PECMC
INTERNATIONAL
Pittsburgh Energy and Carbon Management Conference

Forty-Third Annual International Pittsburgh Energy and Carbon Management Conference

University of Pittsburgh · Swanson School of Engineering

ABSTRACTS BOOKLET

Clean Energy Transformation and Carbon Management for a Sustainable Future

October 28-30, 2026

Virtual Conference via Zoom



Hosted by:

University of Pittsburgh

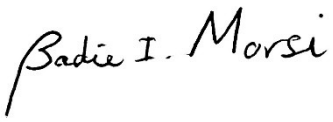
A NOTE TO THE READER

This Abstracts Booklet is prepared solely as a convenient reference for the Conference participants. Abstracts are arranged in time order of the oral sessions as published in the Final Conference Program. Abstracts are organized by session and follow the order of timeline of presentation as given in the Final Conference Program. To locate a specific item, please refer to the session title, time block, presentation title, and presenting author.

It should be cautioned that this Abstracts Booklet is prepared based on the original abstracts that were submitted unless the author noted an abstract change. The contents of the Booklet do not reflect late changes made by the authors for their presentations at the Conference. The reader should consult the Final Conference Program for any such changes. The 2026 conference proceedings will be published online after the Conference.

On behalf of the Forty-Third Annual International Pittsburgh Energy and Carbon Management Conference, I wish to express my sincere appreciation and gratitude to Ms. Rebecca Bauroth for her guidance of the entire conference. My profound gratefulness goes to Dr. Rui Wang for his crucial assistance and dedication in preparing this Abstracts Booklet and the Final Conference Program.

Thank you,



Badie I. Morsi, Editor
Professor and Executive Director of the Conference

Copyright © 2026 Pittsburgh Energy and Carbon Management Conference

TABLE OF CONTENTS

ORAL SESSIONS	PAGE
1. CLEAN COAL AND GAS TO FUELS	1
2. GASIFICATION, VALUE-ADDED COAL PRODUCTS AND COAL SCIENCE	2
3. COAL SCIENCE, CRITICAL MINERALS AND SUSTAINABILITY	7
4. CLEAN FUELS, CLEAN HYDROGEN AND COMBUSTION TECHNOLOGIES	10
5. CARBON CAPTURE, UTILIZATION AND STORAGE	11
6. CARBON STORAGE, COAL BED METHANE AND SHALE GAS	13
7. COAL SCIENCE, CLEAN FUELS AND VALUE-ADDED COAL PRODUCTS	15
8. GAS UTILIZATION, COMBUSTION TECHNOLOGIES, AI AND DIGITAL TWIN	17
9. COAL BED METHANE, SHALE GAS AND CARBON MANAGEMENT	20

WEDNESDAY, OCTOBER 28, 2026 — U.S. EASTERN DAYLIGHT TIME

SESSION 1 (10:30 – 11:50)
CLEAN COAL AND GAS TO FUELS

10:30 Polar-Nonpolar Synergistic Incorporation to Promote Removal of Trace Nitrogen-Containing Compounds from Model Fuels

Yingli Pei, Ph.D. student, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan 030024, China. E-mail address: 2024310179@tyut.edu.cn

[*]Cuiping Ye, Professor, College of Environment and Ecology, Taiyuan University of Technology, Jinzhong 030600, China. E-mail address: yecuiping@tyut.edu.cn

Jieying Jing, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan 030024, China. E-mail address: jingjieying@tyut.edu.cn

Wen-Ying Li, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan 030024, China. E-mail address: ying@tyut.edu.cn

[*]Corresponding author.

The refined oil obtained from coal tar hydrofining is used for the production of high-density fuel via isomerization. However, the trace nitrogen-containing compounds (NCCs) can significantly inhibit catalytic activity, making denitrogenation crucial. Adsorptive separation offers the advantages of mild operating conditions and low energy consumption, while the strong interactions gradually intensify pore blockage and slow down diffusion rate, whereas weak interactions result in poor selectivity. This work employs a defect engineering strategy to tune the polar sites of the metal-organic frameworks using ethanolamine (EA) to improve the separation performance for nitrogen-containing compounds from model fuel. The elemental analysis, electron paramagnetic resonance, and Zeta potential measurements indicate a good correlation between defects and polarity. By controlling the contents of EA, a polar material (Al-PTA-EA-0.6) with smaller particle size and the highest defect concentration is obtained. Al-PTA-EA-0.6 exhibits adsorption capacities of 319.63 $mg \cdot g^{-1}$ quinoline and 314.67 $mg \cdot g^{-1}$ for indole within 10 min, respectively. Thermogravimetry-mass spectrometry (TG-MS) shows that it effectively resists the competitive adsorption of tetralin. Theoretical calculations elucidate that a synergistic adsorption mechanism involving nonpolar van der Waals interactions (H···C 51.5%, H···H 28.5%) and polar hydrogen bonding interactions (H···N and O···H 14.8% in total), where the former acts as the primary driving force and the latter as an auxiliary, and achieve efficient adsorption. Furthermore, the good regeneration performance and stability of Al-PTA-EA-0.6 confirms its potential for practical applications. This work provides a promising solution for preventing neutral oil entrainment duiring adsorptive removal of nitrogen-containing compounds.

Keywords: Polar-Nonpolar, Adsorptive Removal, Denitrogenation, Metal-organic frameworks

10:50 Electronic Structure Modulation of NiAl2O4 Catalysts via Reduction Atmosphere Tuning for Efficient Phenanthrene Hydrogenation

Dongxu Zhao, Master, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA
Email: 2024521080@link.tyut.edu.cn, Phone:+86 19591530914, Fax:+86-351-6018453

Jieying Jing, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA*
Email: jingjieying@tyut.edu.cn, Phone:+86 13453162208, Fax:+86-351-6018453

Polycyclic aromatic hydrocarbons (PAHs) in coal tar can be valorized through selective hydrogenation into high-value chemicals. However, catalyst design strategies that go beyond geometric effects to exploit electronic modulation remain underexplored. Herein, using phenanthrene as a model tricyclic PAH, we investigate how the reduction atmosphere can be leveraged to tailor the electronic properties of $NiAl_2O_4$ spinel catalysts without altering their geometric structure.A series of $NiAl_2O_4$ catalysts with uniform particle size and Ni dispersion was synthesized by systematically varying the H_2 partial pressure (H_2/N_2 ratio) during reduction. XRD, TEM, and CO-pulse chemisorption confirmed that the Ni particle size remained constant at ~5 nm across the series, ruling out geometric effects. XPS revealed a progressive negative shift in the Ni $2p_{3/2}$ binding energy with decreasing H_2 partial pressure; $NiAl_2O_4$-4/6 (reduced under H_2/N_2 = 4:6) exhibited a binding energy of 851.7 eV, 0.9 eV lower than that of $NiAl_2O_4$-10/0 (reduced under pure H_2, 852.6 eV), indicating substantially enhanced electron density on Ni. Under optimized conditions (300 °C, 5 MPa H_2, WHSV = 52 h^{-1}), $NiAl_2O_4$-4/6 achieved a perhydrophenanthrene yield of 94.26%, markedly surpassing the 84.03% obtained with $NiAl_2O_4$-10/0. Notably, at a high WHSV of 1040 h^{-1}, the initial conversion of $NiAl_2O_4$-4/6 remained at 40%, twice that of $NiAl_2O_4$-10/0 (~20%). H_2-TPD and TG-MS analyses indicated that the electron-rich $NiAl_2O_4$-4/6 provides moderate adsorption strength for both H_2 and phenanthrene, facilitating an optimal balance between substrate activation and product desorption.

Keywords: Coal tar; Phenanthrene hydrogenation; $NiAl_2O_4$ catalyst; Electronic structure modulation; Uniform particle size.

11:10 Enhanced catalytic hydrogenation of 1-methylnaphthalene over CeO_2-modified $NiAl_2O_4$ spinel catalyst

Haoye Qi, Master, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA
Email: 2024521016@link.tyut.edu.cn, Phone:+86 13383571502, Fax:+86-351-6018453

Jieying Jing, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA*
Email: jingjieying@tyut.edu.cn, Phone:+86 13453162208, Fax:+86-351-6018453

The catalytic hydrogenation of polycyclic aromatic hydrocarbons (PAHs) in coal tar to produce high-energy-density fuels is a key route for the clean and efficient utilization of coal resources. The electron-deficient state of the active metallic nickel is significantly intensified by the strong charge transfer induced by the robust adsorption of -H in 1-methylnaphthalene. This electronic structure destabilization of the catalytic active sites macroscopically suppresses the deep hydrogenation of polycyclic aromatic hydrocarbons. In this work, we report on the performance of mechanically mixed CeO_2 and $NiAl_2O_4$ catalysts for the hydro-saturation of 1-methylnaphthalene (1-MN). The nickel-aluminum spinel precursor was synthesized via a sol-gel method and subsequently modified through mechanical mixing with CeO_2, Based on the cerium-to-nickel ratio, the doping amount of cerium oxide is categorized into five distinct levels: 0, 0.1, 0.125, 0.15, and 0.175. Under optimized conditions (260 °C, 5 MPa H_2, 3 h, 1.0 wt% 1-MN in cyclohexane), the 0.125-CeO_2-modified catalyst afforded a 1-MN conversion of 95.52% and a 1-methyldecalin yield of 77.00%, markedly outperforming the pristine $NiAl_2O_4$

catalyst (94.53% and 55.62%, respectively). X-ray photoelectron spectroscopy (XPS) of fresh and spent catalysts reveals that the enhanced activity originates from the exceptional electron-transfer capability of CeO_2, which maintains metallic Ni in a moderately electron-deficient state, thus favoring the adsorption and activation of 1-MN. Furthermore, H_2 temperature-programmed desorption (H_2-TPD) profiles demonstrate that the modified catalyst possesses a superior capacity for H_2 adsorption and dissociation, promoting the generation of active hydrogen species and thereby accelerating the overall hydrogenation process.

Keywords: Catalytic hydrogenation; 1-methylnaphthalene; nickel-aluminum spinel; electron-transfer.

11:30 Tunable Microstructure of Nano Iron-Based Catalysts for Efficient Direct Coal Liquefaction and Heavy Oil Upgrading

Xinwen Zhang, Graduate Student, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, Shanxi, China
zhangxinwen1141@tuyt.edu.cn,
+86 18404901361,
+86 351 6010482
Xingbao Wang,Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, Shanxi, China
wangxingbao@tyut.edu.cn
+86 15698308577
+86 351 6010482
(Gaixia Shi,Master Graduate, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, Shanxi, China)
sgx20000611@163.com
+86 18835946119
+86 351 6010482

Direct coal liquefaction (DCL) is a critical technical route to secure domestic oil supply in China. Commercial Shenhua DCL unit still faces two prominent bottlenecks: insufficient macromolecular cracking and hydrogenation activity of conventional iron catalysts, and low light oil yield caused by highly condensed asphaltene-rich atmospheric tower heavy oil accumulated during operation. This work proposes a crystal regulation strategy to fabricate coal-supported nano iron-based catalysts with optimized microstructural features.

Controllable nucleation and crystal growth of γ-FeOOH precursors are realized via microstructure tuning, which weakens preferred c-axis growth and enriches high-index (410) facets abundant with coordinatively unsaturated hydroxyl active sites. Characterizations including HRTEM, XPS and XRD confirm that the optimized catalyst exhibits minimum particle size, uniform dispersion and maximized sulfided Fe_{1-x} active phases after pre-sulfurization. DCL evaluations with mixed medium/high-temperature circulating solvents demonstrate that the regulated catalyst greatly accelerates cleavage of coal C–O bridge bonds, suppresses radical repolymerization, and raises coal conversion and oil yield distinctly.

Further upgrading experiments on atmospheric tower heavy oil reveal that supplementary addition of tuned iron catalyst at optimal dosage promotes deep hydrocracking of condensed asphaltenes. Excessive catalyst addition leads to particle agglomeration and side reactions, reducing light fraction output. This structural modulation approach provides a facile strategy to boost the catalytic performance of iron species for both raw coal liquefaction and heavy distillate hydro-upgrading, offering technical guidance for improving overall oil recovery of industrial DCL processes.

SESSION 2 (12:50 – 14:10)
GASIFICATION, VALUE-ADDED COAL PRODUCTS AND COAL SCIENCE

12:50 Pioneering New Pathway of Chemical Energy Utilization in the Coal Industry — An Executive Summary of 18 Years of Technology Strategy Research by an Independent Private Energy Technology Company Addressing Global Climate Change in the Coal Energy Industry

Changdong Zhang, CEPIU & SDUET, 242 Shanda Road, Jinan, Shandong, China; cepiu6868@163.com, +86-13905313555

August 10, 2026

Keywords: Coal energy industry; chemical-energy-led utilization; addressing the root causes of greenhouse-gas formation; new approach in production-process design; wave-bed coal gasification.

Abstract and Background

SDUET&CEPIU (hereinafter SD&CE) is a self-funded private research and technology company established by Chinese and international experts in science, economics, and engineering. Its primary focus is developing technology strategies for transforming the coal energy industry and addressing climate change. SD&CE was legally registered in Mainland China in 2007 and Hong Kong, China, in 2009.

SD&CE proposes a new approach to process-structure design that would transform coal-based energy production from its current emphasis on physical-heat utilization to one led by chemical-energy utilization. By addressing the causes of greenhouse-gas formation at the source of the industrial chain and upgrading production equipment, this approach seeks to convert climate-harming energy into useful energy for producing new energy sources and advanced materials. It aims to achieve the dual benefits of climate mitigation and industrial transformation.

Through sharing incremental industrial revenues, this approach could help bridge strategic differences between developed and emerging economies in addressing climate change, turning competition over interests into mutually beneficial cooperation. It also aims to achieve, five years ahead of schedule, the global greenhouse-gas reduction target of 20 billion tonnes by 2050 referenced in the Paris climate agenda and the “Nicholas Stern Review”.

In 2008, SD&CE initiated international energy-efficiency and emissions-reduction joint-venture projects involving three coal-fired combined heat and power plants in northern China. It completed feasibility studies, environmental-impact assessments, and a national energy-efficiency assessment. The partners initially planned to introduce the then-leading IGCC technology—Integrated Gasification Combined Cycle.

However, the 2008 financial crisis disrupted project financing. In 2009, several major international IGCC projects were suspended or shut down because high coal-gasification operating costs undermined their commercial prospects. Despite the loss of direction in global climate-change technology strategies and the difficulties faced by small and medium-sized innovators, SD&CE has persevered through 18 years of challenging development.

Based on extensive production-practice investigations and in-depth research, SD&CE has developed the following strategic ideas and action proposals for addressing global climate change, presented for consideration by leaders of the Parties, international organizations, relevant experts, and industry professionals.

1. The Overlooked Risk of Direct Coal Combustion

Extensive production experience indicates that direct coal combustion primarily utilizes coal’s physical heat. Approximately 15%–30% of its chemical energy is converted during the process into greenhouse-gas-related waste streams, including waste gas, wastewater, and solid residues.

SD&CE considers this a major process-technology risk overlooked by governments, administrative bodies, and relevant professionals worldwide. It is also regarded as a root cause of greenhouse-gas generation and a primary contributor to global climate change.

2. Refocusing Climate-Change Strategies

Over the past three decades, United Nations climate conferences have largely emphasized reducing the scale of coal-based energy production. In SD&CE's view, this has diverted attention from the primary objective of controlling greenhouse-gas emissions and overlooked the potential for technological progress in the coal energy industry to address their formation.

This situation should be corrected promptly. Countries should break down technological monopolies, encourage innovation through diverse channels, and use market competition and industrial practice to address greenhouse-gas generation and climate change.

3. Wave-Bed Coal-Gasification Technology

Based on extensive market research and analysis, SD&CE has developed the world's first industrial wave-bed rotary coal-gasification system: the L-Shaped Horizontal Rotary Wave-Bed Coal-Gasification Process and System.

After a three-year formal opposition procedure and four rounds of international technical defense involving experts from the United Kingdom, Germany, and Italy, the technology was granted an invention patent. It has been presented at nine international professional conferences, received favorable evaluations, and won three international awards.

SD&CE regards this technology as the third major converter-technology revolution in industrial history, following those in the steel and cement industries. It provides new pathways through innovative process design, new production equipment, intelligent operation, and carbon-emissions control and monitoring, offering economically viable solutions for addressing climate change.

This report presents 30 years of research and analysis on the climate-change challenges facing the international community. While recognizing coal energy's historic contribution to the Industrial Revolution, particularly the development of the steam-engine industry, it identifies a fundamental structural deficiency in coal production: the long-term discharge of waste gas and solid residues. With the expansion of production over the past century, this deficiency has become a root cause of the disruption of global climate and ecological balance. The report proposes a new pathway for transforming the coal energy industry from physical-heat-led utilization to chemical-energy-led utilization. It highlights the historical necessity of commercializing innovative technologies while addressing the deficiencies of the traditional coal industry. The report identifies the causes of the current global climate crisis and demonstrates the feasibility and promising prospects of a new production system that addresses the causes of greenhouse-gas formation within the production process itself.

The report presents the scientific principles and economic advantages of wave-bed rotary coal-gasification technology, together with the principal findings of research papers from SD&CE's three-stage, 18-year technology program. It explains the substantial development potential and potential trillion-dollar market growth associated with chemical-energy-led utilization. Compared with other forms of new-energy development, the commercial deployment of wave-bed rotary coal-gasification technology offers distinctive advantages, including the comprehensive utilization of coal resources, zero-emission operation, and the simultaneous production of multiple types of new energy and advanced materials, creating multiplied economic benefits.

The report calls on the international community, under the leadership of the United Nations and its intergovernmental organizations, to restore global leadership in scientific and industrial innovation and uphold the consensus of the United Nations Framework Convention on Climate Change. It urges scientists and entrepreneurs to foster an open and transparent technology market, establish an International Cooperation Fund for Scientific Production, and develop open investment and financing mechanisms to support innovative climate solutions.

These efforts would promote new business models based on international climate cooperation, encourage collaboration and mutual support among enterprises worldwide, and accelerate the transformation and upgrading of the global coal energy industry.

The report is organized into four main topics (see the Appendix for details):

Research and Analysis of the Failure of Climate-Change Technology Strategies over the Past Three Decades

Transformation and Development of Technology Strategies for the Coal Energy Industry to Address Climate Change

Research and Development of Wave-Bed Rotary Coal-Gasification Technology

The Broad Prospects of a New Chemical-Energy-Led Pathway for the Coal Energy Industry

Conclusion

1. Overcoming Climate Challenges: A Major Opportunity for Technological Breakthroughs in the Global Coal Energy Industry

From a broad perspective suited to the new era, the global effort to overcome climate challenges should not be viewed merely as a passive crisis or pressure. It can instead be understood as a vast opportunity to develop resources and energy, a once-in-a-generation opportunity for technological innovation and entrepreneurship, and a major test of international cooperation and infrastructure.

According to our commercialization plan for wave-bed coal-gasification technology, an additional US$60 million in industrialization funding—building on the technological achievements already attained—would enable the construction and trial operation of three first-of-a-kind demonstration projects in different countries, each capable of processing 1.2 million tonnes of coal annually, using coal resources of different qualities.

Through technology-sharing partnerships and subsequent large-scale market deployment, these projects could drive the global coal energy industry toward chemical-energy-led utilization. By increasing the production of new energy and advanced materials, this pathway could also contribute to achieving the global CO_2 emissions-control target for 2050.

2. Building Global Consensus on Climate Action

We sincerely invite colleagues from the global scientific, technology, industrial, and financial communities to build consensus through dialogue and debate, and to form a strong alliance for industrial cooperation on climate action.

Together, we propose establishing an International Cooperation Fund for Scientific Production to share the multiplied benefits of technological progress. Guided by the principles of the United Nations Framework Convention on Climate Change, the initiative seeks to rebuild international consensus based on contractual integrity, mutual trust, assistance, and shared benefit.

Through coordinated action, we aim to achieve the Paris climate agenda's Nicholas Stern Review target of reducing global CO_2 emissions by 20 billion tonnes.

Appendix: Main Contents of the Report

I. Research and Analysis of the Failure of Climate-Change Technology Strategies over the Past Three Decades

The coal energy industry must undergo a transformation in production-process structure—from physical-heat-led utilization to chemical-energy-led utilization.

For more than a century, physical-heat-led coal utilization has delivered major benefits, but direct coal combustion has also left unresolved problems, including flue-gas pollution and uncontrolled conversion of chemical energy into greenhouse-gas emissions. These causes should be addressed through chemical-energy utilization and innovative process design.

The report argues that a ten-year window for transformation has already been missed and calls for an urgent global consensus on chemical-energy-led industrial development. This transition could address greenhouse-gas formation at the source of the industrial chain while creating major commercial opportunities.

The steam-driven Industrial Revolution represented a transition to physical-heat-led production. The report identifies greenhouse-gas emissions as a structural deficiency of production processes based on fossil-fuel combustion. Addressing climate challenges requires identifying, controlling, and utilizing relevant chemical phenomena through reforms in coal chemical-energy utilization and production-process structures. It should therefore be treated as a scientific, technological, and economic issue—not solely as an administrative matter of intergovernmental moral responsibility.

II. Transformation and Development of Coal-Energy Technology Strategies for Addressing Climate Change

Accurately Identifying the Causes of Climate Challenges

Past climate conferences have focused excessively on responsibility and interests, elevating technical problems within enterprise-level production

processes into complex disputes among national governments over responsibility, authority, and interests. Problems of process structure and chemical phenomena have consequently evolved into geopolitical issues in multilateral cooperation.

A clear understanding of the principal causes of climate challenges can help identify effective technological solutions, build global consensus on climate strategies, and strengthen leadership in scientific production.

Focusing on Solutions at the Source of the Industrial Chain

Industrial chains are divergent structures. If greenhouse-gas formation cannot be addressed at their source, reducing emissions only at downstream production stages cannot achieve overall emissions control across the industrial system.

Production activities anywhere on Earth affect the global atmospheric environment. All Parties should therefore act under the principles of the United Nations Framework Convention on Climate Change, build shared leadership, and promote open and transparent competition.

Establishing Global Cooperation and Financing Mechanisms

Large coal-gasification systems are fundamental-energy infrastructure. They involve large-scale, costly equipment, numerous components, highly technical manufacturing requirements, complex operating-control systems, and rigorous standards. International cooperation is necessary not only today but also for future production, operation, and management.

In responding to climate change, cooperation is essential. Global mechanisms for industrial technological innovation, collaboration, and investment and financing are necessary safeguards for effective climate action. Financial support enables technological innovation to drive industrial transformation, while countries may retain control over investment proportions and operating enterprises to protect their energy security.

III. Research and Development of Wave-Bed Rotary Coal-Gasification Technology

New Concepts in Process Design

The technology introduces three principal innovations:

It replaces conventional gasification designs constrained by coal particle size with a process-design approach based on the utilization of coal's multiple inherent chemical-energy components.

It replaces conventional single vertical, static furnace structures with a wave-bed rotary technology system centered on heat-exchange performance.

It replaces high-temperature, high-pressure, high-rate processes dependent on high-quality coal with intelligent processes designed for coal of differing qualities and regions, using varied temperature and pressure parameters to maximize chemical-energy utilization.

Scientific Basis and Economic Advantages

These integrated technological advances are intended to generate several economic benefits:

Increased revenue from oil, gas, and new-material products by 15%–25% through chemical-energy utilization;

Reduced high-temperature and high-pressure equipment costs by more than 30% through equipment and process-structure innovation;

Reduced operating energy consumption by more than 12% through improved heat-exchange performance;

Shortened investment payback periods from 15–20 years to 8–10 years.

IV. Broad Prospects for a Chemical-Energy-Led Pathway in the Coal Energy Industry

The transition to chemical-energy-led coal utilization offers three distinctive advantages: lower investment, faster results, and higher resource-utilization efficiency.

Addressing greenhouse-gas formation at the source of the industrial chain offers an effective means of controlling emissions.

Integrating innovative technologies into existing energy-equipment manufacturing systems enables transformation with relatively low investment and rapid results.

Bringing coal resources of different qualities into cleaner production can enable the discovery and utilization of additional scarce resources.

This transition could create a large number of high-quality projects with benefits for all participants:

Coal mining could shift from single-product coal extraction to integrated production of oil, gas, heat, power, and new materials, increasing value creation.

Coal-energy equipment manufacturing could benefit from the transition between existing and new production capacity.

Downstream industries across the coal-energy supply chain could also achieve increased benefits through expanded production and cooperation.

13:10 Coal-to-Asphalt: Project Update on Low-Carbon Footprint Asphalt from Wyoming Coal

Jeramie J. Adams, Vice President, Western Research Institute, 3474 North 3rd Street, Laramie, WY 82072, USA
jeramie.adams@uwyo.edu, Phone: (307) 721-2324
Y. Kumbargeri, D. Lesueur, C.J. Lowry, S.T. Bassham, Western Research Institute, 3474 North 3rd Street, Laramie, WY 82072, USA
jeramie.adams@uwyo.edu, Phone: 307-721-2324
L.C. Muller, M. Behrens, S. Holberg, Y. Yao, T.I. Pfeiffer, P. Behrens, M. Dudgeon, University of Wyoming - School of Energy Resources, 1000 E. University Ave. Laramie, WY 82071, USA
tpfeiff1@uwyo.edu, Phone: 720-331-0569

A coal-to-asphalt process is being developed to convert Wyoming sub-bituminous coal into asphalt binders for paving and roofing applications. The current liquefaction-based process converts approximately 70–85% of the coal feedstock into asphalt-like material and can be tailored to produce performance-graded (PG) binders for a range of climatic conditions. Preliminary analysis indicates that the process may achieve a carbon footprint approximately 80% lower than that of conventional petroleum-based asphalt production.

The technology has advanced from laboratory-scale development to larger-scale asphalt production. Recent scale-up efforts successfully produced multi-gallon quantities of material for external evaluation and commercialization activities. A PG58-40 asphalt binder, suitable for use in very cold climates has been prepared and will be discussed.

Progress has also been made toward demonstration-scale deployment. Design activities are underway for an 11-ton/day demonstration plant in Gillette, Wyoming. The facility will operate in partnership with industry stakeholders to produce asphalt for paving test sections while generating engineering, operational, economic, and performance data required for future commercialization.

Future work will focus on extensive performance testing of asphalt and roofing products, process optimization, and techno-economic and sustainability assessment. The demonstration plant will provide the quantities of asphalt binder required to validate the coal-to-asphalt concept under field-relevant conditions and support the development of commercially viable pathways for producing low-carbon, high-volume infrastructure materials from Wyoming coal.

13:30 An overview of Coal beneath federal lands — mines, reserves, and resources

Brian N. Shaffer, Supervisory Geologist, U.S. Geological Survey, Denver Federal Center, Lakewood, CO, USA
Email: bshaffer@usgs.gov
Scott A. Kinney, Physical Scientist, U.S. Geological Survey, Denver Federal Center, Lakewood, CO, USA
Email: skinney@usgs.gov

Federal lands hold a substantial endowment of coal reserves and resources for the United States. The newly published U.S. Geological Survey (USGS) Information Circular 1570 reports on coal mines on Federal lands, reported coal reserves, and available coal resources beneath Federal lands in the conterminous United States, and potential coal resources beneath Federal lands in Alaska. The information circular reports that in 2024, 34 coal mines on Federal lands produced more than 261 million short tons of coal, which represents 51.06 percent of all coal produced in the United States that year.

Wyoming has the most coal mines on Federal lands (14), followed by Colorado (6), North Dakota (4), Utah (4), Alabama (3), and Montana (3). Wyoming also produces the most coal from Federal lands, accounting for almost 72 percent of the coal mined from Federal lands. Montana and North Dakota each produce just under 10 percent of the coal mined from Federal lands. The Powder River Basin is the most productive basin or coal field within Federal lands in the United States, with 14 mines (12 in Wyoming, 2 in Montana) producing over 204 million short tons of coal in 2024. The most productive mine (in short tons of coal produced) in the United States, whether on Federal, State, or private lands, is the North Antelope Rochelle Mine, which produced almost 60 million short tons of coal in 2024 from Federal lands in Wyoming in the Powder River Basin. Coal used for electrical power generation (thermal coal) is produced by 29 of the coal mines on Federal lands, while coal used in conventional steelmaking (metallurgical coal) is produced at 3 coal mines on Federal lands. Coal used in the cement-making process is produced at one mine on Federal lands and one other mine on Federal lands is currently idled. Surface mining methods are used at 23 of the coal mines on Federal lands, while underground mining methods are used at 11. Reported reserves for the 34 coal mines are more than 4.2 billion short tons. More than 98 percent of those reported coal reserves beneath Federal lands are west of the Mississippi River. According to previous USGS coal assessment studies, most of the available coal resources beneath Federal lands in the conterminous United States are also west of the Mississippi River. There are five basins or coal fields in the Western United States that each contain available coal resources beneath Federal lands of more than 25 billion short tons. The USGS estimates that more than 355 billion short tons of available coal resources remain beneath Federal lands in the conterminous United States. Alaska also contains substantial quantities of coal resources. The USGS estimates that Alaska has at least 140 billion short tons of identified available coal resources but may ultimately have as much as 5.5 trillion short tons of coal resources.

13:50 Domestic Coal – A Precious Resource

Evan J. Granite
United States Department of Energy
Email: evan.granite@doe.gov

Coal is a precious resource, both in the United States and around the world. The United States has at least a 300-year supply of coal and generates approximately 17% of its electricity through coal combustion. Coal has greatly contributed to world prosperity, and with a little imagination, will continue to help humanity for hundreds of years. Approximately 1 Gt of coal has been mined annually in the United States from 1990-2014, but in recent years the quantity has been closer to 500 Mt per year.

Coal catalyzed the industrial revolution, domestic prosperity, and modern life, enabling reliable long-distance transportation; production of steel, electricity, and chemicals; home heating; and city lights. Currently, most of the coal produced in the United States is burned for power generation, but substantial quantities are also employed in the manufacture of steel, chemicals, activated carbons and for exports. Coal has a positive impact upon many industries, including mining, power, rail transportation, manufacturing, chemical, steel, activated carbon, and fuels.

There are challenges in the utilization of coal. Without proper precautions, underground mining can be a hazardous endeavor. Everything that is in the earth's crust is also present within coal to some extent; some of these elements can be volatilized during combustion or gasification; and the challenge is always to use abundant domestic coal for a prosperous economy and environment. Much of the recent research on coal utilization in the United States has focused upon the capture of pollutants such as acid gases, particulates, and mercury, as well as carbon dioxide, from combustion at power stations. In response to the 1973 oil embargo, early ERDA and DOE work also focused on the production of liquid fuels from coal through direct liquefaction.

DOE sponsored research has enabled the use of abundant domestic coal for a prosperous economy and environment, with near complete capture of sulfur, nitrogen and halogen containing gases, particulates, and mercury, from either combustion or gasification plants, which is an extraordinary accomplishment. In addition, the valuable elements present within coal and coal byproducts are also being targeted for capture and recovery through DOE supported work.

The DOE has supported many breakthroughs in the utilization of coal. Some of these, including Advances in Production of Abundant, Affordable, Reliable, and Secure Electricity; Pollution Control for Combustion and Gasification; Critical Materials, including Graphite; Coal Mining; Coal Preparation and Processing; Exports; and Carbon Products – Solids, Liquids, and Gases; will be briefly summarized.

Novel production, processing and utilization of coal is an exciting research area, representing a dramatic paradigm shift. The DOE Office of Coal conducts work on Mining, Processing, and Exports of Coal; Coal Conversion and Gasification; and on Coal Burning Power Plants, enabling expanded production and use of abundant domestic coal. The efforts of The Office of Coal will be briefly highlighted, and future research areas will be suggested by the author.

Acknowledgments

The author thanks Adam Wong, Sarah Forbes, Sarah Chan, Kevin Dooley, Emily Connor, Ayaka Jones, Ian Rowe, Dan Hancu, Joe Giove, Tom Sarkus, Curt Coccodrilli, John Lassek, and all his DOE colleagues, for their support and efforts. Evan is grateful that Professor S.I. Cheng from The Cooper Union, Henry Pennline from DOE, and Professor Badie Morsi from the University of Pittsburgh started him on his coal journey. Dick Winschel (Consol) provided information on the DOE liquefaction program and NIOSH provided historical photos of coal mining. Tom Sarkus provided slides on the Acid Rain Control Program; the Hot Carbonate Process; and Fluidized Bed Reactors.

Disclaimer

This paper was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

References – Critical Materials

1. "Resources From Abundant Domestic Wastes, Byproducts and Non-Traditional Sources", Evan J. Granite, Grant Bromhal, Jen Wilcox, Mary Anne Alvin, National Academy of Engineering, The Bridge, 53(3), 59-66, Fall 2023.
2. "Extractability indices for screening coal combustion byproduct feedstocks for recovery of rare earth elements", W. Burgess, C.F. Chiu, T. Cain, Elliot Roth, Murphy Keller, Evan Granite, International Journal of Coal Geology 281, 104401, January 2024.
3. "Leaching of Rare Earth Elements and Yttrium from a Central Appalachian Coal and the Ashes Obtained at 550-950°C", Ronghong Lin, Elliot Roth, Murphy Keller, Bret Howard, Yee Soong, Ping Wang, and Evan Granite, Journal of Rare Earths, 40(5), 807-814, May 2022.
4. "Chemistry of Trace Inorganic Elements in Coal Combustion: A Century of Discovery", Constance Senior, Evan Granite, William Linak, and Wayne Seames, Energy & Fuels, 34, 12, 15141-15168, 2020.
5. "Investigation of Thulium and other Rare Earth Element Concentrations in NIST 1632a Bituminous Coal Standard Reference Material" by Roth, Elliot; Bank, Tracy; Granite, Evan, Geostandards and Geoanalytical Research, 42(2), 263-269, June 2018.
6. "Evaluation of Rare Earth Elements and Yttrium in U.S. Coal Using the USGS COALQUAL Database Version 3.0", Ronghong Lin, Yee Soong, Evan Granite, International Journal of Coal Geology, 192, 1-13, 2018.
7. "Evaluation of Critical Elements in U.S. Coals Using the USGS COALQUAL Database Version 3.0", Ronghong Lin, Yee Soong, Evan Granite, International Journal of Coal Geology, 192, 39-50, 2018.
8. "Application of Sequential Extraction and Hydrothermal Treatment for Characterization and Enrichment of Rare Earth Elements from Coal Fly Ash", Ronghong Lin, Mengling Stuckman, Bret Howard, Yee Soong, Tracy Bank,

Christina Lopano, Elliot Roth, Megan Macala, Evan Granite, Fuel, volume 232, 124-133, 2018.
9. “Effect of Pre-Reaction Ball Milling on Kinetics of Lanthanum Phosphate Roasting with Sodium Carbonate", Ward Burgess, Murphy Keller, Jonathan Lekse, Bret Howard, Elliot Roth, Evan Granite, Industrial & Engineering Chemistry Research, 57, 6088−6096, 2018.
10. “Distribution and Speciation of Rare Earth Elements in Coal Combustion By-Products via Synchrotron Microscopy and Spectroscopy”, Mengling Stuckman, Christina Lopano, Evan Granite, International Journal of Coal Geology, 195, 125-138, 2018.
11. “Analysis of Rare Earth Elements in Coal Fly Ash Using Laser Ablation Inductively Coupled Plasma Mass Spectrometry and Scanning Electron Microscopy”, Robert L. Thompson, Tracy Bank, Scott Montross, Elliot Roth, Bret Howard, Circe Verba, and Evan Granite, Spectrochimica Acta Part B, 143, 1-11, 2018.
12. “Enrichment of Rare Earth Elements from Coal and Coal By-Products by Physical Separations”, Ronghong Lin, Tracy Bank, Bret Howard, Yee Soong, Elliot Roth, Evan Granite, Fuel, 200, 506-520, 2017.
13. “Rare Earth Elements in Alberta Oil Sand Process Streams”, Elliot Roth, Tracy Bank, Bret Howard, Evan Granite, Energy & Fuels, 31, 4714-4720, 2017.
14. “Organic and Inorganic Association of Rare Earth Elements in Coal”, Ronghong Lin, Tracy Bank, Elliot Roth, Yee Soong, Evan Granite, International Journal of Coal Geology, volume 179, 295-301, 2017.
15. “Notes on Contributions to the Science of Rare Earth Element Enrichment in Coal and Coal Combustion By-Products”, James Hower, Evan Granite, David Mayfield, Ari Lewis, Robert Finkelman, Minerals, 6, 32, 2016.
16. "Analysis of Rare Earth Elements in Geologic Samples using Inductively Coupled Plasma Mass Spectrometry", Tracy Bank, Elliot Roth, Phillip Tinker, and Evan Granite, US DOE Topical Report DOE/NETL-2016/1794, April 14, 2016
17. “Recovery of Rare Earths from Coal and By-Products - A Paradigm Shift for Coal Research”, Evan J. Granite, Elliot Roth, Mary Anne Alvin, National Academy of Engineering’s The Bridge, 46(3), 56-57, Fall 2016.
18. “Resolution of BaO Interferences on Eu Peaks in Fossil Energy Byproduct Samples Using High-Resolution Sector-Field ICP-MS”, Robert L. Thompson, Tracy Bank, Elliot Roth, and Evan Granite, Fuel, vol. 185, 94-101, December 2016.
19. Report to Congress “Recovery of Rare Earth Elements and Critical Materials from Coal and Coal Byproducts”, released May 25, 2022.
20. Department of the Interior, Geological Survey, Final 2025 List of Critical Minerals, Federal Register, November 7, 2025, https://www.govinfo.gov/content/pkg/FR-2025-11-07/pdf/2025-19813.pdf, accessed April 24, 2026.
21. “Computational Screening of Fly Ash Zeolite Sorbents for Boric Acid Removal” John Findley, Evan Granite, Eric Grol, and Jan Steckel, AIChE Journal, Volume 72, Issue 1, January 2026, https://doi.org/10.1002/aic.70065 .
22. “Machine Learning for Optimization of Zeolites for Boric Acid Sorption”, Aaron Perez, John Findley, Evan Granite, Eric Grol, and Jan Steckel, AIChE Journal, Volume 72, Issue 2, February 2026, https://doi.org/10.1002/aic.70154 .

References – Pollution Control, Combustion, and Gasification

1. “Chemistry of Trace Inorganic Elements in Coal Combustion Systems: A Century of Discovery”, Connie Senior, Evan Granite, William Linak, Wayne Seames, Energy & Fuels, 34 (12), 15141-15168, 2020.
2. “Mercury Control for Coal-Derived Gas Streams”, Evan J. Granite, Henry W. Pennline, Connie Senior, editors and co-authors, Wiley-VCH, January 2015.
3. “Comment on “Mercury Oxidation by UV Irradiation: Effect of Contact Time, UV Wavelength, and Moisture Content”, Evan J. Granite, Industrial & Engineering Chemistry Research, 56, 9408−9409, 2017.
4. “Preface”, Evan J. Granite, in “Mercury Control for Coal-Derived Gas Streams”, Wiley-VCH, January 2015.
5. Chapter 21, “Novel Capture Technologies: Non-Carbon Sorbents and Photochemical Oxidations”, p. 339-356, Karen J. Uffalussy and Evan J. Granite in “Mercury Control for Coal-Derived Gas Streams”, Wiley-VCH, January 2015.
6. Chapter 22, “Sorbents for Gasification Processes”, p. 357-374, Henry W. Pennline and Evan J. Granite in “Mercury Control for Coal-Derived Gas Streams”, Wiley-VCH, January 2015.
7. Arsenic Adsorption on Palladium-Copper Alloy Films, Karen Uffalussy, James Miller, Bret Howard, Dennis Stanko, Evan Granite, Industrial & Engineering Chemistry Research, 53(18), 7821-7827, 2014.
8. Pilot-Scale Capture of Mercury, Arsenic and Selenium from Warm Syngas at Elevated Pressures by Palladium Sorbents, Evan Granite, Hugh Hamilton, Stephen Poulston, Liz Rowsell, Wilson Chu, Andrew Smith, Tony Wu, Subhash Datta, Robert Lambrecht, John Wheeldon, Henry Pennline, to be submitted to Industrial & Engineering Chemistry Research, October 2026.
9. Evaluation of Palladium-Based Sorbents for Trace Mercury Removal in Electricity Generation, Christopher Munson, Pradeep Indrakanti, Massood Ramezan, Evan Granite, Jenny Tennant, International Journal of Clean Coal and Energy, 3, 65-76, November 2014.
10. Laboratory Scale Studies of Pd-Al2O3 Sorbents for the Removal of Trace Contaminants from Coal-Derived Fuel Gas at Elevated Temperatures, Erik C. Rupp, Evan J. Granite, Dennis C. Stanko, Fuel, 108, 131-136, June 2013.
11. Catalytic Formation of Carbonyl Sulfide during Warm Gas Clean-Up of Simulated Coal-Derived Fuel Gas with Palladium Sorbents, Erik C. Rupp, Evan J. Granite, Dennis C. Stanko, Fuel, 92, 211-215, February 2012.
12. Palladium Based Sorbents for High Temperature Arsine Removal from Fuel Gas, Stephen Poulston, Evan J. Granite, Henry Pennline, Hugh Hamilton, Andrew W.J. Smith, Fuel, 90, 3118-3121, October 2011.
13. Effect of Dispersion on the Capture of Toxic Elements from Fuel Gas by Palladium-Alumina Sorbents, John P. Baltrus, Evan J. Granite, Erik C. Rupp, Dennis C. Stanko, Bret Howard, Henry W. Pennline, Fuel, 90, 1992-1998, May 2011.
14. Method for Detection of Trace Metal Contaminants in Coal-Generated Fuel Gas Using Gas Chromatography – Ion Trap Mass Spectrometry, Erik Rupp, Evan J. Granite, Dennis C. Stanko, Analytical Chemistry, 82(14), 6315-6317, July 15, 2010.
15. Surface Characterization of Palladium-Alumina Sorbents for High Temperature Capture of Mercury and Arsenic from Fuel Gas, John P. Baltrus, Evan J. Granite Henry W. Pennline, Dennis C. Stanko, Hugh Hamilton, Stephen Poulston, Liz Rowsell, Andrew Smith, Wilson Chu, Fuel, 89(6), 1323-1325, June 2010.
16. Ancillary Oxygen-Fired Combustion with Electrochemical Cells, Henry W. Pennline, Evan J. Granite, David Luebke, John Kitchin, James Landon, Lisa Weiland, Fuel, 89(6), 1307-1314, June 2010.
17. Preface – Special Issue: Advanced Fossil Fuel Utilization: Emissions and Control, Dushyant Shekhawat, Evan J. Granite, Henry W. Pennline, Dave Berry, James Spivey (Guest Editors) Fuel, 89(6), 1185-1186, June 2010.
18. Measurement of Mercury Flux from Coal Utilization By-Products with a Laboratory Flux Chamber, Natalie Pekney, Don Martello, Karl Schroeder, Evan J. Granite, Fuel, 88(5), 890-897, May 2009.
19. The Implications of Mercury Interactions with Band-Gap Semiconductor Oxides, Evan J. Granite, William P. King, Dennis C. Stanko, and Henry W. Pennline, Main Group Chemistry, 7(3), 227-237, September 2008.
20. Surface Characterization of Pd/Al2O3 Sorbents for Mercury Adsorption from Fuel Gas, John P. Baltrus, Evan J. Granite Henry W. Pennline, and Dennis C. Stanko, Main Group Chemistry, 7(3), 217-225, September 2008.
21. Preface – Special Issue: Mercury and other Trace Elements in Fuel: Emissions and Control, Evan J. Granite, (Guest Editor) Main Group Chemistry, 7(3), 167, September 2008.
22. Comment on Role of SO2 for Elemental Mercury Removal from Coal Combustion Flue Gas by Activated Carbon, Evan J. Granite and Albert A. Presto, Energy & Fuels, 22, 3557-3558, September 2008.
23. Noble Metal Catalysts for Mercury Oxidation in Utility Flue Gas, Albert A. Presto and Evan J. Granite, invited paper for Platinum Metals Review, 52(3), 144-154, July 2008.
24. Reply to Comment on “Impact of Sulfur Oxides on Mercury Capture by Activated Carbon”, Evan J. Granite, Albert A. Presto, Environmental Science & Technology, 42, 972, January 2008.

25. Further Investigation of the Impact of Sulfur Oxides on Mercury Capture by Activated Carbon, Albert A. Presto, Evan J. Granite, Andrew Karash, Industrial & Engineering Chemistry Research, 46, 8273-8276, November 2007.
26. The Thief Process for Removal of Mercury from Flue Gas, Evan J. Granite, Mark C. Freeman, William J. O'Dowd, Richard A. Hargis, Henry W. Pennline, Journal of Environmental Management, 84(4), 628-634, September 2007.
27. Impact of Sulfur Oxides on Mercury Capture by Activated Carbon, Albert A. Presto and Evan J. Granite, Environmental Science & Technology, 41(18), 6579-6584, September 2007.
28. Metal Sorbents for High Temperature Mercury Capture from Fuel Gas, Stephen Poulston, Evan J. Granite, Henry W. Pennline, Christina R. Myers, Dennis P. Stanko, Hugh Hamilton, Liz Rowsell, Andrew W. J. Smith, Thomas Ilkenhans, and Wilson Chu, Fuel, 86(14), 2201-2203, September 2007.
29. Sorbents for Mercury Capture from Fuel Gas with Application to Gasification Systems, Evan J. Granite, Christina R. Myers, William P. King, Dennis Stanko, Henry W. Pennline, Industrial & Engineering Chemistry Research, 45(13), 4844-4848, June 2006.
30. Critical Review: Survey of Catalysts for Oxidation of Mercury in Flue Gas, Albert A. Presto and Evan J. Granite, Environmental Science & Technology, 40(18), 5601-5609, September 2006.
31. A Kinetic Approach to the Catalytic Oxidation of Mercury in Flue Gas, Albert A. Presto, Evan J. Granite, Andrew Karash, Richard A. Hargis, William J. O'Dowd, and Henry W. Pennline, Energy & Fuels, 20(5), 1941-1945, September 2006.
32. A Method to Remove Mercury from Flue Gas: The Thief Process, Henry W. Pennline, William J. O'Dowd, Mark C. Freeman, Evan J. Granite, Andrew Karash, Clem Lacher, Fuel Processing Technology, 87(12), 1071-1084, December 2006.
33. The PCO Process for Photochemical Removal of Mercury from Flue Gas, Christopher McLarnon, Evan J. Granite, Henry W. Pennline, Fuel Processing Technology, 87(1), 85-89, December 2005.
34. Effect of Porous Structure and Surface Functionality on the Mercury Capture of a Fly Ash Carbon and its Activated Sample, M. Mercedes Maroto-Valer, Y. Zhang, Evan J. Granite, Zhong Tang, Henry W. Pennline, Fuel, 84, 105-108, January 2005.
35. Mercury Detection at Boron Doped Diamond Electrodes Using a Rotating Disk Technique, A. Manivannan, L. Ramakrishnan, M.S. Seehra, Evan J. Granite, J.E. Butler, D.A. Tryk, A. Fujishima, Journal of Electroanalytical Chemistry, 577, 287-293, April 2005.
36. Review of Novel Methods for Carbon Dioxide Separation from Flue and Fuel Gases, Evan J. Granite, Thomas O'Brien, Fuel Processing Technology, 86, 1423-1434, October 2005.
37. Recent Advances in Mercury Removal Technology at the National Energy Technology Laboratory, William J. O'Dowd, Richard A. Hargis, Evan J. Granite, Henry W. Pennline, Fuel Processing Technology, 85, 533-548, 2004.
38. DOE/NETL's Mercury Control Technology Research Program for Coal-Fired Power Plants, Tom Feeley, James Murphy, Jeff Hoffmann, Evan Granite, and Scott Renninger, EM, 16-23, October 2003.
39. 2003 AWMA Critical Review: Separation and Capture of CO2 from Large Stationary Sources and Sequestration in Geological Formations - Coalbeds and Deep Saline Aquifers, Curt White, Brian Strazisar, Evan Granite, James Hoffman, and Henry Pennline, J. Air & Waste Manage. Assoc., 53(6), 645-715, June 2003.
40. Separation and Capture of CO2 from Large Stationary Sources and Sequestration in Geological Formations, Curt White, Brian Strazisar, Evan Granite, James Hoffman, and Henry Pennline, EM, 29-34, June 2003.
41. Photochemical Removal of Mercury from Flue Gas, Evan Granite and Henry Pennline, Industrial & Engineering Chemistry Research, vol. 41, pp. 5470-5476, October 2002.
42. Novel Sorbents for Mercury Removal from Flue Gas, Evan Granite, Henry Pennline, and Richard Hargis, Industrial & Engineering Chemistry Research, vol. 39, pp. 1020-1029, April 2000.
43. Effects of Photochemical Formation of Mercuric Oxide, Evan Granite, Henry Pennline, and James Hoffman, Industrial & Engineering Chemistry Research, vol. 38, pp. 5034-5037, December 1999.
44. An Assessment of Potential Sorbents for Mercury Removal from Fuel Gas, William King, Evan Granite, and Henry Pennline, United States Department of Energy Topical Report, July 2003.
45. Sorbents for Mercury Removal from Flue Gas, Evan Granite, Henry Pennline, and Richard Hargis, United States Department of Energy Topical Report, Federal Energy Technology Center TR-98-01, January 1998.
46. Solid Electrolyte Aided Studies of Oxide Catalyzed Oxidation of Hydrocarbons, Evan Granite, PhD Thesis in Chemical Engineering, The University of Rochester, Rochester, New York, May 1994.
47. A Pilot Plant Design for The Integrated Gasification Process, Evan Granite, MS Thesis in Chemical Engineering, The Cooper Union, New York, New York, May 1989.
48. Thief Process for the Removal of Mercury from Flue Gas, Henry Pennline, Evan Granite, Mark Freeman, William O'Dowd, and Richard Hargis, U.S. Patent 6,521,021; February 18, 2003.
49. Method for Removal of Mercury from Various Gas Streams, Evan J. Granite and Henry W. Pennline, U.S. Patent 6,576,092; June 10, 2003.
50. Method for High Temperature Mercury Capture from Gas Streams, Evan J. Granite and Henry W. Pennline, U.S. Patent 7,033,419; April 25, 2006.
51. Catalysts for Oxidation of Mercury in Flue Gas, Evan J. Granite and Henry W. Pennline, U.S. Patent 7,776,780; August 17, 2010.
52. Semi-Continuous Detection of Mercury in Gases, Evan J. Granite and Henry W. Pennline, U.S. Patent 8,069,703; December 6, 2011.
53. Thief Carbon Catalyst for Oxidation of Mercury in Effluent Stream, Evan J. Granite and Henry W. Pennline, U.S. Patent 8,071,500, December 6, 2011.
54. Ancillary Oxygen-Fired Combustion with Electrochemical Cells, Henry W. Pennline, Evan J. Granite, and David Luebke, Filed with US Patent & Trademark Office January 2008.
55. Iridium-Based Catalysts for Oxidation of Mercury, Evan J. Granite and Henry W. Pennline, U.S. Patent Application, DOE Case S-105,871, Filed with US Patent & Trademark Office, July 14, 2010.

Relevant Recent Presentations

1. "Beyond Combustion – Coal in the 21st Century - Carbon Products from Coal", Evan J. Granite, seminar for DOE Coal and Critical Materials Seminar Series, July 9, 2025.
2. "Graphite – King of the Coal Family", Evan J. Granite, seminar for DOE Coal and Critical Materials Seminar Series, April 29, 2026.
3. "Domestic Wastes and Byproducts – A Resource for Critical Material Supply Chains", Evan J. Granite, seminar for DOE Coal and Critical Materials Seminar Series, May 6, 2026.
4. "Overview of Mercury Control Options for Coal-Burning Power Plants", Evan J. Granite, seminar for DOE Coal and Critical Materials Seminar Series, May 13, 2026.

SESSION 3 (14:20 – 15:40)

COAL SCIENCE, CRITICAL MINERALS AND SUSTAINABILITY

14:20 Graphite – King of the Coal Family

Evan J. Granite
United States Department of Energy
Email: evan.granite@doe.gov

Graphite has been determined to be a critical material by the Department of Energy, Department of Interior, and Department of War. Graphite has great importance to our economy and national defense, and, unfortunately, The United States is currently completely reliant upon imports of natural graphite. Graphite can be obtained through mining, recycling, and production of synthetic graphite. The status of these three routes will be reviewed, with an emphasis on the techniques for graphitization of carbonaceous materials.

Disclaimer

This paper/information was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any

warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Acknowledgement

The author thanks Badie Morsi, Massood Ramezan, and the PECMC for the opportunity to present this talk, and his DOE colleagues Adam Wong and Sarah Forbes for their support.

14:40 A Mathematical Approach to Quantify Heat of Coal Pyrolysis at High Heating Rates

Saurav Pokharel, PhD Candidate, Department of Mechanical Engineering, University of Wyoming, Laramie, Wyoming, WY, USA ssauravpokharel@gmail.com, +1 307 2236919

Michael Stoellinger, Associate Professor, Department of Mechanical Engineering, University of Wyoming, Laramie, WY, USA mstoell@uwyo.edu, +1 (307) 766-3226

Introduction: The coal pyrolysis process involves the thermal decomposition of raw coal in an inert atmosphere into hydrocarbons, non-condensable gases, and tar; leaving solid carbon residue as char. Coal pyrolysis is also a precursor to industrial coal utilization processes like combustion, gasification, cooking, and liquefaction [1], [2], [3]. With ever-increasing computational power, computational fluid dynamics(CFD) has proven to be an effective tool in modeling coal utilization systems. The prediction capability of CFD simulations is directly dependent on the pyrolysis model employed. However, most CFD simulations do not incorporate appropriate heat of coal pyrolysis(HCP): either a constant value is used, or it is completely ignored [4], [5], [6], [7]. This can be ascribed to: (1) inconsistency in the reported HCP and/or (2) HCP deemed to be insignificant. Numerous efforts have been made to predict the HCP, with most being conducted experimentally, while very few employ a theoretical approach. Thermogravimetric-differential scanning calorimetry(TG-DSC) is a widely used experimental method to study the thermal effects of the pyrolysis process. The DSC curve requires adjustment using a baseline to calculate the reaction HCP, yet calculating the baseline remains a major challenge to date. Most of the studies employ a subsequent DSC run using the char produced at the end of pyrolysis to estimate the baseline under the assumption that the specific heat capacity (C_p) of raw coal and the char produced at the end are equal [8], [9], [10]. However, it demonstrated that the C_p of char is different in subsequent runs, indicating that C_p of initial coal and first-run char would differ substantially [11], [12]. Merrick [13] calculates the reaction HCP by solving an energy balance equation assuming that the composition of tar is constant, and consequently, the enthalpy of tar depends only on the temperature. Although the above-mentioned methods provide some insights into HCP, they are not suited for CFD applications as they lack char conversion dependent formulation of HCP and violate energy, element and mass conservation. This study develops a CFD-compatible, conversion-dependent model for predicting HCP that conserves both elemental composition and energy, using only proximate and ultimate analysis of coal and heating rate as inputs.

Mathematical Model: The pyrolysis of dry coal is described by a finite-rate, single-step reaction that converts raw coal into char, tar, and volatile gases. The reaction only includes primary pyrolysis in the condensed solid phase, excluding any homogenous reactions that may occur in the gas phase. As pyrolysis progresses, the composition of char, tar, and gases varies. The composition of char is represented by the elements C, H, O, N, and S; tar composition by elements C, H, and O; and volatile gas composition by H_2O, H_2, CO, CO_2, HCN, CH_4, C_2H_4, C_2H_6, and H_2S. The yield and composition of pyrolysis products are calculated using the network-based high-fidelity FLASHCHAIN [3] model using commercially available software package "PC Coal Lab (PCCL)" [14]. To formulate the mathematical model, a control volume is drawn around a coal particle undergoing pyrolysis in a DSC, and energy conservation is invoked to obtain Eq. (1), where Q_t is total HCP (sensible + reaction heat), h_i is specific enthalpy of species i, m_i is the mass of species i, T is the temperature of char, $Y_k{}^i$ is the mass fraction of k in species i, and t_f is the duration of pyrolysis. Here, it is assumed that tar and volatiles are in thermal equilibrium with the char and escape the DSC as soon as they form. Dropping the second term in the RHS of the equation (1) gives the expression for the reaction HCP (Q_r). The specific enthalpy of char is calculated using the Mason and Gandhi equation [15] and the C_p char is calculated from Einstein's Model using the characteristics temperatures of 1800 K and 380 K [13]. The tar is approximated as the combination of large hydrocarbon molecules adopted from Tufano et al. [16] such that the elements are conserved. A few hydrocarbon species and solid C are added to approximate a wider range of tar composition. The enthalpy of approximated tar species and primary volatiles are calculated by using NASA 7-coefficient polynomial using Cantera [17]. The Full Model(FM) described above requires PCCL to predict pyrolysis products and their composition, but PCCL is a licensed software that cannot be integrated into other tools. In addition, such a high-fidelity model is computationally expensive for CFD applications. So, a stand-alone and computationally efficient Simplified Model(SM) is developed. For the SM, it is assumed that tar and char both are composed of C, H, and O; and volatile gas is composed of H_2O, H_2, CO, CO_2, CH_4, and C_2H_4. The pyrolysis yield is predicted by Single First-Order Reaction Model which is calibrated using PCCL results. The composition of tar at the end of pyrolysis (from PCCL) is assumed to be the composition of tar throughout the pyrolysis and the composition of char is calculated by difference. Now, Eq. (1) is modified for the reduced number of species and composition of tar accordingly to get Q_t.

$$Q_t = \int_0^{t_f} \left[h_{\text{char}} \frac{dm_{\text{char}}}{dt} + m_{\text{char}} \frac{\partial h_{\text{char}}}{\partial T} \frac{dT}{dt} + m_{\text{char}} \sum_{k=1}^{4} \left(\frac{\partial h_{\text{char}}}{\partial Y_k^{char}} \frac{dY_k^{char}}{dt} \right) + h_{\text{tar}} \frac{dm_{\text{tar}}}{dt} + m_{\text{tar}} \sum_{k=1}^{2} \left(\frac{\partial h_{\text{tar}}}{\partial Y_k^{tar}} \frac{dY_k^{tar}}{dt} \right) + h_{\text{vol}} \frac{dm_{\text{vol}}}{dt} + m_{\text{vol}} \sum_{k=1}^{8} \left(\frac{\partial h_{\text{vol}}}{\partial Y_k^{vol}} \frac{dY_k^{vol}}{dt} \right) \right] dt. \quad (1)$$

Results: The pyrolysis of 25 different coal samples was simulated at heating rates ranging from 100 °C/s to 10000 °C/s. Figure 1a and 1b illustrate the reaction heat rate $\left(\frac{dQ_r}{dt}\right)$ and cumulative reaction heat (Q_r) for various samples.

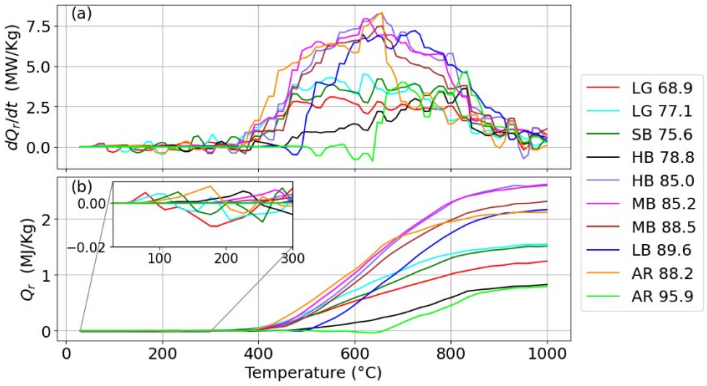


Figure 1: Reaction heat rate and reaction heat of coal Pyrolysis

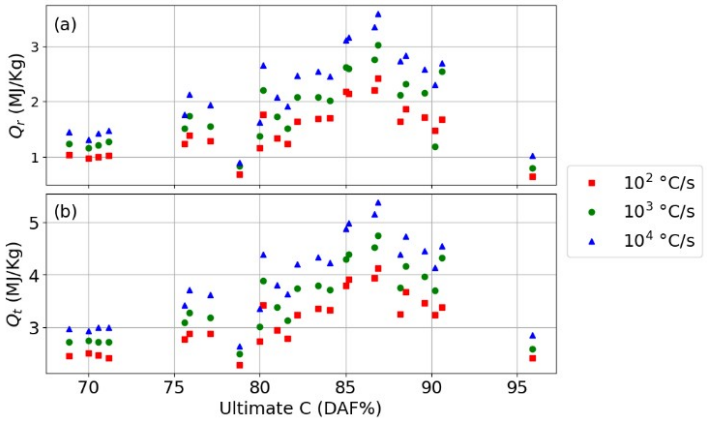


Figure 2: Reaction heat and total heat of coal pyrolysis

LG, SB, HB, MB, LB, and AR represent Lignite, Sub-bituminous, high-volatile bituminous, medium-volatile bituminous, low-volatile bituminous, and anthracite samples, respectively. The numerical values indicate ultimate dry ash free (DAF) C% of the samples. Q_r is endothermic for all coal samples throughout the pyrolysis which agrees with the experimental results [9], [10], [12]. The enthalpy calculation (not shown here) shows that the specific enthalpy of char and volatile gases are comparable, but the specific enthalpy of tar(h_{tar}) is very high compared with char and volatile. Thus, the volatile gas formation can be endothermic or exothermic depending on the composition of char and volatiles, but tar formation is highly endothermic. The initial stage of pyrolysis (T< 400 °C) shows only a mild change in the Q_r as hardly any pyrolysis occurs at this stage. But as soon as T> 400 °C, the tar formation begins and the pyrolysis becomes highly endothermic. This also explains the discrepancy between the reaction heat rate and weight loss rate (not shown here) that was also observed by Wang et al. [18]. Because of high h_{tar}, reaction heat rate curve is dominated by tar formation rate and does not necessarily agree with the weight loss curve. Merrick [13] reported exothermic reaction heat rate for the entire temperature range because of the underestimated h_{tar}, contributing to the overestimation of exothermic effect of pyrolysis. Some experimentally observed exothermic Q_r [11],[18], especially at the later stage of the pyrolysis can be attributed to the tar conversion to soot. The experiment has no way of preventing the secondary tar conversion reaction that is an exothermic reaction [19]. The observed exothermicity in the experiments is more pronounced at low heating rates and higher temperature as these conditions favor tar conversion [19], [20]. Figure 2 shows the effect of heating rate and C% on the Q_r and Q_t. Both Q_r and Q_t increase with the heating rate because higher heating rates favor tar formation [20]. The trend is consistent with the experiments [18], [21], however the experiments report a steep rise in endothermicity that can be attributed to the tar conversion reaction occurring at the lower heating rate. Regardless of heating rates, both Q_r and Q_t initially rise with C% peaking at 86.9 and then decline for higher C%. The trend agrees with the experimental observation [8]; but in the experiment, peak is observed at C% of 81.6. The Simplified Model (SM) demonstrates good agreement with the FM. Across 25 different coal samples and three different heating rates (100 °C/s, 1000 °C/s, 10000 °C/s), the average error in Q_r is 2.94% and that of Q_t is 1.19%.

Conclusion: The mathematical framework developed here can accurately predict the HCP for a wide range of coal types and heating conditions, unlike the experimental methods which are limited to low heating rates (<1 °C/s). All the coal samples exhibit endothermic Q_r and Q_t that increases with the heating rates. HCP increases with the coal rank and reaches a maximum for ultimate C% of 86.9 and decreases thereafter. The HCP is predominantly dictated by tar formation, not the overall weight loss. The SM significantly improves the robustness and computational efficiency of the FM, but with a minor sacrifice in accuracy.

References:

[1] Z. Niu, G. Liu, H. Yin, and C. Zhou, "Devolatilization behaviour and pyrolysis kinetics of coking coal based on the evolution of functional groups," *J. Anal. Appl. Pyrolysis*, vol. 134, pp. 351–361, 2018, doi: https://doi.org/10.1016/j.jaap.2018.06.025.

[2] P. R. Solomon, T. H. Fletcher, and R. J. Pugmire, "Progress in coal pyrolysis," *Fuel*, vol. 72, no. 5, pp. 587–597, 1993, doi: https://doi.org/10.1016/0016-2361(93)90570-R.

[3] S. Niksa and A. R. Kerstein, "FLASHCHAIN theory for rapid coal devolatilization kinetics. 1. Formulation," *Energy & fuels*, vol. 5, no. 5, pp. 647–665, 1991.

[4] M. Vascellari, D. G. Roberts, S. S. Hla, D. J. Harris, and C. Hasse, "From laboratory-scale experiments to industrial-scale CFD simulations of entrained flow coal gasification," *Fuel*, vol. 152, pp. 58–73, 2015, doi: https://doi.org/10.1016/j.fuel.2015.01.038.

[5] B. Goshayeshi and J. C. Sutherland, "A comparison of various models in predicting ignition delay in single-particle coal combustion," *Combust. Flame*, vol. 161, no. 7, pp. 1900–1910, 2014, doi: https://doi.org/10.1016/j.combustflame.2014.01.010.

[6] K. Wan, J. Xia, Z. Wang, L. C. Wrobel, and K. Cen, "Online-CPD-coupled large-eddy simulation of pulverized-coal pyrolysis in a hot turbulent nitrogen jet," *Combustion Science and Technology*, vol. 189, no. 1, pp. 103–131, 2017.

[7] M. Vascellari, R. Arora, M. Pollack, and C. Hasse, "Simulation of entrained flow gasification with advanced coal conversion submodels. Part 1: Pyrolysis," *Fuel*, vol. 113, pp. 654–669, 2013, doi: https://doi.org/10.1016/j.fuel.2013.06.014.

[8] O. P. Mahajan, A. Tomita, and P. L. Walker Jr, "Differential scanning calorimetry studies on coal. 1. Pyrolysis in an inert atmosphere," *Fuel*, vol. 55, no. 1, pp. 63–69, 1976.

[9] P. J. J. Tromp, F. Kapteijn, and J. A. Moulijn, "Characterization of coal pyrolysis by means of differential scanning calorimetry. 1. Quantitative heat effects in an inert atmosphere," *Fuel processing technology*, vol. 15, pp. 45–57, 1987.

[10] A. J. Lopez-Peinado, P. J. J. Tromp, and J. A. Moulijn, "Quantitative heat effects associated with pyrolysis of coals, ranging from anthracite to lignite," *Fuel*, vol. 68, no. 8, pp. 999–1004, 1989.

[11] X. Cheng, L. Shi, Q. Liu, and Z. Liu, "Heat effects of pyrolysis of 15 acid washed coals in a DSC/TGA-MS system," *Fuel*, vol. 268, p. 117325, 2020.

[12] J. Tomeczek and H. Palugniok, "Specific heat capacity and enthalpy of coal pyrolysis at elevated temperatures," *Fuel*, vol. 75, no. 9, pp. 1089–1093, 1996.

[13] D. Merrick, "Mathematical models of the thermal decomposition of coal: 2. Specific heats and heats of reaction," *Fuel*, vol. 62, no. 5, pp. 540–546, 1983.

[14] Niksa Energy Associates LLC, "PC Coal Lab Version 5.1," 2020.

[15] D. Van Essendelft, T. Li, P. Nicoletti, and T. Jordan, "Advanced chemistry surrogate model development within C3M for CFD modeling, part 1: methodology development for coal pyrolysis," *Ind. Eng. Chem. Res.*, vol. 53, no. 18, pp. 7780–7796, 2014.

[16] G. L. Tufano *et al.*, "Fully-resolved simulations of coal particle combustion using a detailed multi-step approach for heterogeneous kinetics," *Fuel*, vol. 240, pp. 75–83, 2019.

[17] D. G. Goodwin, H. K. Moffat, I. Schoegl, R. L. Speth, and B. W. Weber, "Cantera: An Object-oriented Software Toolkit for Chemical Kinetics, Thermodynamics, and Transport Processes," 2023. doi: 10.5281/zenodo.8137090.

[18] T. Wang *et al.*, "Experimental investigation of thermal effect in coal pyrolysis process," *Fuel Processing Technology*, vol. 200, p. 106269, 2020.

[19] T. Blacha, M. Di Domenico, P. Gerlinger, and M. Aigner, "Soot predictions in premixed and non-premixed laminar flames using a sectional approach for PAHs and soot," *Combust. Flame*, vol. 159, no. 1, pp. 181–193, 2012.

[20] S. Niksa, "4 - Primary devolatilization behavior," in *Process Chemistry of Coal Utilization*, S. Niksa, Ed., in Woodhead Publishing Series in Energy. , Woodhead Publishing, 2020, pp. 73–141. doi: https://doi.org/10.1016/B978-0-12-818713-5.00004-6.

[21] D. Liang, "Measurement of coal pyrolysis reaction heat by empirical baseline method," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, pp. 1–11, 2020.

15:00 FINAL STEP: A FUNDED DOMESTIC COMMERCIAL PLANT TO PRODUCE RARE EARTH ELEMENT (REE) MAGNETS

Howard G McClintic
Concurrent Technologies Corporation, USA
Email: McClintH@ctc.com

The principals and senior Staff of Concurrent Technologies Corporation (CTC) have been and still are completely committed to developing a domestic supply chain of converting rare earth oxides (REOs) into rare earth elements (REEs). Domestically produced REEs are readily and usually made into either neodymium or praseodymium magnets. The demand for these magnets is and will dramatically increase throughout this decade and long thereafter.

CTC has developed and greatly progressed a high temperature gasification technology that reaches and exceeds 3000 degrees centigrade. More specifically, two particular magnets are neodymium (3074°C) and praseodymium (3520°C) are used in electric vehicles (some four pounds) and wind turbine nacelles (at least 200 pounds). Currently and prospectively, the Texas panhandle has a high concentration of wind power resources.

Besides having a clear market perspective, CTC has identified sources of venture capital to either match public funding or fully capitalize various phases or entire projects.

15:20 From black coals to nuclear cores: Repurposing and decarbonizing coal power

Mikael Höök, Associate Professor, dep. of Earth Sciences, Uppsala University, SWEDEN
Mikael.Hook@geo.uu.se, +46730208116, +46184712592)

Continued reliance on coal-fired power generation presents a major challenge for the development of sustainable energy systems. Despite rapid growth in renewable energy, coal remains a substantial source of electricity generation and associated greenhouse gas emissions in many major economies. Repurposing existing coal-fired power plants for nuclear generation could provide an alternative pathway for reducing emissions while retaining valuable energy infrastructure. This study evaluates the potential of Coal-to-Nuclear (C2N) conversion as a transition pathway, using China as a case study to assess its potential scale and capacity requirements.

Historical electricity-generation data are used to develop trend-based projections of future coal-fired generation for 2030, 2040, 2050, and 2060. Two scenarios are considered: (i) continued reliance on coal, and (ii) a transition pathway characterized by a gradual decline in coal generation towards China's 2060 net-zero target. These projections are combined with existing assessments of Chinese coal-fired power plants suitable for nuclear conversion. The resulting generation gap is used to estimate the additional nuclear capacity, expressed as the number of small modular reactors (SMRs), required to replace remaining coal-fired generation.

The results provide a national-scale assessment of the nuclear capacity required to replace coal while maximizing the reuse of existing infrastructure. The analysis illustrates the extent to which C2N conversion could reduce the need for entirely new nuclear capacity and identifies the additional SMR deployment required under alternative coal-transition pathways. More broadly, the study explores how infrastructure reuse and modular nuclear technologies could complement renewable energy deployment and contribute to China's long-term decarbonization. The findings also highlight the potential relevance of C2N strategies for other countries facing the combined challenges of coal phase-out, infrastructure replacement, and rapidly growing demand for low-carbon electricity.

THURSDAY, OCTOBER 29, 2026 — U.S. EASTERN DAYLIGHT TIME

SESSION 4 (10:30 – 11:50)
CLEAN FUELS, CLEAN HYDROGEN AND COMBUSTION TECHNOLOGIES

10:30 Hollow Mesoporous Carbon-Shelled CaO–Ca3Al2O6 Sorbents with Tunable Pore Interconnectivity for Durable CO2 Capture in Sorption-Enhanced Hydrogen Production

YuXin Liu, Master, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA
Email: 2024521000@link.tyut.edu.cn, Phone:+86 15226114892, Fax:+86-351-6018453
Jieying Jing, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA*
Email: jingjieying@tyut.edu.cn, Phone:+86 13453162208, Fax:+86-351-6018453

Sorption-enhanced water-gas shift (SEWGS) enables one-step high-purity H_2 production with in-situ CO_2 capture by selectively removing CO_2 to overcome thermodynamic equilibrium limitations. The industrial viability of this technology, however, depends critically on the development of advanced sorbents that combine high CO_2 uptake reactivity with robust long-term cycling durability. Herein, we systematically investigated the performance advantages and structural evolution of core-shell composite sorbents in the SEWGS process. A core-shell adsorbent with a CaO-$Ca_3Al_2O_6$ core and a hollow mesoporous carbon (HMCS) shell was prepared using a one-pot method. The physical confinement effect exerted by the carbon shell effectively accommodates the substantial volumetric changes between CaO (16.7 cm^3/mol) and $CaCO_3$ (36.9 cm^3/mol) during cyclic carbonation/regeneration, thereby significantly enhancing the structural stability of the material. Notably, the use of sacrificial SiO_2 templates proved pivotal in constructing the mesoporous architecture, and fine-tuning the etching time enabled precise control over pore interconnectivity to facilitate CO_2 diffusion. Under optimized operating conditions (carbonation at 600 °C for 50 min, regeneration at 750 °C for 15 min, 20 vol% CO_2/N_2 balance at 50 mL min^{-1}), the best-performing CaO-$Ca_3Al_2O_6$@C-36 sorbent delivered a maximum CO_2 uptake of 8.62 mmol g^{-1} and exhibited excellent stability across four consecutive cycles. BET analysis revealed that this sample possessed the largest specific surface area and average pore diameter, which are attributed to the well-developed and highly interconnected mesoporous carbon shell templated by sacrificial SiO_2. This robust architecture supplies abundant accessible active sites and rapid CO_2 diffusion channels, accounting for the superior adsorption performance.

Keywords: Sorption-enhanced water-gas shift (SEWGS); core-shell structure; hollow mesoporous carbon shell; CO_2 capture

10:50 Integration of Sorption-Enhanced Water-Gas Shift with Reforming Technologies for Syngas Conditioning: A Comparative Simulation and Techno-Economic Study

Cheng Gu, Master, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA
Email: 2024510596@link.tyut.edu.cn, Phone:+86 17808092275, Fax:+86-351-6018453
Jieying Jing, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA*
Email: jingjieying@tyut.edu.cn, Phone:+86 13453162208, Fax:+86-351-6018453

Syngas composition adjustment to achieve the desired H_2/CO molar ratio is critical for downstream chemical synthesis, directly governing process efficiency and product selectivity. This work systematically investigates the technical potential of sorption-enhanced water-gas shift (SEWGS) for syngas conditioning. Steady-state full-process simulation models of three configurations were developed in Aspen Plus V15 and comprehensively evaluated in terms of gas production performance, energy consumption, and techno-economics: a conventional composition adjustment baseline (Process A); a combination of dry reforming of methane (DRM) with low-temperature SEWGS (LT-SEWGS) (Process B); and an integrated process coupling high-temperature SEWGS (HT-SEWGS) with sorption-enhanced steam methane reforming (SESMR) (Process C). The results demonstrate that, relative to Process A, the effective syngas (H_2+CO) yield for Processes B and C increases by 66.5% and 63.0%, respectively, significantly enhancing production efficiency. Energy consumption is reduced by 34.9% and 38.2%, exhibiting substantial energy-saving potential. Techno-economic analysis reveals that operating costs decrease by 34.8% and 37.6%, while the unit production cost of effective syngas drops by 60.5% and 61.5%, confirming the pronounced economic advantages of the proposed SEWGS-integrated routes. These findings indicate that coupling SEWGS with reforming technologies offers a highly efficient and cost-effective pathway for syngas conditioning.

Keywords: syngas composition adjustment; sorption-enhanced water-gas shift; process simulation; process comparison; techno-economics

11:10 Core-Shell Porous Silica-Converter Dust Nanoparticles with Sintering Resistance for High-Performance Ammonia Cracking Reaction

Xueyan Liu, Ms., State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan, Hubei 430074, CHINA)
d202380519@hust.edu.cn, +86 182 3415 2377
Zhouyang Shen, Xin Yu, Dunxi Yu, State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan, Hubei 430074, CHINA*
yudunxi@hust.edu.cn, +86 138 7135 2094

Catalyst-assisted ammonia cracking offers an efficient route for on-site hydrogen production to support low-carbon ironmaking, while developing low-cost and eco-friendly catalysts is critical for industrial sustainability. This work proposes a circular strategy to upcycle converter dust (CD), a typical Fe-rich steelmaking waste, into a high-efficiency catalyst for ammonia conversion, aiming to decarbonize the ironmaking process. The method simply involved encapsulating nanoparticles of the CD with nanostructured silica, generating nanosized and core-shell structured catalysts (CD@SiO_2) with different dosages of silica. The catalytic activity and long-term stability of CD and CD@SiO_2 in ammonia (NH_3) cracking were comparatively investigated over a wide temperature range (450-800 ℃). It was found that 100% NH_3 conversion was achieved with catalysts at 800 ℃. Compared with CD, CD@SiO_2 always showed a higher activity below 800 ℃. The dosage of SiO_2 had an apparent effect on the activity, and CD@SiO_2-1 was the most active in NH_3 cracking among them. Further investigations showed that the lower the temperature, the larger difference in the activity between the CD and CD@SiO_2-1, suggesting that the catalyst encapsulated by silica is superior to the CD especially in partial ammonia cracking. The observed increase in the activity of the CD@SiO_2 catalysts was attributed to the formed porous shell of SiO_2, which increased the contact area between ammonia and the catalyst particles and the formation of a new active phase (Fe_2N). This study not only realizes high-value utilization of steelmaking solid waste but also provides a low-cost, self-compatible catalytic technology for ammonia cracking in hydrogen-based low-carbon ironmaking.

11:30 Oxidation Kinetics of Single Char Particles under Pressurized Oxy-Fuel Conditions

Sheng Zhang, Master student, State Key Laboratory of Coal Combustion, School of Energy and Power Engineering, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan 430074, CHINA
m202671241@hust.edu.cn, +86 27 8755 2151
Qianyun Chen, PhD, State Key Laboratory of Coal Combustion, School of Energy and Power Engineering, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan 430074, CHINA
win@hust.edu.cn, +86 27 8755 2151
Jing Li, Associate professor, State Key Laboratory of Coal Combustion, School of Energy and Power Engineering, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan 430074, CHINA
jingli@hust.edu.cn, +86 27 8755 2151
Junjun Guo, Associate researcher, State Key Laboratory of Coal Combustion, School of Energy and Power Engineering, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan 430074, CHINA
jguo@hust.edu.cn, +86 27 8755 2151
Zhaohui Liu, Professor, State Key Laboratory of Coal Combustion, School of Energy and Power Engineering, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan 430074, CHINA
zliu@hust.edu.cn, +86 27 8755 2151

Pressurized oxy-fuel combustion (POC) is a promising carbon capture technology for coal-fired power plants, yet char oxidation kinetics at elevated pressures remain poorly quantified, with most available data obtained from low-heating-rate devices using contact-based measurements. This study investigates the oxidation kinetics of single char particles derived from three coals of different ranks: Jincheng anthracite (JC), Shenmu bituminous coal (SM), and Honghe lignite (HH). Experiments were conducted in an optically accessible pressurized flat-flame reactor (OPFFR) at 1400 K and pressures of 0.1-1.2 MPa. A high-speed microscopic imaging system, combined with two-color pyrometry and particle tracking, simultaneously measured particle size, velocity, and temperature, providing datasets ranging from hundreds to tens of thousands of particles under each condition. Experiments were performed in O_2/N_2 and O_2/CO_2 atmospheres containing 10-40% O_2, including two series at a fixed O_2 concentration (20%) and a fixed O_2 partial pressure (0.04 MPa), respectively. Apparent oxidation-gasification kinetics were derived using a single-film model accounting for boundary-layer diffusion, Stefan flow, and C-CO_2 gasification, while apparent activation energies (Ea) were determined from Arrhenius fits to individual-particle data. At a fixed O_2 concentration of 20%, increasing pressure increases the char particle temperature and reaction rate while shortening the burnout time. In contrast, at a fixed O_2 partial pressure, the particle temperature and reaction rate decrease markedly from 0.1 to 0.3 MPa and subsequently level off, accompanied by an increase in burnout time. Compared with O_2/N_2, the O_2/CO_2 atmosphere reduces the char particle temperature by approximately 100-200 K at 0.1 MPa, while this difference diminishes with increasing O_2 concentration or pressure. C-CO_2 gasification becomes significant at particle temperatures above approximately 1800 K, corresponding to pressures ≥0.5 MPa and O_2 concentrations ≥20% under the conditions investigated . The apparent Ea increases with pressure for all three chars under both pressure-varying conditions, indicating a transition from kinetic-diffusion control toward kinetic control. Moreover, Ea is consistently higher in O_2/CO_2 than in O_2/N_2 and decreases with increasing O_2 concentration. These results provide pressure-resolved, single-particle kinetic data and clarify the roles of CO_2 gasification and reaction-regime transitions in char oxidation under pressurized oxy-fuel conditions.

SESSION 5 (12:50 – 14:10)
CARBON CAPTURE, UTILIZATION AND STORAGE

12:50 Plasmonic Pd–Ag Bimetallic Synergy on TiO2 for Highly Selective Photothermal CO2 Hydrogenation to Formic Acid

Zijia Kong, Master, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA
Email: 2024510614@link.tyut.edu.cn, Phone: +86 18233010812, Fax: +86-351-6018453
Jieying Jing, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA*
Email: jingjieying@tyut.edu.cn, Phone: +86 13453162208, Fax: +86-351-6018453

Photothermal catalytic CO_2 hydrogenation to formic acid (HCOOH) using solar energy is a highly attractive route for achieving carbon neutrality and storing renewable energy. However, the insufficient utilization of visible-to-near-infrared (Vis-NIR) light by conventional catalysts severely limits the enhancement of photothermal conversion efficiency. Herein, a series of Pd-Ag bimetallic catalysts supported on P25 (TiO_2) were synthesized via an impregnation-reduction method, and their photothermal catalytic performance for CO_2 hydrogenation to formic acid was systematically evaluated under simulated solar irradiation (0.12 W/cm^2, $P(CO_2)$: $P(H_2)$ = 1:1). The introduction of Ag nanoparticles with strong localized surface plasmon resonance (LSPR) effects significantly extended the light absorption range and enhanced the photothermal conversion capacity. The optimized $PdAg_{0.5}$/P25 catalyst achieved a CO_2 conversion of 6.65% and a solar-to-chemical (STC) conversion efficiency of 7.23% within 1 h, while gas chromatography analysis confirmed nearly 100% selectivity toward formic acid with no detectable CO or CH_4 by products. Photothermal temperature-rise measurements showed that a trend in complete accordance with catalytic activity ($PdAg_{0.5}$ > Pd/P25 > $Ag_{0.5}$/P25), and the photothermal conversion efficiency of $PdAg_{0.5}$/P25 reached

51.15%. Mechanistically, Ag acts as a “plasmonic antenna” that generates energetic hot electrons and intense localized thermal fields via LSPR, while Pd serves as the active site to promote CO_2 adsorption and activation.

Keywords: Photothermal catalysis; CO_2 hydrogenation; Formic acid; Bimetallic catalysts; LSPR effect

13:10 Highly Conductive and Non-Fluorinated Anion Exchange Membrane for Electrocatalytic CO2 Conversion in Membrane-Electrode Assemblies

Hongxing Kang, Postdoctoral Appointee, Applied Materials Division, Argonne National Laboratory, 9700 S Cass Avenue, Lemont, IL 60439, USA
hkang@anl.gov, 619-626-8984
Vivek Adepu, Postdoctoral Appointee, Applied Materials Division, Argonne National Laboratory, 9700 S Cass Avenue, Lemont, IL 60439, USA
vadegu@anl.gov
Shichen Guo, Postdoctoral Appointee, Chemical Sciences and Engineering Division, Argonne National Laboratory, 9700 S Cass Avenue, Lemont, IL 60439, USA
sguo@anl.gov
Di-Jia Liu, Senior Chemist, Chemical Sciences and Engineering Division, Argonne National Laboratory, 9700 S Cass Avenue, Lemont, IL 60439, USA
djliu@anl.gov
Chaoyi Ba, Materials Scientist, Applied Materials Division, Argonne National Laboratory, 9700 S Cass Avenue, Lemont, IL 60439, USA*
cba@anl.gov
Meltem Urgun-Demirtas, Department Director, Applied Materials Division, Argonne National Laboratory, 9700 S Cass Avenue, Lemont, IL 60439, USA*
demirtasmu@anl.gov

Electrochemical CO_2 reduction in membrane electrode assemblies (MEAs) offers a promising pathway for converting carbon dioxide into multicarbon (C_{2+}) fuels and chemicals at industrially relevant current densities and low cell voltages. Despite substantial advances in catalyst development, system-level bottlenecks continue to limit reactor efficiency, including insufficient single-pass carbon utilization, long-term performance decay, and severe crossover of liquid and gaseous products through the membrane. Among these challenges, membrane transport selectivity remains an underexplored engineering lever for improving overall reactor performance. In this work, we report the design and synthesis of highly conductive anion exchange membranes (AEMs) with tailored microstructures and functional surface to simultaneously optimize ionic conductivity, mechanical robustness, and crossover resistance for CO_2 electrolysis in MEAs.

The engineered membranes (ANLix-Q100) exhibit hydroxide exchange capacities up to 2.6 mmol g^{-1} and tensile strengths exceeding 50 MPa, enabling the fabrication of mechanically stable ultrathin membranes (~20 µm). Relative to commercial PiperION membranes, the developed AEMs deliver over 80% higher bicarbonate conductivity, leading to improved ion transport and reduced ohmic losses under device operation. When integrated into CO_2 reduction MEAs, the membranes achieved 80% Faradaic efficiency toward C_{2+} products at 200 mA cm^{-2}, surpassing the 60-70% C_{2+} selectivity observed with commercial benchmarks under comparable conditions. Furthermore, the ANLix-Q100 membrane was reinforced by incorporating a polymer with a rigid cardo backbone. The resulting ANLix-Q80 membrane shows long-term durability under various conditions without sacrificing ion conductivity and effectively suppresses anolyte crossover. These results establish a strategy for developing next-generation non-fluorinated, ion-selective AEMs for CO_2 conversion and utilization.

13:30 Comparative Study of MOF-Integrated Polyacrylonitrile Nanofiber Membranes for Direct Air Capture of CO_2

Sunith B. Madduri, Postdoctoral Researcher, Center for Energy and Environmental Sustainability, Prairie View A&M University, Prairie View, TX 77446, USA
sbmadduri@pvamu.edu, 9362611648
Rishikishore R. Anugula, Prashan M. Rodrigo, Center for Energy and Environmental Sustainability, Prairie View A&M University, Prairie View, TX 77446, USA
Corresponding Author (Raghava R. Kommalapati, Director, Center for Energy and Environmental Sustainability, Prairie View A&M University, Prairie View, TX 77446, USA, and Professor, Department of Civil and Environmental Engineering, Prairie View A&M University, Prairie View, TX 77446, USA)
rrkommalapati@pvamu.edu, 9362611660, (936) 261 1662

Rising atmospheric CO_2 concentrations reaching nearly 429 ppm as reported by the NOAA Global Monitoring Laboratory necessitate the development of low-energy, scalable, and continuous carbon capture technologies. Direct air capture (DAC), which removes CO_2 directly from ambient air at concentrations of approximately 0.04%, represents a critical pathway toward achieving global net-zero emission targets. Current DAC methods, including KOH liquid systems requiring calcination at 900°C and amine scrubbing consuming 3.5–4.0 GJ per ton of CO_2, remain prohibitively energy-intensive for large-scale deployment. This study presents the fabrication, characterization, and comparative performance evaluation of three metal-organic framework (MOF)-integrated polyacrylonitrile (PAN) nanofiber membranes — UiO-66-NH_2/PAN, ZIF-8/PAN, and ZIF-67/PAN — each representing a structurally distinct CO_2 capture mechanism: amine-mediated dual physisorption–chemisorption, molecular sieving, and Lewis acid–base interaction, respectively. Membranes were fabricated via electrospinning at 15 kV, 0.6 mL h^{-1}, and 16 cm tip-to-collector distance from 10 wt% PAN/DMF solutions containing 10 wt% MOF loading. Comprehensive characterization by X-ray photoelectron spectroscopy (XPS), Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and Brunauer–Emmett–Teller (BET) surface area analysis confirmed successful MOF synthesis, uniform nanofiber morphology (250–350 nm diameter), and retention of functional groups post-electrospinning. BET surface areas of 691.1, 1217.5, and 1608.1 $m^2 g^{-1}$ were determined for UiO-66-NH_2, ZIF-8, and ZIF-67, respectively. Notably, UiO-66-NH_2 exhibited a Type IV(a) isotherm with H4 hysteresis — indicative of a hierarchical micro-mesoporous structure arising from amine-induced linker defect formation — in contrast to the Type I(b) microporous behavior observed for ZIF-8 and ZIF-67. The fabricated membranes were integrated into a hollow fiber membrane contactor operating with 1M NaOH absorbent at 10 PSI inlet pressure and 0.5 LPM gas flow rate for continuous 2-hour operation. CO_2 removal was monitored in real time by dual non-dispersive infrared (NDIR) sensors, with total inorganic carbon (TIC) analysis on the liquid absorbent side confirming mass balance closure of approximately 97%. UiO-66-NH_2/PAN achieved the highest CO_2 removal efficiency of 46.8%, followed by ZIF-67/PAN (32.4%), ZIF-8/PAN (26.1%), and pristine PAN baseline (8.2%). These results demonstrate that amine-mediated chemisorption dominates over physisorption driven by surface area at ambient CO_2 concentrations of 0.04%, establishing UiO-66-NH_2/PAN as a scalable, low-energy, and corrosion-free platform for direct air capture applications.

13:50 The Central Appalachian Partnership (CAP) for Carbon Storage Deployment: A Web-Based Tool for Site Characterization

Michele Johnston, PG, Geoscience Supervisor, Pennsylvania Geological Survey, 400 Waterfront Drive, Pittsburgh, PA 15222, USA
miljohnston@pa.gov, 412-442-4235
Kristin Carter, PG, Assistant State Geologist, Pennsylvania Geological Survey, 400 Waterfront Drive, Pittsburgh, PA 15222, USA
krcarter@pa.gov, 412-442-4235
Jessica Moore, Director, West Virginia Geological and Economic Survey, 1 Mont Chateau Road, Morgantown, WV 26508, USA
jmoore@wvgs.wvnet.edu, 304-594-2331
Philip Dinterman, Deputy Director, West Virginia Geological and Economic Survey, 1 Mont Chateau Road, Morgantown, WV 26508, USA
pdinterman@wvgs.wvnet.edu, 304-594-2331
Richard Binns, Manager GIS and Informational Services, West Virginia Geological and Economic Survey, 1 Mont Chateau Road, Morgantown, WV 26508, USA
rbinns@wvgs.wvnet.edu, 304-594-2331
Al Guiseppe, Geoscience Manager, Pennsylvania Geological Survey, 3240 Schoolhouse Road, Middletown, PA 17057, USA
aguiseppe@pa.gov, 707-702-2024
Katherine Schmid, PG, Senior Geoscientist, Pennsylvania Geological Survey, 400 Waterfront Drive, Pittsburgh, PA 15222, USA
kschmid@pa.gov, 412-442-4235

The Pennsylvania Geological Survey (PAGS), in partnership with the West Virginia Geological and Economic Survey (WVGES), was awarded DE-FE0032394 in January 2024 by the Department of Energy (DOE) National Technology Energy Laboratory (NETL). The project, Regional Initiative to Accelerate Carbon Capture, Utilization, and Storage (CCUS) Deployment – The Central Appalachian Partnership (CAP) for Carbon Storage Deployment represents a two-and-a-half-year effort to reduce barriers for entry to carbon storage project opportunities, particularly in the deepest parts of the Appalachian basin, thereby accelerating the deployment of CCUS in Pennsylvania and West Virginia.

The need for safe and secure geologic storage of carbon dioxide (CO2) is an important component for the energy transition in the Appalachian basin. The interest places state geological surveys in a unique position to help decrease technical barriers to entry that are commonly experienced by operators new to the basin while gaining access to industry-quality datasets to advance states' knowledge of subsurface geological frameworks. Over the past two decades, PAGS and WVGES have participated in the DOE's Regional Initiatives (RIs), which provided a strong foundation of subsurface geologic information for the basin. However, this work highlighted major data gaps that will translate to significant risk for companies interested in geologic storage. Primary among these data gaps are direct measurements of porosity and permeability in reservoir targets, geomechanical integrity tests of potential confining intervals, and spatial identification of pre-regulatory oil and gas wells that must be located, characterized, and potentially mitigated before a site can be considered for storage.

The CAP Project provides new, value-added technical and geologic information to the regional database by aggregating the most pertinent geologic and geospatial datasets in a free, public-facing Web-Based Tool. The Web-Based Tool, hosted by WVGES, incorporates the results of subsurface geologic mapping and strategic data acquisition into a centralized application that provides data visualization, data download, and technical outreach support capabilities. The "Geochemical and Rock Property Analysis" area of the tool presents analytical information for core and cuttings samples in Pennsylvania and West Virginia including geomechanical, porosity and permeability, and thermal maturation measurements along with mineralogy results. Three case studies are presented for southwest, central, and north-central Pennsylvania – areas that have extensive history of hydrocarbon production and are now being considered for CO2 enhanced gas recovery (EGR) and/or underground storage of CO2. The laboratory analytical results from these areas, with accompanying documents and map layers, are presented as case studies to demonstrate the utility of information within the tool, identify trends in reservoir and cap rocks and facilitate understanding of the subsurface as it relates to recovery and storage projects. The free access to map layers, well document downloads, legacy and new analytical information and related carbon capture, utilization, and storage (CCUS) data for both reservoir and cap rocks is the first of its kind for PAGS and WVGES. The tool will be available for use by industry, academia and the public in January 2027.

SESSION 6 (14:20 – 15:20)
CARBON STORAGE, COAL BED METHANE AND SHALE GAS

14:20 Offshore Carbon Sequestration Operations in the United States Outer Continental Shelf: A Literature Review and Synthesis of Potential Impacts to Marine Environments

Joel Sminchak, Senior Research Scientist, Battelle, 505 King Ave., Columbus, Ohio, USA
sminchak@battelle.org, 01-614-424-7392, 01-614-458-7392
Melissa Batum, Senior Geologist and Michelle Garig, Marine Biologist U. S. Bureau of Ocean Energy Management, 45600 Woodland Road, Sterling, Virginia, USA
Melissa.Batum@boem.gov, Michelle.Garig@boem.gov, 01-202-208-6474
Brigette Petras, Subsurface Scientist, Battelle, 505 King Ave., Columbus, Ohio, USA Petras@battelle.org
Kristen Bachand, Coastal Environmental Scientist, TRC, 404 Wyman Street, Suite 375, Waltham, MA 02451 USA

Geologic carbon sequestration projects are expanding to offshore locations along the United States Outer Continental Shelf (OCS). To better understand the potential impacts of offshore geologic carbon sequestration (CS) operations on marine environments of the Atlantic, Gulf of America, and Pacific OCS Regions, a focused literature review and synthesis was completed. The literature search identified 1,351 relevant journal articles and other sources that were compiled, organized, and summarized with natural language processing methods. The project team also interviewed 14 organizations experienced in offshore carbon sequestration to obtain their input on the state of the science regarding the impacts of offshore carbon sequestration. The references were organized into a database for use by the Bureau of Ocean Energy Management. Of the ~1400 literature sources, the project team identified and analyzed ~300 articles that directly relate to how geologic carbon sequestration operations may affect the physical, biological, and socioeconomic resources of the marine environment in the U.S. OCS. The articles were evaluated to provide data and information on impact producing factors, CS lifecycle activities, and environmental resources in each OCS Region. Monitoring options for the offshore US marine environment were also reviewed in relation to potential impacts to marine resources related to carbon sequestration. Recommendations for lease stipulations and conditions of approval for OCS carbon sequestration operations were provided.

Results of the study reflect the state of offshore carbon sequestration projects in the U.S. Other parts of the world have often focused on deploying offshore carbon sequestration, while active carbon sequestration projects in the U.S. are focused at onshore locations. As of 2026, there are ten offshore projects proposed in state waters off Louisiana and Texas currently in various stages of planning, but none are yet injecting CO_2. As such, much of the information on potential impacts from offshore carbon sequestration relies on projects in the UK, Norway, Australia, Japan, and other countries. Many articles covered multiple topics related to potential impacts to marine environments from CS activities. Articles in the search mostly focused on monitoring for CO_2 in the sub-seabed (56%) and modeling & characterization of deep geological rock layers (39%). Benthic communities & habitats (21%), water quality (20%), and invertebrates were also covered by many articles. The articles suggest there may be local impacts to marine resources due to activities like geologic and geophysical characterization, well construction, and monitoring. Impacts due to leakage or migration of CO_2 into the seabed or seawater would be localized near the leak and include biogeochemical changes. Each OCS Region

has unique physical, geological, biological, and socioeconomic resources for consideration during carbon sequestration activities. While many of the offshore oil and gas exploration and development technologies and operations are similar to offshore CS activities, such as geophysical surveying, drilling, and platform and pipeline construction, the manner, frequency, and duration of the use of these technologies for CS may, and in some cases will, be dramatically different from oil and gas. Therefore, although offshore oil and gas technologies and operations may serve as an analog for the purpose of identifying the impact producing factors and understanding potential environmental impacts for offshore CS, they must be reexamined within the framework of the CS lifecycle, which, for some operations, will identify potential impacts that are much different in scope than oil and gas operations.
This study funding was provided by the U.S. Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program, Washington, DC under Contract Number 140M0124R0003.

14:40 Biomass Carbon Removal and Storage (BiCRS) in Unmineable Coal Seams: An Adsorption-Dominated Mechanism Conferring Geologically Permanent Carbon Removal that Resolves the Early-Time Limitations of Conventional CCS

Michael A. Urynowicz
Professor, Department of Civil & Architectural Engineering and Construction Management
Director, Center for Biogenic Natural Gas Research
University of Wyoming
Laramie, WY. USA 82071-3295
307-766-4398
murynowi@uwyo.edu
Zaixing Huang
Associate Director, Center for Biogenic Natural Gas Research
University of Wyoming
Laramie, WY. USA 82071-3295
307-766-4398
zhuang@uwyo.edu
Samir Budhathoki
University of Wyoming
Laramie, WY. USA 82071

Durable carbon dioxide removal (CDR) is essential for achieving net-zero greenhouse gas emissions, yet conventional geological storage approaches — which rely on injection of mobile supercritical CO_2 into saline aquifers or depleted hydrocarbon reservoirs — face a fundamental early-time vulnerability: containment depends heavily on caprock integrity, pressure management, and long-term monitoring before slower trapping mechanisms take effect. Here we evaluate Biomass Carbon Removal and Storage (BiCRS) in unmineable coal seams as an adsorption-dominated alternative that resolves this limitation from the outset. In this system, also referred to as BiCRS+RNG when methane is recovered, biomass-derived organic substrates are converted in situ by indigenous microbial consortia into methane and CO_2, with CO_2 immobilized predominantly through molecular-scale adsorption onto the coal matrix under near-hydrostatic pressure conditions. Unlike conventional reservoirs where free-phase CO_2 remains buoyant and mobile for extended periods, coal seams immobilize CO_2 from inception, suppressing buoyancy-driven migration without reliance on time-dependent structural, residual, or solubility trapping. Vertically stacked coal seam architectures further enhance containment security by introducing distributed secondary barriers through multiple low-permeability interburden units. Using a simplified reservoir model comparing enhanced oil recovery (EOR)-based Class VI geological CO_2 storage with BiCRS in one- to three-seam coal systems, we demonstrate that BiCRS exhibits markedly lower early-time CO_2 mobility (<10–15% mobile fraction versus 50–60% in EOR), substantially reduced pressure perturbations (<1.5 MPa versus 10–15 MPa), and adsorbed fractions exceeding 85% in multi-seam configurations. These results demonstrate that BiCRS in unmineable coal seams shifts geological carbon storage from a caprock-dependent paradigm to one governed by pore-scale adsorptive immobilization, positioning coal seams among the lowest-risk reservoirs for millennial-scale durable carbon removal.

15:00 3D Geological Modelling of a Multi-Seam Coal Deposit for Methane Drainage Optimization in the Budryk Coking Coal Mine

Małgorzata Słota-Valim PhD Eng. Oil and Gas Institute – National Research Institute,
Lubicz 25A 31-503 Kraków, POLAND
slota-valim@inig.pl, *Phone: +48 12 421 00 33, Fax: +48 12 430 38 85*
Renata Cicha-Szot PhD Eng., Oil and Gas Institute – National Research Institute, Lubicz 25A, 31-503, Kraków, Poland
cicha-szot@inig.pl, Phone: +48 12 421 00 33, Fax: +48 12 430 38 85
Eugeniusz Krause, Prof. Eng., GIG - National Research Institute, Plac Gwarków 1, 40-166 Katowice, Poland
e.krause@gig.eu, Phone: +48 32 259 2000, Fax: +48 32 259 6533
Marcin Karbownik, PhD Eng., GIG - National Research Institute, Plac Gwarków 1, 40-166 Katowice, Poland
mkarbownik@gig.eu, +48 32 259 2000, Fax: +48 32 259 6533
Tomasz Goliwąs, MSc Eng., GIG - National Research Institute, Plac Gwarków 1, 40-166 Katowice, Poland
tgoliwas@gig.eu, Phone: +48 32 259 2000, Fax: +48 32 259 6533
Aleksandra Koteras, PhD Eng., GIG - National Research Institute, Plac Gwarków 1, 40-166 Katowice, Poland
akoteras@gig.eu, Phone: +48 32 259 2000, Fax: +48 32 259 6533
Dariusz Babczyński, MSc Eng., GIG - National Research Institute, Plac Gwarków 1, 40-166 Katowice, Poland
Email: dbabczynski@gig.eu, Phone: +48 32 259 2000, Fax: +48 32 259 6533

Coal mine methane (CMM) constitutes one of the major natural hazards affecting underground coal mining operations in the Upper Silesian Coal Basin (USCB), Poland. Effective methane drainage is therefore essential not only for improving mine safety but also for enhancing methane utilization as a low-carbon energy source. The design of methane drainage systems in multi-seam coal deposits requires detailed characterization of the geological structure, coal seam geometry, and spatial relationships between exploited seams and surrounding strata.

This study presents an integrated workflow for the development of a high-resolution 3D geological model of a multi-seam coking coal deposit in the Budryk Coal Mine, one of the most methane-rich mines operating within the USCB. The primary objective of the study was to develop a high-resolution 3D structural and geological model of the mine that could support the design and optimization of a methane drainage system for the planned extraction panel B-1 in seam 405/2.

The model was developed through the integration of multiple geological and mining datasets, including structural maps of coal seams, geological cross-sections, underground exploration boreholes, directional drilling trajectories, and lithological information from surface and underground investigations. Based on comprehensive data analysis, a detailed structural framework model was constructed, incorporating the geometry of the exploited seam, adjacent coal seams, fault systems, and methane-bearing strata occurring above and below the mined seam. Additionally, a detailed lithological and facies model was developed to reproduce the spatial distribution of coal seams and surrounding barren rocks. The model enabled the identification of lithological intervals providing favorable drilling conditions and improved borehole stability, while simultaneously supporting trajectory optimization and avoiding structural disturbances such as faults that could negatively affect drilling performance. The integrated structural and facies modelling workflow enabled an accurate reconstruction of the geometry and sequential arrangement of multiple coal seams and intervening strata.

The resulting 3D geological model was used to identify the most prospective methane drainage zones and to optimize the location, orientation, length, and spacing of directional drainage boreholes. Particular attention was given to the characterization of the methane emission sources associated with the mined seam, overlying coal seams, and surrounding fractured strata within the methane-bearing zone affected by longwall extraction. Based on the developed

geological framework and methane emission forecast, a methane drainage system consisting of 27 long-reach directional boreholes was designed for different stages of panel development and extraction.

The integrated geological modelling approach provided a consistent representation of the complex multi-seam geological architecture and enabled the development of a methane drainage strategy and provided a reliable geological framework for planning directional boreholes in a structurally complex multi-seam coal deposit. The results demonstrate that detailed 3D geological characterization constitutes a critical element of methane hazard management and supports the optimization of methane drainage systems in deep, methane-rich coking coal mines. The study highlights the role of integrated 3D geological modelling as a decision-support tool for methane drainage planning and methane hazard mitigation in complex multi-seam coal deposits.

FRIDAY, OCTOBER 30, 2026 — U.S. EASTERN DAYLIGHT TIME

SESSION 7 (10:30 – 11:50)
COAL SCIENCE, CLEAN FUELS AND VALUE-ADDED COAL PRODUCTS

10:30 Preparation of β-Zeolite Using Quang Ninh Coal Ash in Vietnam and their Reactivity in Catalytic Cracking of LDPE

Atsushi Ishihara, Mie University, 1577 Kurima Machiya-Cho, Tsu City, Mie Pref. JAPAN
Email ishihara@chem.mie-u.ac.jp, Phone 81-59-231-9434, Fax 81-59-231-9436
Kairi Hirayasu, Mr., Mie University, 1577 Kurima Machiya-Cho, Tsu City, Mie Pref., JAPAN
Takashi Nakane, Mr., Mie University, 1577 Kurima Machiya-Cho, Tsu City, Mie Pref., JAPAN
Seiya Kondo, Mr., Mie University, 1577 Kurima Machiya-Cho, Tsu City, Mie Pref., JAPAN
Hung Quang Viet Nguyen, Dr., Mie University, 1577 Kurima Machiya-Cho, Tsu City, Mie Pref., JAPAN
Shinya Matsuura, Dr., Mie Prefecture Industrial Institute, 5-5-45 Takajaya, Tsu City, Mie Pref., JAPAN
Tadanori Hashimoto, Dr., Mie University, 1577 Kurima Machiya-Cho, Tsu City, Mie Pref., JAPAN

Some of the coal ash contained in coal is reused for cement raw materials and roadbed materials in civil engineering and construction, while the majority of the remainder is treated as waste. As a way to utilize coal ash, since most coal ashes contain high levels of SiO_2 and Al_2O_3, the main components of zeolites, their potential as raw materials for zeolite synthesis has been considered. We have analyzed the composition of Vietnam Carbon ash, which has been rarely studied before, and examined the potential applications for these properties. Additionally, it has been reported that by utilizing the coal ash generated when Quang Ninh (QN) coal, which is rich in SiO_2 and Al_2O_3 among Vietnam coals, is burned, ZSM-5 zeolite can be directly synthesized, which can be used for the catalytic cracking of low-density polyethylene (LDPE). In this study, β-zeolite was synthesized using QN coal ash as a raw material and the catalytic cracking characteristics of LDPE were examined.

QN coal ash, which contains multiple metal elements, was heated at 1000°C to produce QN coal ash (real Quang Ninh Coal Ash, RQNCA). β-zeolite was synthesized by hydrothermal synthesis using colloidal silica as a source of insufficient silica, a structure-directing agent tetraethylammonium hydroxide (TEAOH), NaOH, and water. Raw materials were added to a stainless-steel sealed container, sealed at 145°C for 72 hours, and crystallized to prepare the product. Additionally, the H-type sample was prepared by cation-exchange with ammonium nitrate in the obtained Na-type sample. The sample was β_X (X: SiO_2-Al_2O_3 ratio,13~78). For catalyst characterization, XRD, nitrogen adsorption and desorption, NH_3-TPD, TEM and TG-DTA measurements were performed. Reaction experiments were conducted using a Curie Point Pyrolyzer under conditions of 1.0 mg catalyst, 500°C, 0.2 mg LDPE, and 0.6 MPa He. Liquid and gaseous products were directly analyzed using GC-FID. Samples with SiO_2-Al_2O_3 ratios of 13, 39, 52, and 78 were produced. As the SiO_2-Al_2O_3 ratio increased, the degree of crystallization tended to rise, and XRD measurements showed that the signal intensity increased, with the highest intensity at β_78, where less ash was used. Nitrogen adsorption and desorption measurements showed that as the SiO_2-Al_2O_3 ratio decreased, the BET surface area increased, consistent with the growth of zeolite crystals. On the other hand, BJH surface area and pore volume are not significantly different from commercially available β-zeolites, so they are hardly formed. In NH_3-TPD, regardless of the SiO_2-Al_2O_3 ratio of the sample, catalysts with RQNCA showed a decrease in acid sites. This is thought to be because alkali and alkaline earth metals left in the catalyst neutralized the acid sites. On the other hand, β_78 showed an increase in amount of acid sites. Although the amount of Al decreased due to an increase in the SiO_2-Al_2O_3 ratio, it is thought that as crystallization progressed, the remaining Al was incorporated into the zeolite skeleton. The amounts of Ti and Fe also decreased, but these elements are known to be incorporated into the zeolite skeleton, suggesting that new acid sites may be formed as crystallization progresses. TG-DTA measurements show a decreasing trend compared to commercially available β-zeolites, suggesting that the acid site neutralization by added ash in samples is considered to have an effect.

CPP reaction experiments showed that conversions of β_13 and β_39 were lower than that of commercial β-zeolite, and the main cause is thought to be the reduction in amount of acid sites due to residual base components. On the other hand, β_52 and β_78 showed conversions equivalent to β-zeolite, suggesting that increased crystallinity and maintenance of the acid sites were related. Regarding the generated gasoline fractions, it was found that catalysts using RQNCA showed a decrease in amount of acid sites, while the olefin/paraffin ratio decreased and paraffin increased. This suggests that the residual Fe fraction in the ash may have accelerated the hydrogen transfer reaction. The *iso-*/*n-* ratios of β_52 and β_78 were higher than other catalysts, which is thought to be related to improved crystallinity.

10:50 Evolution of Carbon Skeleton and Primary Volatiles from Fast Pyrolysis of Low-Rank Coal in N_2 and/or H_2 atmosphere

Yan-Hong Liu[a,b], Wang Li[b], Yu-Han Sun[b], Wen-Ying Li[a,b,*]
[a] State Key Laboratory of Clean and Efficient Coal Utilization (Taiyuan University of Technology), Taiyuan 030024, China
[b] Shanxi Research Institute of Huairou Laboratory, Taiyuan, 030031, China
Email address: liuyanhong0193@link.tyut.edu.cn; liwang@sxri.hrl.ac.cn; sunyh@sxri.hrl.ac.cn; ying@tyut.edu.cn; Tel.: & fax, +86-351-6018453

Fast pyrolysis of low-rank coal is a feasible route to produce tar for coal-valued liquid fuels. Nevertheless, the transformation mechanisms of primary volatiles under hydrogen and inert atmospheres remain ambiguous. In this work, isothermal fixed-bed pyrolysis experiments combined with an online pyrolysis-synchronous vacuum ultraviolet single-photon ionization time-of-flight mass spectrometry (Py-SVUV-TOF-PIMS) system were adopted to simulate fast pyrolysis with heating rates exceeding 10^3 °C/s. The temperature-programmed module delivered coal samples to pre-set reaction zones accurately, enabling in-situ capture of dynamic evolution information of transient volatile products. A comparative investigation on the skeletal structural evolution and primary volatile release behaviors of low-rank coal under N_2 and H_2 atmospheres was carried out. Benefiting from the soft ionization property of vacuum ultraviolet single-photon ionization, secondary fragmentation of products was greatly suppressed to realize high-precision in-situ diagnosis of transient volatiles. Electron paramagnetic resonance (EPR), Fourier transform infrared spectroscopy (FTIR), Raman spectroscopy and solid-state ^{13}C nuclear magnetic resonance (NMR) were further utilized to characterize the carbon structural evolution of pyrolytic semi-coke. Results demonstrated that both the escape rate and signal intensity of volatiles continuously increased within 400–650 °C. Short-chain olefins generated by the cleavage of aliphatic side chains reached their maximum release at 25 s, while polycyclic aromatic hydrocarbons exhibited obvious release hysteresis.

Alkyl naphthalene presented bimodal signals originating from primary pyrolysis and intermolecular polycondensation, which directly verified the distinct activation energy barriers for the depolymerization of aliphatic chains and aromatic nuclei. Compared with nitrogen atmosphere, hydrogen radicals reduced pyrolysis activation energy and advanced the release temperatures of olefins and monocyclic aromatics. The maximum tar yield reached 0.172 $g \cdot g^{-1}_{coal,\ daf}$ under H_2 atmosphere, representing a 4.526 wt% improvement relative to N_2 atmosphere. Hydrogen radicals facilitated hydrodeoxygenation reactions to suppress the formation of diphenols and enrich monophenols favorable for fuel upgrading, meanwhile alleviating the polycondensation of aromatic fused rings in semi-coke. This study clarifies the differentiated formation pathways of aliphatic fragments and polycyclic aromatics under two atmospheres, and reveals the regulatory mechanism of hydrogen radicals on pyrolysis intermediates and solid carbon skeletons, providing theoretical guidance for targeted enhancement of tar yield and component optimization of coal-based liquid fuels.

Keywords: fast pyrolysis, low-temperature coal tar, Py-SVUV-TOF-PIMS; modulation of target product formation

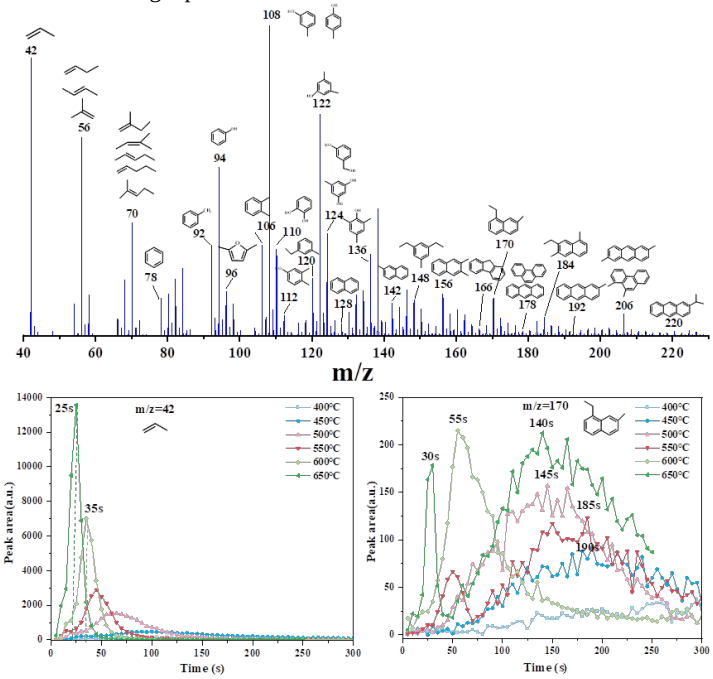


Figure 1. Release profiles of volatiles measured by Py-SVUV-TOF-PIMS as a function of temperature.

11:10 Separation of polycyclic aromatic hydrocarbons in coal direct liquefaction oil

Meng-Yao Chen, Master, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA 2024520943@link.tyut.edu.cn, Phone: +86-351-6018957, Fax: +86-351-6018453

Yun-Cai Song, Associate Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA*

Email: songyuncai@tyut.edu.cn, Phone: +86-351-6018957, Fax: +86-351-6018453

Jie Feng, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA

Email: fengjie@tyut.edu.en, Phone: +86-351-6018957, Fax: +86-351-6018453

Wen-Ying Li, Professor, State Key Laboratory of Clean and Efficient Coal Utilization, Taiyuan University of Technology, Taiyuan, CHINA

Email: ying@tyut.edu.cn, Phone: +86-351-6018957, Fax: +86-351-6018453

Coal direct liquefaction oil is rich in high-value components such as alkanes and aromatics. Achieving efficient enrichment of these homologous components and purification of aromatic monomers is of practical significance for reducing dependence on petroleum and enhancing the high-value utilization of coal resources. This study identifies naphthalene and methylnaphthalene as the target separation monomers, based on the characteristics of the oil composition and the product value. Based on the distribution characteristics of the oil components, and combining screening using COSMO software, phase equilibrium experiments, and solvent extraction experiments with actual oil samples, the extractants were systematically evaluated. Results indicated that dimethyl sulfoxide (DMSO) was the optimal extractant; the optimal process conditions were a mass ratio of extractant to crude oil of 2:1 and an extraction temperature of 50 °C, under which the mass fraction of the mixed aromatics reached 81.27 wt% and the extraction yield was 41.30%. The separation efficiency was primarily attributed to the significant differences between alkanes and aromatics in terms of molecular polarity index (MPI) and van der Waals surface electrostatic potential.

11:30 Application of Composite External Electron Donor Technology to Anti-Agglomeration in Coal-Based Polypropylene Production

Peiqian Yu, Professor of Engineering, National Institute of Clean-and-Low-Carbon Energy, #9 Chuanghua Road, Future Science & Technology City, Changping Dist., Beijing, 102211 P. R. of China

peiqian.yu@chnenergy.com.cn, +86-10-57595665

Yufei Bian, Zhigang Zheng, Xu Liu, Guogang Liu, Yusen Jia, Rongjuan Cong, Linfeng Chen. National Institute of Clean-and-Low-Carbon Energy, #9 Chuanghua Road, Future Science & Technology City Changping Dist., Beijing, 102211 P. R. of China

With the continuous advancement and refinement of modern coal chemical technology, along with its distinct cost advantages and robust resilience to price fluctuations, the coal-based polyolefin industry has come into a phase of rapid development. By the end of 2024, the total production capacity of coal-based polyolefin had reached 19.72 million tons per year, accounting for 25.3% of the national total capacity in China. Moreover, the additional investment is expected to exceed 600 billion RMB in the coal chemical industry by 2026, the production capacity expansion for coal-based polyolefin is on the horizon. Coal-based polyolefin has become a significant growth driver in the polyolefin sector.

From the standpoint of the polymerization process, the coal-based polyolefin processes are almost identical to those of oil-based polyolefin. There is a difference that coal-based polyolefin plants operate on a significantly larger scale, where ensuring safe production and long-term operation are of importance. In practice, the polypropylene plant is prone to particle agglomeration, which can be attributed to several factors: high catalyst activity, accelerated polymerization kinetics, excessive fines content, high comonomer incorporation, reduced isotacticity, and stringent control requirements. The combination of the highly exothermic nature of Ziegler-Natta (ZN) catalyzed polymerizations and the tendency of PP to become sticky under localized hot spots makes thermal runaway a real risk, leading to particle agglomeration.

The novel composite external electron donor technology for industrial coal-based polypropylene production, named NICE-DT-4, has been successfully developed and applied in an Innovene gas-phase PP plant with a capacity of 450,000 tons per year. Through precise regulation of the composite external electron donor formulation, not only can the key properties of random copolymer polypropylene be effectively controlled, including ethylene incorporation rate and distribution, high molecular weight distribution, isotacticity, and soluble fraction content, but more significantly, the technology has effectively improved the agglomeration problem in random copolymer polypropylene production, enabling stable continuous production while maintaining the original product performance. This achievement provides solid technical support for stable plant operation and continuous production of high-quality new polypropylene products.

SESSION 8 (12:50 – 14:10)
GAS UTILIZATION, COMBUSTION TECHNOLOGIES, AI AND DIGITAL TWIN

12:50 Pakistan Needs Gas

Dr. Farid A. Malik
FCC University
Lahore, Pakistan
Email: faridmalik@fccollege.edu.pk
Engr. Abid Aziz
Pak Motors (Pvt) Ltd
Pakistan

Ever since the discovery of natural gas in the year 1952, Pakistan remained an energy surplus nation. At 12 TCF (Trillion Cubic Feet), it was one of the largest deposits of its time. An extensive gas transmission and distribution network spread over 20,000 km was built to facilitate use of this clean fuel.
Unfortunately, due to excessive use and mismanagement, the resource was depleted by 2002, resulting in a shortfall. Currently, about 2000 to 3000 MMCFD LNG (Liquefied Natural Gas) is being imported from Qatar. Considering the spiraling cost, this is a short-term fix.
As the country has an extensive gas network, the most viable option be considered together with affordable, and sustainable source of gas. With a massive coal deposit of 175 billion tons at Thar, gasification is an option to produce both Syngas and Substitute Natural Gas (SNG). In order to meet its fertilizer needs, work has started on building a urea plant based on Syngas produced at site. The cost of producing SNG can be lowered by increasing the coal being mined in Blocks I and II currently 7.6 million tons per year each is being extracted. Shale gas is also an option, and so is the cross-border pipeline from Iran, which has been completed under agreement on the Iranian side. A waiver of sanctions can greatly enhance the adoption of this option. In order to meets its energy needs, Pakistan urgently requires a reliable and affordable source of gas.

13:10 Overview of Mercury Control Options for Coal-Burning Power Plants

Evan J. Granite
United States Department of Energy
e-mail: evan.granite@doe.gov

Coal contains a trace level of mercury of approximately 0.1 ppm. Mercury is a neurotoxin, and elemental mercury can travel long distances once emitted through the stacks of coal-burning power plants. Elemental mercury is slowly oxidized in the atmosphere by species such as ozone, halogens, and hydroxyl radicals. Precipitation removes oxidized mercury from the atmosphere, and deposits it into lakes, rivers, and streams, where it can enter the food chain in the form of methylmercury and accumulates in large fish such as tuna, swordfish, mackerel and shark at the top of the food chain.
Everything that is in the Earth's crust is also present in coal to some extent, and the challenge is always to use abundant domestic coal for a prosperous economy and environment. Trace and minor elements present within the coal such as mercury, arsenic, selenium, cadmium, antimony, phosphorus, chlorine, sulfur and nitrogen, have long been of interest to the DOE and its predecessor agencies due to their roles in producing pollution emissions from combustion and gasification plants. Research on mercury, spurred by concerns on the emissions associated with the combustion of coal began in the early 1970s. Critical elements, such as some of the rare earths present within the coal, have recently been of great interest due to their importance in the world's economy. The DOE Mercury Program started in the mid-1990s. More than $120 million in Federally funded extramural and in-house research was conducted, including more than $30 million in private-sector cost sharing. The research was on five interrelated research areas: Emissions characterization; Development and testing of measurement devices; Speciation research; Development and field testing of control technologies; and Coal utilization byproducts (CUBs) characterization.
Coal is an important resource, both in the United States and around the world. The United States generates approximately 17 percent of its electricity through coal combustion and, at the current overall rate of consumption, has more than a 500-year supply of coal. According to the US Energy Information Administration, approximately 1 Gt of coal has been mined annually in the United States over the twenty-five year period (1990-2014), although the 2025 total was 533 million tons. The recent decline in domestic coal production is due to the availability of inexpensive natural gas; regulatory uncertainty with regards to carbon dioxide emissions; and the retirement of older coal-fired power plants.
In the United States, eighty percent of the coal produced is typically burned for power generation. In addition, substantial quantities of domestic coal are also used in the manufacture of steel, chemicals, and activated carbons, as well as for exports. Numerous industries, such as mining, power, rail transportation, manufacturing, chemical, steel, activated carbon, and fuels, are involved in the production, transportation, and use of coal.
With the USEPA issuing a national regulation requiring removal of mercury, the need exists for low-cost mercury removal techniques that can be applied to coal-burning power plants. The injection of powdered activated carbon into the ductwork upstream of the particulate control device is the most developed technology for mercury capture and has been recently deployed at many US coal-burning power plants. Alternative techniques for mercury capture will also play a role in the near future because of the numerous configurations of air pollution control devices present within the power plants, as well as the many different coals being burned. These methods employ sorbents, catalysts, scrubber liquors, flue gas or coal additives (typically halogens), combustion modification, flue gas cooling, barrier discharges, and ultraviolet radiation for the removal of mercury from flue gas streams. The DOE in-house research on mercury and other trace element contaminants included work on sorbents, catalysts, photochemical, environmental, trace measurement, flue gas chemistry, and syngas impacts upon capture.
Coal is typically burned in twenty percent excess air for complete combustion at a power plant. Flue gas exits the furnace at approximately 2500°F, and heat is extracted along the combustion pathway to make steam to turn a turbine, converting the chemical energy in coal to electrical energy. Untreated coal-derived flue gas is a complex stew, containing moisture, particulates, acid gases, as well as 1 ppb of mercury present in the elemental, compound (presumably as mercuric chloride and bromide) and particulate bound forms. A representative composition of an untreated flue gas is shown in Table 1 below:

Table 1: Typical Composition of an Untreated Coal-Derived Flue Gas

CO_2	13 – 16%
O_2	3 – 4%
H_2O	5 - 7%
N_2	balance – approximately 73%
HCl	10 – 100 ppm
SO_2	100 – 2000 ppm
SO_3	1 – 40 ppm
NO_x	100 – 500 ppm
CO	20 ppm
Hydrocarbons	10 ppm
Total Hg	1 ppb
Fly ash	as small, entrained particulates

Pollution control devices such as SCR catalysts, wet scrubbers, electrostatic precipitators or fabric filter baghouses dramatically reduce the emissions of NOx, SO_2, SO_3, HCl and entrained fly ash particulates, and can also help capture mercury. Mercury is a semi-noble metal, is highly insoluble in water, and can be difficult to capture from flue gas. Control technologies for removing mercury from flue gas include scrubbing solutions and activated carbon sorbents. Mercuric chloride is soluble in water; elemental mercury is not. Dry sorbents have the potential to remove both elemental and oxidized

forms of mercury. Much of the research and commercial efforts for mercury control have focused on adsorption on powdered activated carbons; capture within the wet scrubbers; halogen additives to the coals and flue gas; and oxidation of mercury across the existing SCR catalysts. A schematic of a coal-fired power plant is shown below in Figure 1.

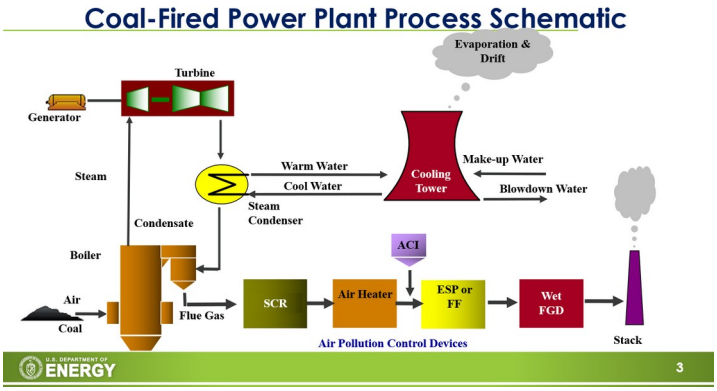


Figure 1: Coal-Fired Power Plant

The infinitesimally small concentration of mercury, present in several forms within a harsh and complex matrix, makes measurement and removal of this pollutant a great and exciting challenge. In the 1990's, an analogy between flue gas and baseball was made to explain this great challenge. Imagine the Houston Astrodome, holding 30 billion ping pong balls representing flue gas. There will be only 30 different colored mercury ping pong balls (representing elemental mercury, mercuric chloride, mercuric bromide, and particulate bound mercury) present in untreated flue gas; these need to be measured; and 27 – 30 (almost all of them) need to be removed.

It was estimated in the year 2000 that mercury could be removed at a cost of $50,000–70,000 per pound. The challenge was compared to finding a needle in a haystack; happily, this challenge has been met, and at a cost far lower than originally estimated (around $10,000 per pound).

The DOE Mercury Program has been a huge success, spurring continuing development, demonstration, and commercialization of many technologies for the capture of mercury. Great progress has been made in reducing the mercury emissions from coal-fired power plants. Approximately 48 tons of mercury were emitted from the stacks of domestic coal-burning power plants in 2000, whereas 5 – 15 tons were emitted in 2017, and less than 5 tons will be emitted annually by 2026.

The on-going research needs for mercury control at coal-burning power plants include improved sorbent-flue gas contact, development of poison-resistant sorbents and catalysts, novel sorbent promoters, new scrubber additives for retention of mercury within wet FGD systems, concrete-friendly activated carbons, new continuous measurement methods, byproducts research, development of ASTM standard lab tests for sorbent activity for mercury capture, and exploration of international markets.

References

1. "Chemistry of Trace Inorganic Elements in Coal Combustion Systems: A Century of Discovery", Connie Senior, Evan Granite, William Linak, Wayne Seames, Energy & Fuels, 34 (12), 15141-15168, 2020.
2. "Mercury Control for Coal-Derived Gas Streams", Evan J. Granite, Henry W. Pennline, Connie Senior, editors and co-authors, Wiley-VCH, January 2015.
3. "Comment on "Mercury Oxidation by UV Irradiation: Effect of Contact Time, UV Wavelength, and Moisture Content", Evan J. Granite, Industrial & Engineering Chemistry Research, 56, 9408−9409, 2017.
4. "Preface", Evan J. Granite, in "Mercury Control for Coal-Derived Gas Streams", Wiley-VCH, January 2015.
5. Chapter 21, "Novel Capture Technologies: Non-Carbon Sorbents and Photochemical Oxidations", p. 339-356, Karen J. Uffalussy and Evan J. Granite in "Mercury Control for Coal-Derived Gas Streams", Wiley-VCH, January 2015.
6. Chapter 22, "Sorbents for Gasification Processes", p. 357-374, Henry W. Pennline and Evan J. Granite in "Mercury Control for Coal-Derived Gas Streams", Wiley-VCH, January 2015.
7. Arsenic Adsorption on Palladium-Copper Alloy Films, Karen Uffalussy, James Miller, Bret Howard, Dennis Stanko, Evan Granite, Industrial & Engineering Chemistry Research, 53(18), 7821-7827, 2014.
8. Pilot-Scale Capture of Mercury, Arsenic and Selenium from Warm Syngas at Elevated Pressures by Palladium Sorbents, Evan Granite, Hugh Hamilton, Stephen Poulston, Liz Rowsell, Wilson Chu, Andrew Smith, Tony Wu, Subhash Datta, Robert Lambrecht, John Wheeldon, Henry Pennline, to be submitted to Industrial & Engineering Chemistry Research, November 2026.
9. Evaluation of Palladium-Based Sorbents for Trace Mercury Removal in Electricity Generation, Christopher Munson, Pradeep Indrakanti, Massood Ramezan, Evan Granite, Jenny Tennant, International Journal of Clean Coal and Energy, 3, 65-76, November 2014.
10. Laboratory Scale Studies of Pd-Al2O3 Sorbents for the Removal of Trace Contaminants from Coal-Derived Fuel Gas at Elevated Temperatures, Erik C. Rupp, Evan J. Granite, Dennis C. Stanko, Fuel, 108, 131-136, June 2013.
11. Catalytic Formation of Carbonyl Sulfide during Warm Gas Clean-Up of Simulated Coal-Derived Fuel Gas with Palladium Sorbents, Erik C. Rupp, Evan J. Granite, Dennis C. Stanko, Fuel, 92, 211-215, February 2012.
12. Palladium Based Sorbents for High Temperature Arsine Removal from Fuel Gas, Stephen Poulston, Evan J. Granite, Henry Pennline, Hugh Hamilton, Andrew W.J. Smith, Fuel, 90, 3118-3121, October 2011.
13. Effect of Dispersion on the Capture of Toxic Elements from Fuel Gas by Palladium-Alumina Sorbents, John P. Baltrus, Evan J. Granite, Erik C. Rupp, Dennis C. Stanko, Bret Howard, Henry W. Pennline, Fuel, 90, 1992-1998, May 2011.
14. Method for Detection of Trace Metal Contaminants in Coal-Generated Fuel Gas Using Gas Chromatography – Ion Trap Mass Spectrometry, Erik Rupp, Evan J. Granite, Dennis C. Stanko, Analytical Chemistry, 82(14), 6315-6317, July 15, 2010.
15. Surface Characterization of Palladium-Alumina Sorbents for High Temperature Capture of Mercury and Arsenic from Fuel Gas, John P. Baltrus, Evan J. Granite Henry W. Pennline, Dennis C. Stanko, Hugh Hamilton, Stephen Poulston, Liz Rowsell, Andrew Smith, Wilson Chu, Fuel, 89(6), 1323-1325, June 2010.
16. Ancillary Oxygen-Fired Combustion with Electrochemical Cells, Henry W. Pennline, Evan J. Granite, David Luebke, John Kitchin, James Landon, Lisa Weiland, Fuel, 89(6), 1307-1314, June 2010.
17. Preface – Special Issue: Advanced Fossil Fuel Utilization: Emissions and Control, Dushyant Shekhawat, Evan J. Granite, Henry W. Pennline, Dave Berry, James Spivey (Guest Editors) Fuel, 89(6), 1185-1186, June 2010.
18. Measurement of Mercury Flux from Coal Utilization By-Products with a Laboratory Flux Chamber, Natalie Pekney, Don Martello, Karl Schroeder, Evan J. Granite, Fuel, 88(5), 890-897, May 2009.
19. The Implications of Mercury Interactions with Band-Gap Semiconductor Oxides, Evan J. Granite, William P. King, Dennis C. Stanko, and Henry W. Pennline, Main Group Chemistry, 7(3), 227-237, September 2008.
20. Surface Characterization of Pd/Al2O3 Sorbents for Mercury Adsorption from Fuel Gas, John P. Baltrus, Evan J. Granite Henry W. Pennline, and Dennis C. Stanko, Main Group Chemistry, 7(3), 217-225, September 2008.
21. Preface – Special Issue: Mercury and other Trace Elements in Fuel: Emissions and Control, Evan J. Granite, (Guest Editor) Main Group Chemistry, 7(3), 167, September 2008.
22. Comment on Role of SO2 for Elemental Mercury Removal from Coal Combustion Flue Gas by Activated Carbon, Evan J. Granite and Albert A. Presto, Energy & Fuels, 22, 3557-3558, September 2008.
23. Noble Metal Catalysts for Mercury Oxidation in Utility Flue Gas, Albert A. Presto and Evan J. Granite, invited paper for Platinum Metals Review, 52(3), 144-154, July 2008.
24. Reply to Comment on "Impact of Sulfur Oxides on Mercury Capture by Activated Carbon", Evan J. Granite, Albert A. Presto, Environmental Science & Technology, 42, 972, January 2008.
25. Further Investigation of the Impact of Sulfur Oxides on Mercury Capture by Activated Carbon, Albert A. Presto, Evan J. Granite, Andrew Karash, Industrial & Engineering Chemistry Research, 46, 8273-8276, November 2007.

26. The Thief Process for Removal of Mercury from Flue Gas, Evan J. Granite, Mark C. Freeman, William J. O'Dowd, Richard A. Hargis, Henry W. Pennline, Journal of Environmental Management, 84(4), 628-634, September 2007.
27. Impact of Sulfur Oxides on Mercury Capture by Activated Carbon, Albert A. Presto and Evan J. Granite, Environmental Science & Technology, 41(18), 6579-6584, September 2007.
28. Metal Sorbents for High Temperature Mercury Capture from Fuel Gas, Stephen Poulston, Evan J. Granite, Henry W. Pennline, Christina R. Myers, Dennis P. Stanko, Hugh Hamilton, Liz Rowsell, Andrew W. J. Smith, Thomas Ilkenhans, and Wilson Chu, Fuel, 86(14), 2201-2203, September 2007.
29. Sorbents for Mercury Capture from Fuel Gas with Application to Gasification Systems, Evan J. Granite, Christina R. Myers, William P. King, Dennis Stanko, Henry W. Pennline, Industrial & Engineering Chemistry Research, 45(13), 4844-4848, June 2006.
30. Critical Review: Survey of Catalysts for Oxidation of Mercury in Flue Gas, Albert A. Presto and Evan J. Granite, Environmental Science & Technology, 40(18), 5601-5609, September 2006.
31. A Kinetic Approach to the Catalytic Oxidation of Mercury in Flue Gas, Albert A. Presto, Evan J. Granite, Andrew Karash, Richard A. Hargis, William J. O'Dowd, and Henry W. Pennline, Energy & Fuels, 20(5), 1941-1945, September 2006.
32. A Method to Remove Mercury from Flue Gas: The Thief Process, Henry W. Pennline, William J. O'Dowd, Mark C. Freeman, Evan J. Granite, Andrew Karash, Clem Lacher, Fuel Processing Technology, 87(12), 1071-1084, December 2006.
33. The PCO Process for Photochemical Removal of Mercury from Flue Gas, Christopher McLarnon, Evan J. Granite, Henry W. Pennline, Fuel Processing Technology, 87(1), 85-89, December 2005.
34. Effect of Porous Structure and Surface Functionality on the Mercury Capture of a Fly Ash Carbon and its Activated Sample, M. Mercedes Maroto-Valer, Y. Zhang, Evan J. Granite, Zhong Tang, Henry W. Pennline, Fuel, 84, 105-108, January 2005.
35. Mercury Detection at Boron Doped Diamond Electrodes Using a Rotating Disk Technique, A. Manivannan, L. Ramakrishnan, M.S. Seehra, Evan J. Granite, J.E. Butler, D.A. Tryk, A. Fujishima, Journal of Electroanalytical Chemistry, 577, 287-293, April 2005.
36. Review of Novel Methods for Carbon Dioxide Separation from Flue and Fuel Gases, Evan J. Granite, Thomas O'Brien, Fuel Processing Technology, 86, 1423-1434, October 2005.
37. Recent Advances in Mercury Removal Technology at the National Energy Technology Laboratory, William J. O'Dowd, Richard A. Hargis, Evan J. Granite, Henry W. Pennline, Fuel Processing Technology, 85, 533-548, 2004.
38. DOE/NETL's Mercury Control Technology Research Program for Coal-Fired Power Plants, Tom Feeley, James Murphy, Jeff Hoffmann, Evan Granite, and Scott Renninger, EM, 16-23, October 2003.
39. 2003 AWMA Critical Review: Separation and Capture of CO2 from Large Stationary Sources and Sequestration in Geological Formations - Coalbeds and Deep Saline Aquifers, Curt White, Brian Strazisar, Evan Granite, James Hoffman, and Henry Pennline, J. Air & Waste Manage. Assoc., 53(6), 645-715, June 2003.
40. Separation and Capture of CO2 from Large Stationary Sources and Sequestration in Geological Formations, Curt White, Brian Strazisar, Evan Granite, James Hoffman, and Henry Pennline, EM, 29-34, June 2003.
41. Photochemical Removal of Mercury from Flue Gas, Evan Granite and Henry Pennline, Industrial & Engineering Chemistry Research, vol. 41, pp. 5470-5476, October 2002.
42. Novel Sorbents for Mercury Removal from Flue Gas, Evan Granite, Henry Pennline, and Richard Hargis, Industrial & Engineering Chemistry Research, vol. 39, pp. 1020-1029, April 2000.
43. Effects of Photochemical Formation of Mercuric Oxide, Evan Granite, Henry Pennline, and James Hoffman, Industrial & Engineering Chemistry Research, vol. 38, pp. 5034-5037, December 1999.
44. An Assessment of Potential Sorbents for Mercury Removal from Fuel Gas, William King, Evan Granite, and Henry Pennline, United States Department of Energy Topical Report, July 2003.
45. Sorbents for Mercury Removal from Flue Gas, Evan Granite, Henry Pennline, and Richard Hargis, United States Department of Energy Topical Report, Federal Energy Technology Center TR-98-01, January 1998.
46. Thief Process for the Removal of Mercury from Flue Gas, Henry Pennline, Evan Granite, Mark Freeman, William O'Dowd, and Richard Hargis, U.S. Patent 6,521,021; February 18, 2003.
47. Method for Removal of Mercury from Various Gas Streams, Evan J. Granite and Henry W. Pennline, U.S. Patent 6,576,092; June 10, 2003.
48. Method for High Temperature Mercury Capture from Gas Streams, Evan J. Granite and Henry W. Pennline, U.S. Patent 7,033,419; April 25, 2006.
49. Catalysts for Oxidation of Mercury in Flue Gas, Evan J. Granite and Henry W. Pennline, U.S. Patent 7,776,780; August 17, 2010.
50. Semi-Continuous Detection of Mercury in Gases, Evan J. Granite and Henry W. Pennline, U.S. Patent 8,069,703; December 6, 2011.
51. Thief Carbon Catalyst for Oxidation of Mercury in Effluent Stream, Evan J. Granite and Henry W. Pennline, U.S. Patent 8,071,500, December 6, 2011.
52. Ancillary Oxygen-Fired Combustion with Electrochemical Cells, Henry W. Pennline, Evan J. Granite, and David Luebke, Filed with US Patent & Trademark Office January 2008.
53. Iridium-Based Catalysts for Oxidation of Mercury, Evan J. Granite and Henry W. Pennline, U.S. Patent Application, DOE Case S-105,871, Filed with US Patent & Trademark Office, July 14, 2010.

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Acknowledgement

The author thanks Badie Morsi, Massood Ramezan, and the PECMC for the opportunity to present this talk, and his DOE colleagues Adam Wong and Sarah Forbes for their support.

13:30 CFD simulation of large-scale pressurized oxy-fuel combustion—understanding the mechanism of solid-fuel flame stabilization

Mao Cheng, Staff Scientist, Washington University in St. Louis, St. Louis, MO 63130, USA
chengmao@wustl.edu, 314-798-8530
Duarte Magalhaes, Staff Scientist, Washington University in St. Louis, St. Louis, MO 63130, USA
duartenuno@wustl.edu, 314-935-7899
Richard Axelbaum, Professor, Washington University in St. Louis, St. Louis, MO 63130, USA
axelbaum@wustl.edu, 314-935-7560

Staged, pressurized oxy-combustion (SPOC) is a novel combustion technology for next-generation power plants supplying reliable, clean, low-cost, and carbon-free electricity. To scale up the SPOC process using PRB coal as a fuel, we designed a 5 MW_{th} SPOC burner and combustor. A computational fluid dynamics (CFD) model, which has been validated with experimental work on a 100 kW_{th} pilot-scale facility at Washington University, was utilized for this scale up. In this study, we conducted extensive CFD simulations on the 5 MW_{th} combustor and performed an in-depth analysis to understand the mechanisms of solid-fuel flame stabilization. The results demonstrate that the large-scale SPOC system can achieve a stable and robust flame, with near-complete burnout in a short residence time. To optimize burner performance, we varied critical parameters, including key structural dimension, oxidizer flow rate, and fuel carrier flow rate. The impact of these parameters were evaluated by analyzing temperature profiles, flow field streamlines, solid

volume fraction, turbulent viscosity, devolatilization rate, CO source rate, volatile fraction, and CO concentration. Comprehensive analyses of the combustion process—encompassing turbulence, gas-solid two-phase fluid mechanics, heat transfer, fuel devolatilization, char gasification, gas-phase reactions, and species transport—were conducted. Finally, a theoretical framework was established to elucidate the complex process of establishing a stable flame.

13:50 Visualization and Quantification of Coal Pores in Atomistic Representations with Eureka Grid Immersion and Retention

Jonathan P. Mathews, Professor, Penn State, 126 Hosler Building, 58 Pollack Road, State College, PA 16802, USA
JMathews@psu.edu, 814-863-6213
Justin K. Watson, Associate Professor, University of Florida, 135A Rhines Hall, 549 Gale Lemerand Dr., Gainesville FL 32611, USA
justin.watson@ufl.edu, Phone 352 273-0241, Fax 352 392-7219

The porosity, pore: size, shape, and connectivity are key parameters that influence the behavior of coal, products, and chars. While there are multiple approaches to quantify the pore size distribution, they all rely on a simplistic shape assumption. The pores in the molecular models/atomistic representations are also difficult to observe when the scale becomes reasonable, that is, large enough to capture a portion of the pore size distribution (micro- and into the mesopore range). While absorbed molecules, solvent surfaces, and wedge slices can provide some insight, they fail to fully reveal the pore structure. Here, a new approach is demonstrated on existing molecular structures. The structure is immersed in a fitted grid of 2Å spacing, and each grid atom is interrogated to see if it is in empty space or overlapping with a structural atom. The grid atoms within empty space are retained and are isolated into pore molecules/objects within PyMOL software. Thus, by atom-filling the individual pores, they become objects/molecules and can be colored to aid communication, and their size and shape can be directly quantified (without a shape assumption) as they are now actual structures rather than empty space. They can also be moved and arranged on a grid to fully show the pore structure components. Those pores that are open and closed to the individual cube surfaces can also be determined. This rapid approach (atom-filling of pores via the EUREKA grid-immersion retention) solves a bottleneck for progression towards digital twins for coal samples. EUREKA programming was completed with the assistance of AI (ChatGPT). This capability is likely to have utility in a broad swath of traditional coal (combustion, gasification, coalbed methane, and CO_2 sequestration) and emerging coal uses (hydrogen storage and battery anodes).

SESSION 9 (14:20 – 15:20)
COAL BED METHANE, SHALE GAS AND CARBON MANAGEMENT

14:20 Assessment of Geological and Mining Factors Controlling Mining-Induced Methane Accumulation Potential in Underground Coal Mines

Grzegorz Suszka
Polish Geological Institute - National Research Institute
Upper Silesian Branch in Sosnowiec, POLAND
grzegorz.suszka@pgi.gov.pl
+48 (32) 296 48 14

Reducing atmospheric methane emissions is a crucial component of current climate policy and the transformation of the energy sector. This issue has gained increasing importance following the entry into force of Regulation (EU) 2024/1787 of the European Parliament and of the Council of 13 June 2024 on the reduction of methane emissions in the energy sector. In the Polish hard coal mining industry, particularly in the Upper Silesian Coal Basin, the issue is especially significant because of the ongoing mining of gassy coal seams and the associated atmospheric emissions. Identifying the factors that affect methane migration and its potential accumulation in post-mining voids is important both for reducing emissions and for assessing the feasibility of methane capture and commercial use.

The aim of this study was to identify and assess the significance of geological and mining factors influencing the potential for methane accumulation in post-mining voids, with a view to using these relationships to identify prospective areas for methane extraction. The analysis was based on data from 49 longwalls mined in 10 coal seams at an operating mine. Among the 18 geological and 13 mining factors identified as being associated with methane desorption, migration, and accumulation, 10 parameters were selected for quantitative analysis: methane content of coal seams, lithology of the mining-induced destressed zone, total coal thickness, tectonic disturbance, size of the coal extraction area, time elapsed since the end of longwall mining, duration of methane drainage, longwall methane emissions, mining depth, and distance from the ventilation shaft.

The relationships among the analyzed factors were evaluated statistically. Because direct and representative data on methane accumulation in post-mining voids were unavailable, the potential significance of these factors for subsequent methane desorption, migration, and accumulation was assessed indirectly by correlating their values with methane emissions recorded during longwall mining. This approach made it possible to identify the factors most strongly associated with methane content distribution and with the potential for methane accumulation during and after mining operations.

The results indicate that the potential for methane accumulation in post-mining voids depends on the interaction of numerous geological and mining factors. Methane content of coal seams, lithology of the mining-induced destressed zone, and the geometric parameters of the mined longwalls were found to be the most significant. High initial methane contents of coal seams disturbed by mining may indicate an increased potential for methane accumulation in post-mining voids, whereas the destressed zone lithology may affect methane migration pathways. A particularly clear relationship was observed for the proportion of claystone, which repeatedly showed negative correlations. Strong positive correlations were found for the geometric parameters of the mined longwalls, which influence the extent of the destressed zone.

The findings suggest that the comprehensive geological and mining characterization performed using multifactorial analysis can provide a basis for identifying areas with an elevated potential for methane accumulation in post-mining voids. Combining information on methane content, the lithology of the destressed zone, and mined longwall geometry may support the further development of a methodology for forecasting prospective methane-capture zones. Consequently, this research can support efforts to reduce atmospheric methane emissions and, where technically and economically feasible, to recover methane for energy use.

Keywords: coalbed methane; post-mining voids; methane accumulation; methane content; methane capture; Upper Silesian Coal Basin; methane emission reduction; carbon management.

14:40 METH2GEN: An Integrated Approach to Coal Mine Methane Abatement through Hydrogen-Assisted Conversion to Low-Carbon Gaseous Fuels

Renata Cicha-Szot PhD Eng. Oil and Gas Institute – National Research Institute,
Lubicz 25A 31-503 Kraków, POLAND
cicha-szot@inig.pl, *Phone: +48 12 421 00 33, Fax: +48 12 430 38 85*
Małgorzata Słota-Valim PhD Eng. Oil and Gas Institute – National Research Institute,
slota-valim@inig.pl, Phone: +48 12 421 00 33, Fax: +48 12 430 38 85

Methane emissions from coal mine degasification systems represent a significant environmental challenge and a substantial source of greenhouse gas emissions. In many cases, methane streams recovered during mine methane drainage cannot be fully utilized in conventional gas engines due to fluctuations in gas quality, limited local demand, or operational constraints. As a result, a portion of the recovered methane remains underutilized, reducing the environmental and economic benefits of mine methane recovery.

The METH2GEN project investigates an innovative pathway for the utilization of surplus methane originating from coal mine degasification systems. The concept integrates methane recovery with renewable hydrogen production and gas conversion technologies to increase the value of mine-derived gaseous resources while reducing greenhouse gas emissions. The proposed approach enables the transformation of underutilized methane into low-carbon gaseous fuels that can support energy storage and contribute to the decarbonization of the gas sector.

An equally important objective of the METH2GEN project is to significantly improve the efficiency of methane drainage in underground coal mines by implementing advanced Long Reach Directional Drilling (LRDD) technology combined with intelligent monitoring and control systems. The project aims to demonstrate, for the first time in Poland, the application of directional boreholes as the primary methane drainage system for longwall mining. Enhanced geological characterization and optimized borehole placement are expected to substantially increase methane capture efficiency, reduce methane concentrations in ventilation air, and improve mine safety by mitigating methane hazards. Increasing the effectiveness of methane drainage also creates the conditions for higher recovery of methane suitable for further conversion into valuable energy carriers, thereby strengthening both the environmental and economic performance of coal mine methane management.

This presentation will discuss the technological framework of the METH2GEN project, characteristics of methane streams from coal mine drainage systems, integration with renewable energy sources, and opportunities for producing synthetic fuels compatible with existing gas infrastructure. The environmental benefits associated with methane emission mitigation and carbon management will be evaluated, together with preliminary techno-economic considerations.

The project demonstrates how coal mine methane, traditionally regarded as a waste or low-value by-product, can become an important component of future low-carbon energy systems. The proposed solution contributes simultaneously to methane emission abatement, renewable energy integration, and the development of sustainable gaseous energy carriers.

15:00 CO_2 Adsorption and CH_4 Desorption in South African Coals: A Pressure-Temperature-Rank Matrix Approach

L Koech,
Tshwane University of Technology, Department of Chemical, Metallurgical and Materials Engineering, Private Bag X680, Pretoria, 0001, Republic of South Africa.
KoechLK@tut.ac.za
K Premlall and DG Faurie
Tshwane University of Technology, Department of Chemical, Metallurgical and Materials Engineering, Private Bag X680, Pretoria, 0001, Republic of South Africa.

Carbon dioxide sequestration in unmineable coal seams, coupled with enhanced coalbed methane (ECBM) recovery, offers a promising dual-benefit strategy for carbon management in coal-dependent economies. However, the sorption behaviour of South African (SA) coals, characterised by a wide range of metamorphic ranks, remains poorly constrained, limiting reliable ECBM resource assessments in the region. This study investigates CO_2 adsorption and CO_2-induced CH_4 desorption on SA coals with varying vitrinite reflectance values ranging from 0.64% to 1.26%, representing medium-rank coking to high-rank bituminous classifications. Experiments were conducted using a high-pressure volumetric adsorption system (HPVAS) under isothermal conditions at 35°C and 55°C, with CO_2 injection pressures ranging from 10 to 90 bar (sub- to supercritical). CH_4-saturated coal samples were prepared at 2 bar and analysed using gas chromatography to quantify desorbed CH_4 at each CO_2 pressure step. Excess CO_2 adsorption was determined via the Gibbs approach, with phase density corrections applied using NIST equation-of-state data. Maximum CH_4 desorption at 55°C reached 1.01, 0.93, and 0.61 mmol/g for samples TN (V_oR_{mr} = 1.26%), BL (0.70%), and EM (0.64%), respectively, indicating a positive correlation between coal rank and CH_4 release capacity. Increasing temperature from 35°C to 55°C enhanced CH_4 desorption rates across all coals, with the most pronounced effect observed above 30 bar, attributed to elevated molecular kinetic energy. Equilibrium data were fitted to Langmuir, Freundlich, and Temkin isotherm models. The Temkin model provided the best fit for CH_4 desorption, while the Langmuir model showed significant deviation at 30–40 bar in the binary CO_2/CH_4 system, confirming its limitations in competitive sorption environments.

Keywords: CO_2 sequestration, ECBM, CH_4 desorption, South African coal, adsorption isotherms.

ADVISORY BOARD

Massood Ramezan, Chair, KeyLogic Systems, Inc., USA

Prof. Richard Bajura, West Virginia University, USA

Prof. Tarunjit Butalia, The Ohio State University, USA

Dr. Daniel Connell, CONSOL Energy Inc., USA

Mr. John Duddy, HTI, USA

Dr. Evan Granite, U.S. DOE/NETL, USA

Prof. Atsushi Ishihara, MIE University, JAPAN

Mr. Andrew Kramer, Gas Technology Institute, USA

Dr. Holly Krutka, University of Wyoming, USA

Mr. Francis Lau, EverBright & Associates, USA

Dr. Rolf Maurer, Hamilton Maurer International, USA

Prof. Badie I. Morsi, University of Pittsburgh, USA

Prof. Masakatsu Nomura*, Osaka University, JAPAN

Dr. Alberto Pettinau, Sotacarbo S.p.A., ITALY

Dr. Andreas Richter, Freiberg University of Mining & Technology, GERMANY

Dr. Daniel Roberts, CSIRO, AUSTRALIA

Dr. Leslie Ruppert, U.S. Geological Survey, USA

Mr. Thomas Sarkus, U.S. DOE/NETL, USA

Mr. Brian Shaffer, U.S. Geological Survey, USA

Dr. Aleksander Sobolewski, Institute for Chemical Processing of Coal, POLAND

Mr. Don Stevenson, GTI Energy, USA

Mr. Gary Stiegel, Consultant, USA

Dr. Johan van Dyk, GTI, USA

Prof. Ting Wang, University of New Orleans, USA

Mr. Richard Winschel, Longbridge Energy Consulting, USA

*Emeritus

INTERNATIONAL VICE CHAIRS

Prof. Atsushi Ishihara, MIE University, JAPAN

Prof. Chung-Hwan Jeon (Steve Jeon), Pusan National University, SOUTH KOREA

Dr. Daniel Roberts, CSIRO, AUSTRALIA

Prof. Aleksander Sobolewski, Institute for Chemical Processing of Coal, POLAND

Dr. Johan van Dyk, GTI, USA

PROCEEDINGS

The 2026 conference proceedings will be published online after the conference.

Authors should email their English manuscripts to the Conference Office before the conference.

ANNOUNCING PECMC 2027

Forty-Fourth Annual International Pittsburgh Energy and Carbon Management Conference

Hosted by:



University of Pittsburgh

TBD

Conference Office: ipcc@pitt.edu

Phone: +1 (412) 624-7440

Proceedings published online after the conference.

PCC WEBSITE: www.pccpitt.org