Pacific Economic Cooperation (APEC) region and around the world are still planning new coal generating capacity, and many economies will continue operating their existing coal plants for many years, especially in the APEC region where many plants are newer and have not been fully amortized. In 2018, 45% of power generation in the APEC region economies came from coal. This situation exists for a variety of reasons, including domestic and local politics and limited energy resource endowments (especially using natural gas as a transition fuel), along with energy and/or environmental policies, which include positive benefits of employment and high wages in their coal and power sectors and the reliability and security of coal-based power generation.

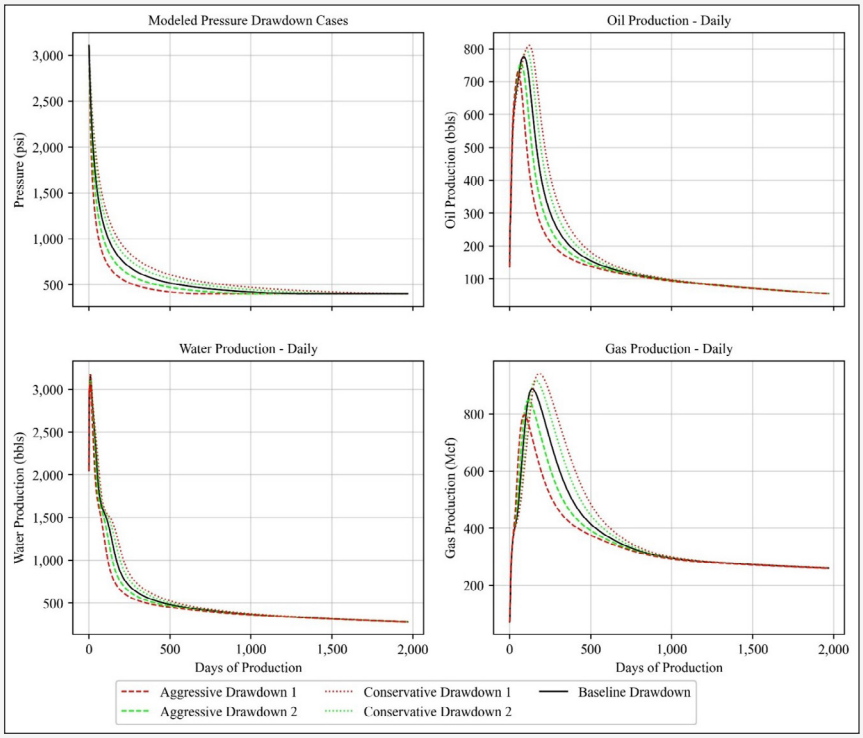
To the extent that new coal plants are built, understanding and incorporating the most advanced designs and features will help minimize the environmental footprint of these plants and aid the transition to a lower carbon future. In support of the deployment of the most advanced coal technologies, a report examining the design features and operational attributes of the best plants in the APEC region was recently released by APEC. The report titled "'Best' Coal Power and Cogeneration Plant Case Studies" was sponsored by FECM and prepared by SSAE and NETL support contractors for APEC. The 16 case studies presented in this report highlight advancements in one or more technology designs or operating features that can improve plant performance. Such improvements include higher operating efficiency, reduced emissions of conventional pollutants, reduced water usage and reductions in construction and/or operations costs. Collecting this information into a single document will allow decision makers to identify and incorporate advanced technologies in future planning exercises.

Pressure Maintenance Strategies in Unconventional Wells Explored in SSAE Report

A case study evaluating the production implications of pressure maintenance strategies in an unconventional well in the Permian Basin using a Machine Learning (ML) Modeling Approach was assessed in a recent report. The study implemented the proprietary ML-based model developed under a 2022 study. The model, developed using an exclusive dataset that includes time series production data from an operator in the Permian Basin, is designed to jointly predict daily oil, gas and water production for horizontal wells as a function of bottomhole pressure drawdown, spatial placement across the study domain and well-completion attributes.

In the case study, the model was explicitly applied to explore its utility to evaluate the impact of varying drawdown strategies on the production forecast of a well in the Permian Basin dataset. Managing pressure drawdown has been identified as a way to improve estimated ultimate recovery from unconventional shale wells due to the stress-dependent nature of fractures in shale reservoirs. Research has shown that applying a lower pressure drawdown helps to maintain the reservoir conductivity, resulting in higher productivity over the life of a well. Historic bottomhole pressure data from the well over time was used as a benchmark to set more and less aggressive pressure decline rates as bounding modeling cases. All pressure decline rates/strategies were forecasted over five years, and the model was used to generate oil, water and gas prediction over the same timeframe (see the figure below).

Results indicate that rapid drawdown of pressure generates higher initial oil and gas (O&G) production from the well. However, overall O&G production over the medium to long term from rapid drawdown strategies is lower compared to conservative drawdown strategies that sustain pressure. Rapid drawdown strategies resulted in lower water production over the life of the well compared to conservative drawdown strategies. The case study presents the results from the production forecast and discusses potential operational and economic implications with contrasting perspectives between well productivity and profitability given typical O&G economics and the volatility in the O&G market.



Pressure drawdown strategies and forecasted daily rates for oil, water and gas over the first five years of production

Staff Spotlight

Since joining in August 2021, Radhakrishna Tumbalam Gooty* has been supporting SSAE's PSE at NETL Pittsburgh in design, analysis and optimization of various energy and power systems. He has primarily contributed toward FLECCS and the Design Integration and Synthesis Platform to Advance Tightly Coupled Hybrid Energy Systems (DISPATCHES) projects. As part of FLECCS and DISPATCHES, he was involved in the development of a framework for assessing the economics of novel technologies in the context of an electric grid, which he later used to assess overall economics of a direct-fired supercritical carbon dioxide (sCO_2) power cycle with a liquid oxygen storage system, and for TEA of retrofitting an existing nuclear power plant with a low-temperature electrolysis unit. He looks forward to supporting NETL on various energy projects.

Radhakrishna attended the Indian Institute of Technology in Madras, India, where he received a bachelor's degree with honors and a master's degree in 2015, both in Chemical Engineering. He then moved to the United States to attend Purdue University, where he received a Ph.D. in Chemical Engineering in December 2020. His contributions on distillation were recognized by the American Institute of Chemical Engineers (AIChE) Separations Division with a Graduate Student Research Award. In his free time, he enjoys long walks, playing chess and binge-watching.

// NOTICES

UPGrants Website Launched

DOE's FECM, through the Carbon Conversion Program and enabled by provisions included in the Bipartisan Infrastructure Law Section 40302, issued a notice of intent to establish a demonstration grant program called the Utilization Procurement Grants (UPGrants). This program will issue grants to states, local governments and public utilities or agencies to procure and use commercial or industrial products derived from the conversion of anthropogenic carbon oxides. For a product to be eligible, it must demonstrate significant greenhouse gas (GHG) emissions reduction compared to incumbent products.

SSAE life cycle analysis (LCA) researchers Michelle Krynock and Sheikh Moni* will manage critical reviews of product data to verify substantial net reduction of GHG emissions compared to benchmarks. Product manufacturers are required to complete their LCA using the NETL UPGrants LCA Guidance Toolkit. It provides instructions, requirements, templates and tools for analysis.

Additionally, carbon conversion product manufacturers have the option (but are not required) to submit data related to TEA, which will facilitate further development of the Carbon Conversion Program.

NETL launched a website for manufacturers to submit LCA data and be considered for inclusion in the program. This site provides the NETL UPGrants LCA Guidance Toolkit and additional resources for manufacturers. Additionally, the site includes UPGrants-specific TEA (TEA Guidance and a Reporting Template) for manufacturers to submit TEA-related information.

SSAE's Baseline Study Data Serves as Basis for NREL's 2022 ATB

Data from SSAE's "Cost And Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 4A" served as the basis for FECM's input to NREL's 2022 Electricity Annual Technology Baseline (ATB) mid-year update. The ATB provides detailed current and projected technology cost and performance data for electricity generation and storage across a range of research and development (R&D) scenarios. This data can help stakeholders perform various U.S. energy analyses and help answer new and emerging questions about the U.S. power system.

OHI Collaboration to Result in Toolkit for Hydrogen Producers

SSAE is collaborating with GTI Energy to build a global, transparent toolkit for hydrogen producers to assess the cradle-to-gate carbon intensity of hydrogen production at the asset level. The toolkit and accompanying protocols will allow users to incorporate measured data and receive a data quality score that communicates the reliability of the reported carbon intensity.

This collaboration is part of the Open Hydrogen Initiative (OHI), which is a consortium of energy sector professionals led by GTI, S&P Global Commodity Insights and NETL, aiming to improve transparency into the environmental impact of hydrogen production.

SSAE researcher Megan Henriksen* is managing model development and state-of-the science reviews conducted by technical working groups focused on natural gas, biomass and renewable natural gas, electricity generation and delivery and carbon management. These groups are led by Scott Matthews*, Bob Wallace*, Matthew Jamieson and Michelle Krynock.

Henriksen provided a briefing on technical work-to-date at The Future of Hydrogen Markets workshop co-hosted by OHI and the Stanford Hydrogen Initiative in February 2023 at Stanford University. Her presentation provided an overview on unit process model development, looked ahead to data quality tasks and toolkit development and discussed topics relevant to stakeholders.

* NETL Support Contractor

// NOTICES cont'd

SSAE's Subsurface Analysis Team to Highlight Research at CCUS Conference

Research of SSAE's Subsurface Analysis Team will be showcased this month at the Carbon Capture, Utilization and Storage (CCUS) 2023 conference in Houston, Texas from April 25-27, 2023. The meeting, organized and presented by the Society of Petroleum Engineers, American Association of Petroleum Geologists and Society of Exploration Geophysicists, features presentations on a variety of technical and economic topics with a focus on CO_2 storage, transportation and utilization. Listed below are the SSAE presentations, of which publication is pending.

- An overview on the techno-economic models developed by NETL to assess the performance and costs of the CO_2 transport and storage components of the CCS/CCUS value chain will be discussed by Alana Sheriff* on April 26, 2023, during the Theme 7: Carbon Sequestration Economic Drivers session. A study evaluating multiple CCS networks in the Central United States to better understand the benefits and challenges faced by different CO_2 source types when capturing, transporting and storing their CO_2 will also be presented by Sheriff on April 26, 2023, during the Theme 8: Infrastructure I session. NETL-developed models and resources were used to estimate overall CCS costs (in dollars per metric ton) using a modular approach for various source types (with annual CO_2 capture rates ranging from 0.12-4.33 million metric tons), source locations, storage reservoirs and pipeline transportation options in three defined regional impact areas within the Central United States.
- A comparative study of commercial-scale CO_2 storage options in single and stacked saline formations in managing reservoir pressure buildup will be presented by Nur Wijaya* on April 27, 2023, during the Theme 3: Advances in CO_2 Storage Modeling session. The study quantitatively investigates the implications on the subsurface reservoir pressure buildup and interference of multi-well, multi-zone CO_2 injection operations located in proximity.
- A study on CO_2 geologic storage and utilization's potential role in supporting an energy transition for the Intermountain West (I-WEST) region to carbon neutrality by 2050 will be presented by Bailian Chen (Los Alamos National Laboratory) on April 27, 2023, during the Theme 6: Regional to Site Specific Studies session. Co-authored by SSAE researchers Derek Vikara*, Taylor Vactor*, Travis Warner*, Scott Matthews*, David Morgan, Allison Guinan*, Michael Marquis* and Luciane Cunha, this study addresses topics such as CCS opportunities, technical and nontechnical insights to help mitigate risk and perceived risk, techno-economic assessment of regional geologic storage options and next steps to help facilitate storage and utilization deployment in the I-WEST region.

PARETO Highlighted at Recent Meeting

"Project PARETO" —DOE's produced water optimization initiative—recently held its stakeholder board meeting in Houston, Texas, where it was co-located with the Produced Water Society's Annual Conference, a premier event on O&G produced water management and treatment. The board meeting attracted nearly 30 stakeholders from across the produced water community. Represented organizations included ExxonMobil, ConocoPhillips, Chevron, Select Energy, Aris Water, XRI Midstream, Environmental Defense Fund, New Mexico Produced Water Research Consortium, Texas Produced Water Research Consortium, Produced Water Society and others.

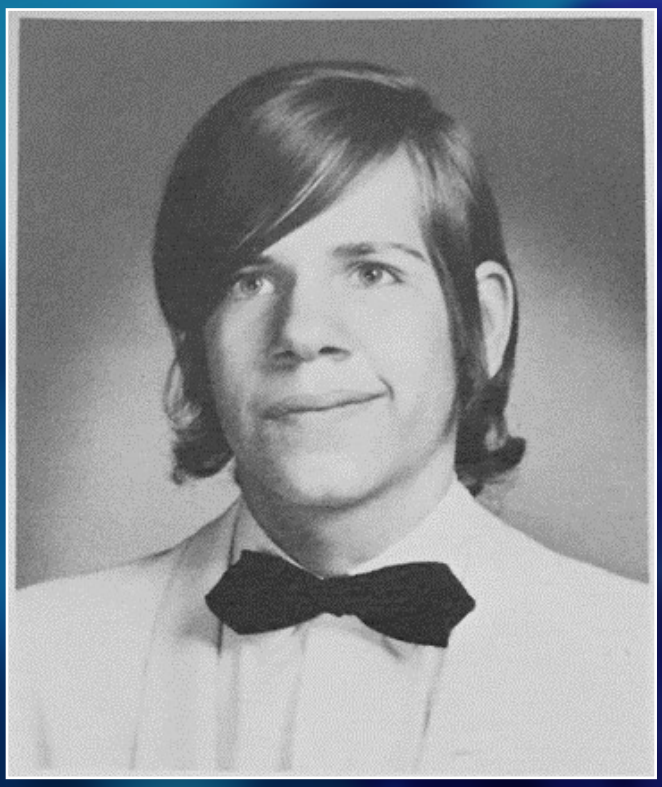
The meeting involved a hands-on PARETO workshop which gave stakeholders the opportunity to experience the PARETO software and its new graphical user interface "live and in color" without having to touch a single line of code. The PARETO team prepared a series of realistic scenarios for individuals to analyze. PARETO—including its graphical user interface, supporting documentation and representative examples—can be downloaded free as open source software.

The PARETO workshop was followed by an open discussion with the board on "PARETO & Beneficial Reuse" to answer the question of how DOE's framework can facilitate the beneficial reuse of produced water in the future. Every attendee had the opportunity to anonymously provide their thoughts on selected questions resulting in the project team having an extensive collection of leads on how it can support the broader community in making beneficial reuse become a reality.

In addition to the stakeholder board meeting, the PARETO team gave three presentations at the Produced Water Society conference: 1) PARETO Updates & Features, 2) PARETO Collaboration with Aris Water and 3) PARETO for REE/CM Recovery.

Want to learn more about SSAE's work?

Click here to see previous SSAE newsletter issues



In Tribute

Dr. Charles “Chuck” W. White unexpectedly passed away in March 2023. Chuck was a long-time NETL site support contractor, his tenure beginning in 1992. Over the past 30 years, Chuck performed techno-economic analyses on energy systems that reflected the changing nature of research priorities over time. Technologies modeled by Chuck included gasification-based processes for power and fuels production, including Fischer-Tropsch syntheses; direct power extraction (magnetohydrodynamics to old-timers); substitute natural gas synthesis reactors; chemical looping systems; monoethanolamine-based CO_2 capture systems; coal and natural gas to hydrogen processes with CO_2 capture; and sCO_2 power cycles—to name a few. Chuck performed foundational work in the area of sCO_2 power cycles, including an extensive analysis of thermophysical properties, particularly near the critical point. Chuck authored or co-authored over 70 publications during his career. After receiving his Ph.D. in Chemical Engineering in 1983 from WVU, Chuck spent the next three years at the same university as an Assistant Professor. Feeling the need for a career change, Chuck entered medical school and received his M.D. degree in 1990 also from WVU. After a two-year residency in internal medicine, Chuck decided to return to his chemical engineering roots, beginning his 30-year collaboration with NETL. Chuck was a consummate professional who took great pride in his work and his invaluable contributions to the lab will be long remembered. He will be greatly missed by friends and colleagues, who will never forget the gentle, humble spirit of a gracious man.

// PERSPECTIVES

United States Maintains Energy Exports Position

The United States became a net total energy exporter (exports are greater than imports) in 2019 for the first time since 1952 and has since, maintained that position. With abundant supplies of petroleum, natural gas and coal, the United States is a world leader in energy exports. This was not always the case. In the 2000s, the United States was proposing to build out its liquified natural gas (LNG) import terminals. Beginning in the 1970s, exports of crude oil were illegal without a permit. Small amounts of oil were exported only to Canada. The ban was repealed in 2015.[1] Now, the United States is exporting more energy than it imports.

Figure 1 shows the last 11 years of U.S. energy exports. Since fossil energy makes up over 98% of the total energy export, current petroleum, natural gas and coal exports will be briefly discussed.

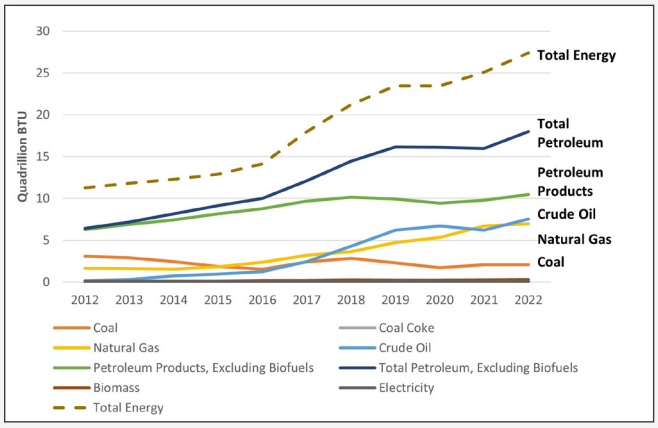


Figure 1. U.S. energy exports[2]

U.S. Petroleum Exports

The majority of U.S. total petroleum exports are petroleum liquids and refined petroleum products. In 2022, the United States exported about 9.6 MMbbl/d and imported about 8.32 MMbbl/d of petroleum, making the United States an annual total petroleum net exporter for the third year in a row for the first time since at least 1949. Figure 2 shows the top ten countries U.S. petroleum is exported.

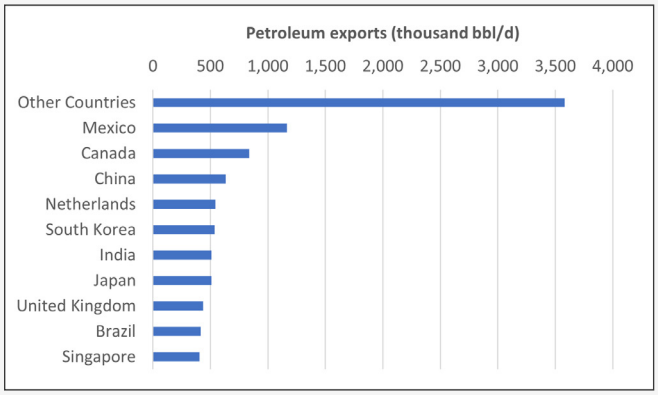


Figure 2. 2022 U.S. petroleum exports by importing country[2]

U.S. Natural Gas Exports

U.S. natural gas exports reached a record high in 2022, with exports reaching 6,892 Bcf.[2] Until 2000, the United States exported relatively small volumes of natural gas and mostly by pipeline to Mexico and Canada. Total U.S. annual natural gas exports generally increased each year from 2000 through 2022 as increases in U.S. natural gas supply from unconventional resources contributed to lower natural gas prices and the competitiveness of U.S. natural gas in international markets.[3] In 2020, the United States exported almost 2,400 Bcf of natural gas in the form of LNG in large LNG tanker ships, along with a small quantity shipped by container or in trucks.[4] Figure 3 shows the top 12 countries U.S. natural gas is exported.

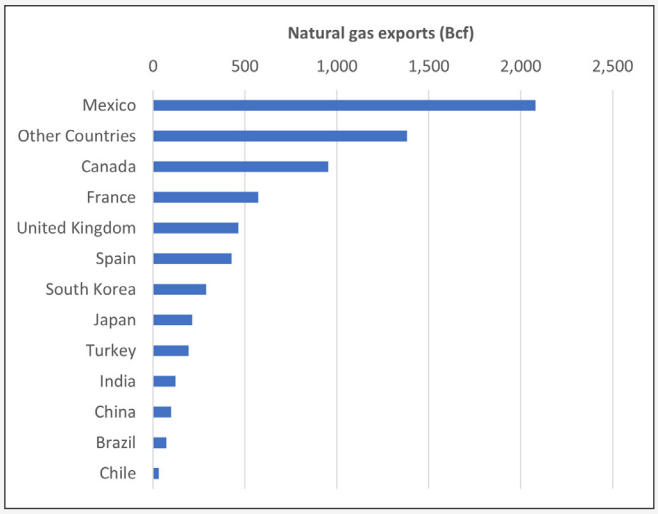


Figure 3. 2022 U.S. Natural gas exports by importing country[2]

U.S. Coal Exports

U.S. coal exports reached a record high of 125.7 million short tons (MMst) in 2012, equal to 12% of U.S. coal production.[2] In 2022, the United States exported about 84.8 MMst of coal—equal to about 14% of U.S. coal production. Figure 4 shows the tons of coal exported to the various continents in 2022 for quarters 1 through 3 (Q1 – Q3). Figure 5 lists the top 20 exports by country in 2022 Q1-Q3. – Contributed by Erik Shuster

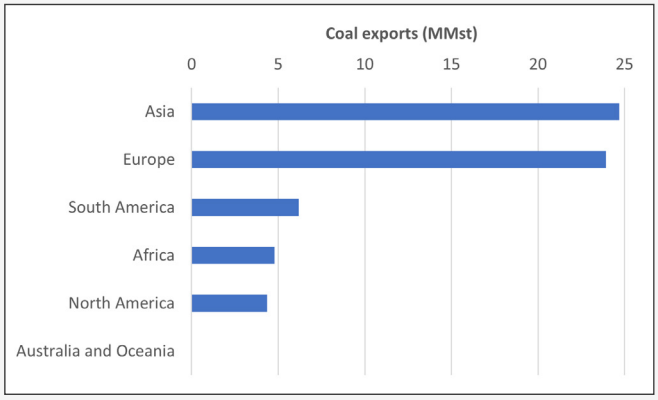


Figure 4. Coal exports by importing continent (2022 Q1-Q3)[5]

// PERSPECTIVES (cont'd)

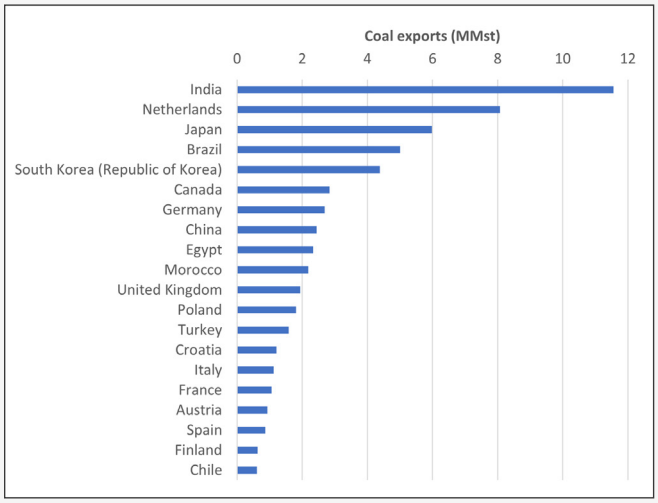


Figure 5. Top 20 U.S. coal exports by importing country (2022 Q1-Q3)[5]

References

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[2] EIA, "Monthly Energy Review," March 2023, Accessed: March 29, 2023.

[3] EIA, "Natural Gas Explained, Natural gas imports and exports," December 16, 2022, Accessed: March 29 2023.

[4] DOE FECM, "Liquefied Natural Gas (LNG)," Accessed: March 29, 2023.

[5] EIA, "Quarterly Coal Report, July - September 2022, Table 7. U.S. coal exports (short tons)," January 2023, Accessed: April 5, 2023.

// UPCOMING CONFERENCES AND EVENTS

SSAE federal staff and NETL support contractor personnel will attend or present at the following conferences and events in April 2023:

- 2023 Laufer Energy Symposium
  Presenter: Kyle Buchheit* – Techno-Economic Analysis of an SOFC Hybrid Carbon Conversion Concept
  St. Louis, Missouri, March 30–April 1, 2023
- Net Zero World Chile Technical Implementation and Capacity Building Workshop
  Presenter: Erik Shuster – Best Practices and Lessons Learned for Coal-Fired Plant Repurposing Plans
  Santiago, Antofagasta and Tocopilla, Chile, April 3–6, 2023
- IEAGHG CCS Cost Network Workshop
  Participant: Timothy Fout
  Groningen, Netherlands, April 10–15, 2023
- NERC Reliability Assessment Subcommittee Meeting
  Participant: John Brewer
  Hybrid (Virtual and Austin, TX), April 11–12, 2023
- 2023 FECM Spring R&D Project Review Meeting
  Presenters: Anthony Burgard – IDAES-Core, Eric Grol – Emissions Control and Gregory Hackett – Status Update of NETL Techno-Economic Analysis of Solid Oxide Cells
  Participants: Eric Lewis, Benjamin Omell and Stephen Zitney
  Pittsburgh, PA, April 18–20, 2023
- 2023 IEEE-IAS/PCA Cement Conference
  Participant: Eric Grol
  Dallas, TX, April 23–27, 2023
- MMTA International Minor Metals Conference 2023
  Participant: Alison Fritz
  Charlotte, NC, April 24–26, 2023
- CCUS 2023
  Presenters: Alana Sheriff* – 1) Techno-Economic Models are Instrumental in Analyzing Decarbonization Strategies and 2) Comparative Economic Analysis of Capture, Transport, and Storage from a CO_2 Source Perspective and Nur Wijaya* – Comparative Study of Commercial-Scale CO_2 Storage Options in Single and Stacked Saline Formations in Managing Reservoir Pressure Buildup
  Houston, TX, April 25–27, 2023

* NETL Support Contractor

// RECENT PUBLICATIONS

Articles

- E. Myshakin, N. Garapati, Y. Seol, X. Gai, R. Boswell, S. Ohtsuki, K. Kumagai, M. Sato, K. Suzuki and N. Okinaka, "Numerical Simulations of Depressurization-Induced Gas Hydrate Reservoir (B1 Sand) Response at the Prudhoe Bay Unit Kuparuk 7-11-12 Pad on the Alaska North Slope," *Energy & Fuels*, vol. 36, no. 5, pp. 2542-2560, March 3, 2022.
- J. Yoneda, K. Suzuki, Y. Jin, S. Ohtsuki, T. Collett, R. Boswell, Y. Maehara and N. Okinaka, "Permeability Measurement and Prediction with Nuclear Magnetic Resonance Analysis of Gas Hydrate-Bearing Sediments Recovered from Alaska North Slope 2018 Hydrate-01 Stratigraphic Test Well," *Energy & Fuels*, vol. 36, no. 5, pp. 2515-2529, March 3, 2022.
- T. Collett, M. Zyrianova, N. Okinaka, M. Wakatsuki, R. Boswell, S. Marsteller, D. Minge, S. Crumley, D. Itter, R. Hunter, A. Garcia-Ceballos and G. Jin, "Planning and Operations of the Hydrate 01 Stratigraphic Test Well, Prudhoe Bay Unit, Alaska North Slope," *Energy & Fuels*, vol. 36, no. 6, pp. 3016-3039, March 17, 2022.
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- P. Flemings, A. Cook , T. Collett and R. Boswell, "Gas hydrates in Green Canyon Block 955, deep-water Gulf of Mexico: Part II, Insights and future challenges", *AAPG Bulletin*, vol. 106, no. 5, pp. 937-947, May 2022.
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Database

- National Energy Technology Laboratory, "Natural Gas Combined Cycle CO_2 Capture Retrofit Database (NGCC CCRD)," National Energy Technology Laboratory, Pittsburgh, PA, March 2023.

Reports/Supporting Documentation

- S. Smith and M. Giampetro, "'Best' Coal-Fired Power Plant and Cogeneration Case Studies," U.S. Department of Energy, National Energy Technology Laboratory, for Asia-Pacific Economic Cooperation, Pittsburgh, PA, December 2022.
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Conference Proceedings and Events

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- E. Hedrick, K. Hedrick, D. Bhattacharayya, S. Zitney and B. Omell, "Integrating Reinforcement Learning with Model Predictive Control for Adaptive Control of Energy Systems," presentation at the 46th International Technical Conference on Clean Energy – The Clearwater Clean Energy Conference, Hybrid (Virtual and Clearwater, FL), August 1–4, 2022.
- M. Bynum, B. Ammari, I. Grossmann, T. Kim, C. Laird, J. Pulsipher, J. Siirola and S. Zitney, "Software and Advanced Solution Methods for Flexibility Analysis," presentation at the 2022 AIChE Annual Meeting, Phoenix, AZ, November 13–18, 2022.
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- E. Hedrick, K. Hedrick, D. Bhattacharyya, S. Zitney and B. Omell, "Offset-Free Control Using Deep Deterministic Policy Gradient Reinforcement Learning Algorithm," presentation at the 2022 AIChE Annual Meeting, Phoenix, AZ, November 16, 2022.

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- K. Hedrick, E. Hedrick, B. Omell, S. Zitney and D. Bhattacharyya, "Development of a Health Monitoring Framework Under Uncertainty for Supercritical Coal Power Plants Considering Material and Operational Uncertainties," presentation at the 2022 AIChE Annual Meeting, Phoenix, AZ, November 16, 2022.
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- J. Pulsipher, D. Ovalle Varela, M. Zamarripa, M. Drouven and C. Laird, "A Decision-Making Framework to Evaluate Opportunities for Recovery of Rare Earth Elements and Critical Minerals in Produced Water Networks," presentation at the Produced Water Society Annual Seminar 2023, Hybrid (Virtual and Houston, TX), February 7, 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

FECM/NETL Unconventional Shale Well Economic Model

Life Cycle Analysis Models

NETL CO2U LCA Guidance Toolkit

NETL UPGrants LCA Guidance 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

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