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ENERGY RESEARCH CENTER

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EDITOR'S NOTE: At the time of printing the article on Mercury Emissions and MATS Rule, the U.S. Supreme Court announced an overturn of the EPA's MATS Rule. However, at least 20 states have laws and regulations requiring mercury emissions limits. Some utility companies that have planned to comply with MATS are still moving ahead with compliance plans.

FOSSIL ENERGY –

MEETING MERCURY EMISSIONS MATS COMPLIANCE

Many utility companies are affected by EPA's 40 CFR Part 63, Subpart UUUUU - National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units, typically referred to as the **Utility MATS Rule**. The compliance date was set for April 16, 2015; however, many utilities have applied for a one-year compliance extension to allow time for installation of emissions controls. One aspect of this regulation that affects about 460 coal-based power plants (approximately 310 GW of installed capacity at 1,100 units) requires continuous compliance with mercury limits. Mercury emissions standards for existing units firing bituminous coal are set at 1.2 lb/TBtu. For Appalachian bituminous coal, with a higher heating value of 12,500 Btu/lb and mercury content of 0.11 ppm_w, the new standard represents a mercury removal of approximately 86%.

The Energy Research Center has been working on mercury emissions research since the early 2000's. The mercury research team, led by Dr. Carlos Romero, has included faculty, research scientists and graduate students from the Mechanical and Chemical Engineering Departments at Lehigh University. Research funding has been provided by OE&M's, such as Foster Wheeler and Hitachi, EPRI, EPA, PITA and utility companies. Romero explains, "Fundamentally, mercury is collected in coal-fired boilers by adsorption onto solid surfaces, like the fly ash; and by chemical absorption of oxidized mercury into aqueous solutions, such as those found at the WFGD. Various mercury control schemes have been developed based on these pathways of mercury reduction. In one of those schemes, activated carbon (or a non-carbon based sorbent) is injected upstream of a particulate collection device (an ESP or baghouse) for enhanced mercury capture. In another scheme that takes advantage of the co-benefit of APCD's installed at the unit, mercury is oxidized by the SCR reactor to the more soluble $HgCl_2$ form and, subsequently, removed by the WFGD scrubber. In some scrubbers, some of the absorbed $HgCl_2$ is reduced back to elemental mercury (or Hg^0), which is re-emitted with the flue gas at the stack. Additives have been developed and used to prevent Hg^0 re-emission at the WFGD. Halogens, such as calcium bromide, are also used for coal treatment, for increased mercury oxidation in the convective pass into a soluble species."

As utility companies develop their compliance strategies to meet MATS, emissions characterization, engineering analysis and construction, control technology demonstration and performance testing are carried out for each particular unit. A survey of the

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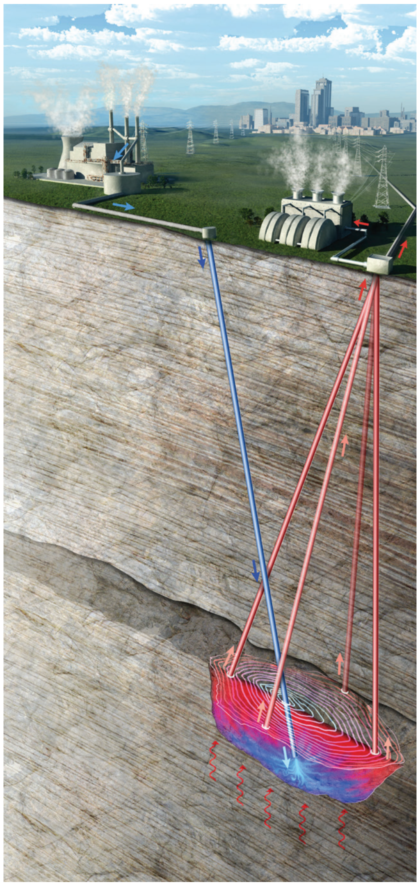
RENEWABLE ENERGY –

USING SCO_2 FOR GEOTHERMAL HEAT MINING

The Energy Research Center (ERC) is leading research to investigate the feasibility of, and test methods of using supercritical carbon dioxide (sCO_2) produced by fossil fuel power plants to enhance the extraction of geothermal energy for power generation applications. CO_2 is expected to be available in the future from carbon capture systems added to fossil-fired power plants for greenhouse gases abatement. This research is part of a project performed in collaboration with the Faculty of Mechanical Engineering at the Universidad Michoacana de San Nicolas de Hidalgo (UMSNH) in Mexico. The three-year project is receiving $1.67 million in total funding from Mexico's Ministry of Energy (SENER) and the National Council for Science and Technology (CONACYT).

The project will deliver several benefits, says ERC's director Dr. Carlos Romero, who is co-principal investigator with Dr. Edward Levy, former ERC director and professor emeritus of mechanical engineering and mechanics. "Because CO_2 is a greenhouse gas, scientists are trying to develop ways of sequestering it, or storing it permanently in underground mines and rock formations, and at the bottom of the ocean. Combining sequestration and the reuse of CO_2 would be a less expensive way of preventing it from entering the atmosphere after it is emitted from fossil-fired power plants. In addition, says Romero, the physical transport properties of CO_2 enable it to harvest geothermal energy more efficiently than water or brine, the conventional geothermal heat extraction medium."



The typical sources of geothermal energy are volcanic rock formations, deep saline aquifers (DSAs) and hot dry rock formations (HDRs), which lie further beneath the earth's surface. Traditional water-based geothermal systems require

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industry prepared by ICAC indicates that approximately 70% of the surveyed units will utilize some sort of sorbent injection, while the remaining 30% will rely on a combination of boiler oxidant/SCR/WFGD (with or without additive). However, as the power plants move into the compliance phase of MATS, issues may arise once the control strategy is operational. These issues are related to consistent additive quality, sorbent injection system reliability and efficiency, fuel switching, balance-of-plant issues, and other unforeseen changes to the unit maintenance and operating conditions. These issues need to be worked out to keep the MATS compliance system working on an optimized, cost-effective fashion year round.

Utility Company Support in MATS Compliance. The Energy Research Center has been working with a utility company to help with mercury MATS compliance at three power stations, which are affected by the MATS Rules. Joshua Charles, a member of the Energy Research Center mercury research team, explains, "These coal units range in size from 106 to 720 MW. All of the units are equipped with WFGD, with oxidation air injection. Some of the units were retrofit with $CaBr_2$ coal conditioning, while others were equipped with injection of an organic sulfide compound at the scrubber. At some of these units a combination of optimization of operating conditions and reagent injection is required to obtain consistent mercury emissions at the stack below the MATS limit, while allowing for variations in unit load and fuel flexibility. Figure 1 below illustrates the inherent variability in the continuous mercury readings at the stack, the importance of well-tuned operating conditions and the opportunity to optimize and use reagent injection for trim mercury control. This particular unit is now capable of operating consistently, without the risk of mercury spikes over the MATS limits, and over the entire load range, at an average level of about 0.5 µg/Nm_3."

According to an engineer at the utility company who is in charge of the mercury compliance plans for the 2015 MATS Rule, "Working with the Energy Research Center, we have achieved a good understanding of the dynamics of mercury behavior and capture across the WFGD's. Specific information was prepared for the different boiler components, listing all the parameters that have an impact on mercury transformation, and with recommendations to achieve maximum level of mercury reduction (See Table 1). The information was well-received by the plants. It will contribute to our ability to achieve potential savings on mercury compliance." Romero concludes, "Many coal-fired units, with mercury control options in place, will benefit from revising their mercury control strategies for continuous, reliable utilization of their mercury control systems. Optimized operational practices of boiler and mercury control equipment will help achieve cost-effective mercury compliance, while managing balance-of-plant impacts.

Parameter	Recommendation	Expected Range of ΔHg^T Reduction Across WFGD	
S/O Relation	Hg removal across the scrubber increases both above and below an S/O ratio of 0.009 lb./scft.	Up to -80% absolute	Most Important ↕ Least Important
Oxidizing Air	Reduce oxidizing air flow rate as much as possible (watch for WFGD product quality).	Up to -12% / 10,000 scfm	
Sulfites	Keep sulfites between concentrations of 2.5 and 5 mM.	Up to -11%	
pH	Slurry pH has an inverse relationship with Hg emissions for pH values between 5.5 and 7.0.	Up to -10%	
ORP	Decrease slurry ORP and keep in the range between 100 - 250 mV.	Up to -10%	
Halides	Keep halides in the range between 5,000 to 10,000 ppm_w. Further halide increases show decreased impact.	Up to -9%	
L/G Ratio	Operate at maximum allowed scrubber L/G ratio, up to 100 gpm/kacfm.	Up to - 0.5%/gpm	
Temperature	Decreasing slurry temperature below 140°F reduces re-emission.	-1.5%/°F	
Blowdown Rate	Reduce slurry blowdown frequency as permitted per WFGD operation.	Marginal Decrease	

Table 1: Parameters affecting mercury in WFGD's.

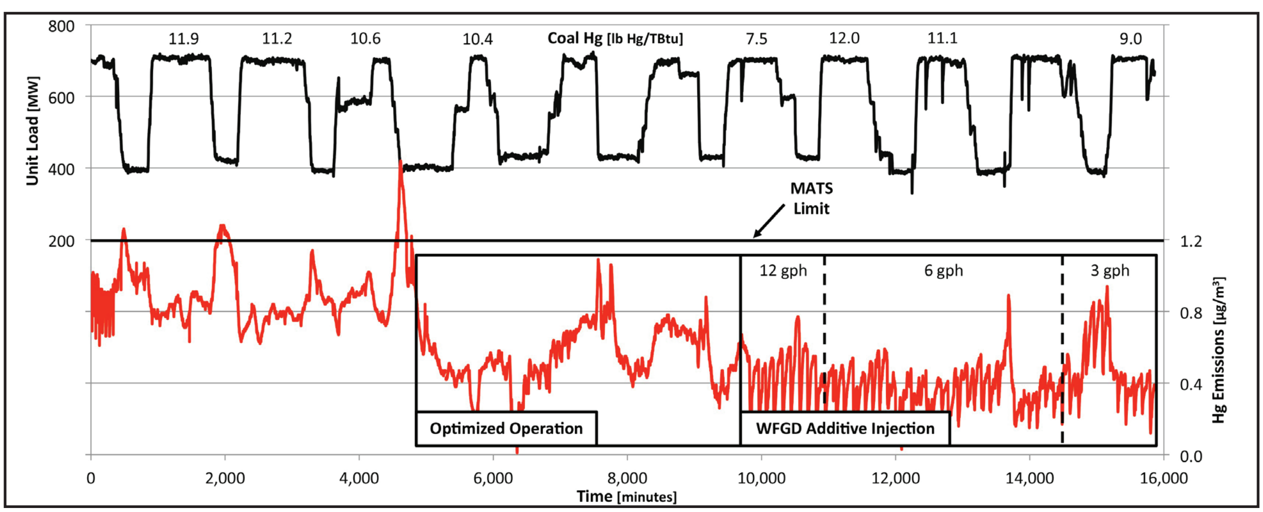

Figure 1: Mercury stack data showing compliance with MATS under optimized operating conditions and additive injection.

RENEWABLE ENERGY

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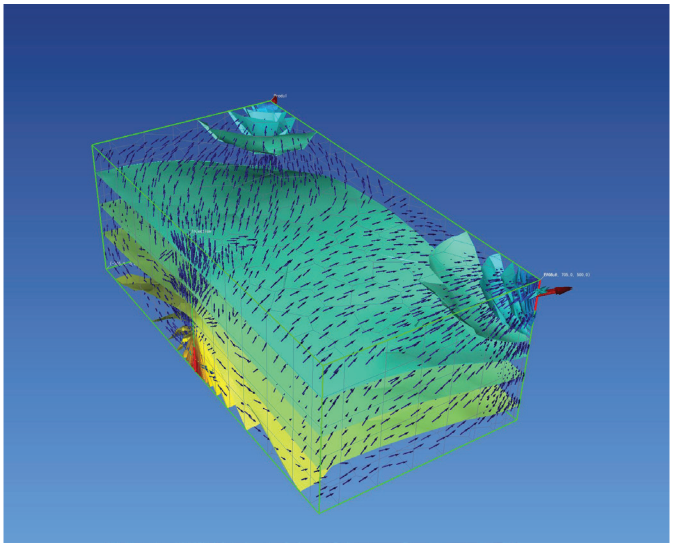
significant amounts of water, a highly permeable and porous formation, and sufficiently high subsurface temperatures. Depending on the enthalpy level of the hydrothermal reservoir, the water in the reservoir can be cleaned of impurities and directly used for geothermal power generation. In its study in Mexico, the Energy Research Center attempts to replace the water or brine with sCO_2 that has been heated and pressurized by the plant CO_2 capture system. Because of its lower viscosity and larger density differences at different temperatures, says Levy, "sCO_2 is more mobile than water and should therefore permeate more readily into the geothermal reservoir, expanding the range of usable natural geothermal formations. Heated CO_2 will rise through production wells, creating several options for generating power. The hot gas can be directly expanded in turbines designed for sCO_2, or it can be diverted into a heat exchanger working with an organic fluid thermal cycle. The geothermal heat can also be used in the process to capture CO_2 at a fossil fuel-fired power plant or for district heating. CO_2 as a geothermal heat mining fluid also provides the added benefit of carbon storage within the geothermal formation."

According to Romero, "Estimations of heat mining potential using sCO_2 were performed using the TOUGH2 computer software. Simulations for three representative reservoirs in Mexico (HDR – Acoculco (260°C, 160 bar), DSA – Puruandiro (165°C, 100 bar), and Low Enthalpy Reservoir, LER - Comondú (95°C, 75 bar) indicate that CO_2-based systems have better heat mining potential than H_2O-based systems, corresponding to enhanced heat extraction rates as high as 160 percent with respect to the H_2O-based systems, with the heat mining benefit by sCO_2 increasing in inverse proportion to the site subsurface temperature. Additional simulations for twenty-one characterized geothermal sites in Mexico estimate a total power generation potential with sCO_2 of 1,161 MWe. This represents 51.4% additional power generation that can be mined by the use of sCO_2, in comparison to water. Additionally, a sCO_2-based geothermal system would be able to sequester in these twenty-one geothermal reservoirs, over an expected 30-year life of the reservoir, approximately 72 million tons of CO_2, or about 10 percent of the current total CO_2 emissions inventory for the country."

Levy adds "The University of Michoacan has two experimental geothermal units capable of generating 600 kW of electricity. The Energy Research Center, in collaboration with UMSNH, will convert one of these units into a pilot plant utilizing sCO_2 and an organic heat-exchange fluid. In the second phase of the project, the researchers will install and test a pilot plant at UMSNH and then deploy the system at a geothermal site. The long-term goal is to construct a geothermal plant in Mexico near, or adjacent to, a fossil-fired power plant, where there will be a readily accessible supply of CO_2."

Other members of the project team include Joshua Charles, a research scientist at the ERC; graduate students Chunjian Pan, Xingchao Wang, Pavel Ramirez; and faculty and researchers from the University of Michoacan, Drs. Carlos Rubio and Oscar Chavez. Rubio, director of the Group of Energy Efficiency and Renewable Energy (GREEN-ER), explains, "Mexico is aiming at expanding the role of geothermal energy, and renewable energy in general, in the country's power generation matrix. Mexico, with 8,000 MW_e, has the world's second-highest proven reserves of geothermal power after Indonesia. It is also the globe's 12^{th}-leading emitter of CO_2. The country has set targets to cut national emissions of CO_2 by 30 percent by 2020 and by 50 percent by 2050. Additionally, Mexico is working to expand over the next four years its reliance on renewable energy sources - from the current 17% of total national consumption to 33% by 2018. In its drive to go green, the country is placing big hopes on geothermal power. Four high-enthalpy sites totaling 953 MW_e are currently under commercial ownership and operation by the Federal Commission of Electricity (CFE) in Mexico.



NEW APPOINTMENT ANNOUNCEMENT

The ERC is pleased to announce the appointment of Ms. Colleen Munion to the position of Administrative Manager, effective April 6, 2015. She is a graduate of Philadelphia University and comes to Lehigh University with extensive experience in contract and project administration, working most recently at ITT Engineered Valves and SPX Heat Transfer, Inc. She replaces Ms. Ursla Levy, who retired on May 29, 2015 after twenty-five years at the ERC. Colleen can be reached at 610-758-4544 or at cam915@lehigh.edu.

WE'D LIKE TO HEAR FROM YOU:

Please take a minute to update us on your activities. You may send your information via e-mail, fax, or mail to:

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