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FEATURES

Carbon Capture, Storage, and Utilization
by Mingming Lu
Carbon capture, storage, and utilization (CCSU) technologies are without doubt a heavy weight among carbon reduction initiatives, and so this month, EM looks at the current state of CCSU technology and development with articles solicited from the United States and China. Page 4

Challenges and Opportunities for Post-Combustion Carbon Capture
by Yongqi Lu and Kevin O’Brien, Prairie Research Institute, University of Illinois at Urbana-Champaign Page 6

Overview: UKy-CAER Carbon Capture Research Projects
by Heather Nikolic, Kun Liu, James Landon, Cameron Lippert, and Kunlei Liu, University of Kentucky Center’s for Applied Energy Research (UKy-CAER) Page 13

Case Study: The Engineering Application of Carbon Capture by Chemical Absorption in China
by Jin Wang, Min Li, and Weiheng Yan, University in Beijing, China Page 20

Carbon Capture and Storage in Natural Gas-Based Heat and Power Plants in China
by Rui Chen, University in Beijing, China Page 24

Microalgae Potential for Carbon Utilization
by Worrarat Thiansathit and Tim Keener, University of Cincinnati Page 28

CONFERENCE HIGHLIGHTS
Highlights from the 2014 FHWA–EPA Northern Transportation and Air Quality Summit
by Kevin Block and Mike Roberts, Federal Highway Administration’s Resource Center; Mike Baker, Pennsylvania Department of Transportation; Brian Rehn and Gregory Becoat, the U.S. Environmental Protection Agency Region 3; Samantha Harmon, Pennsylvania Department of Environmental Protection; Jayme Graham, Allegheny County Health Department; Mark Glaze and John Davies, Federal Highway Administration; and Chuck Imbrogno, Southwestern Pennsylvania Commission Page 32

COLUMNS

PM File: The Five Whys: Getting to the Root of the Problem ......... 38
by David Elam, Jr.

ASSOCIATION NEWS

Message from the President: In Praise of Volunteers .......... 2
by Dallas Baker

IPEP Quarterly: Ready to Register for the A&WMA Conference in Raleigh? ............ 18
by Diana Kobus

Members in the News: Joseph Duckett and J. Wayne Cropp .... 40

DEPARTMENTS

Washington Report .......... 41
Canadian Report .......... 42
News Focus .......... 43
Advertisers’ Index .......... 47
Calendar of Events .......... 48
A&WMA Table of Contents. ........ 48

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In Praise of Volunteers

by Dallas Baker, P.E., BCEE
president@awma.org

The heart of the dedicated volunteer continues to impress. Our members are motivated, capable, and effective in serving the Association in so many ways, and it all starts with commitment. The more I travel to A&WMA meetings, the more I appreciate the countless hours of preparation that produce impressive agendas, inspiring speakers, exhibitor showcases, and enjoyable amenities. I encourage you to check out the awma.org events page for upcoming meetings, conferences, and workshops near you. And for those members working behind the scenes to produce them, you have my appreciation and admiration.

For those of you just joining A&WMA and getting to know us, I extend a sincere welcome. I hope you will quickly discover all the ways your membership will help you achieve your professional goals. From my experience, the best way to get the most out of the Association is to connect with a local Section or Chapter and get involved. If you have a desire to lead, please consider registering for A&WMA’s Leadership Training Academy to be held in Pittsburgh, April 17–19. Over the three-day weekend, instructors will provide information on the fundamentals of leading a local unit, an overview of resources available through the Association’s headquarters, and practical skills, such as running a conference and recruiting new members. Newly-elected Section or Chapter officers are well-suited to attend and will take home techniques to make their local groups even stronger. I look forward to being on hand to congratulate the 2015 class of Academy graduates.

I continue to work diligently with the A&WMA Board of Directors and headquarters staff in Pittsburgh to fulfill our primary purpose: to improve environmental knowledge and decisions by providing a neutral forum for exchanging information important to managers of air and waste. My grandfather’s favorite author, Louis L’Amour, once wrote, “Knowledge is like money: to be of value it must circulate, and in circulating it can increase in quantity and, hopefully, in value.” The value we bring to you, through publications, webinars, workshops, and conferences, is in our unique ability to establish neutral forums and networking channels so that the right information is made available to the key decision-makers.

One advancing technology that is capturing attention is carbon capture and sequestration (CCS). One of the largest U.S. CCS projects is under construction in my home state of Mississippi, and many industry and regulatory leaders are paying close attention to its progress. Southern Company is promising a 65% carbon capture rate at a lignite coal-fired integrated gasification combined cycle (IGCC) power plant in Kemper County. The result will be the equivalent of carbon emissions from a similar-sized natural gas-fired power plant; however, government subsidies, construction delays, and cost overruns (swelling from $2.2 billion to $6.1 billion) give doubts that it will ever be commercially reproducible. This month, EM focuses on CCS technologies like this from the United States and China. CCS will also be a significant topic at our 2015 Annual Conference in June, where leading experts and officials will present the latest understanding of the technology.

As your 2015 president, I hope to be able to meet and get to know as many of you as I can this year. If I don’t have an opportunity to meet with you face to face, feel free to reach out to me via e-mail with your thoughts on how the Association can grow and strengthen.
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by Mingming Lu, Chair, 
EM Editorial Advisory Committee

CARBON Storage &

Spotlight on carbon capture technology and development in the United States and China.
CAPTURE

Utilization

Toward the end of 2014, the United States and the People’s Republic of China—the world’s two largest economies, energy consumers, and emitters of greenhouse gases (GHGs)—issued a ground-breaking joint climate change agreement: The United States pledged to reduce GHG emissions by 26–28% below 2005 levels by 2025; while China pledged to increase non-fossil fuel use for energy by 20% by 2030.

The U.S. Environmental Protection Agency (EPA) recently proposed new rules to regulate carbon pollution: the Clean Power Plan for existing power plants and the Carbon Pollution Standards for new power plants, which were the focus of the last month’s issue of EM. A key element of EPA’s Clean Power Plan is the reduction of atmospheric carbon dioxide (CO2), the primary GHG emitted through human activities. Carbon capture, storage, and utilization (CCSU) technologies are without doubt a heavy weight among carbon-reduction initiatives, and so this month, EM looks at CCSU technology and development with articles solicited from both the United States and China.

Next, a team of researchers from the University of Kentucky’s Center for Applied Energy Research (UKy-CAER; Nikolic et al.) offer an overview of several carbon capture projects undertaken at the center. Since the 1970s, the center has been very active in research to reduce the cost and associated environmental impacts of coal use. The center recently teamed up with Kentucky’s major power companies, state government, and other partners to deploy technologies developed in its laboratory to pilot- and full-scale demonstrations. The researchers are also involved in the joint U.S.–China Clean Energy Research Center focusing on carbon capture technologies.

In the third article, Wang, Li, and Yan present two examples of carbon capture applications in China’s coal-fired power plants: One is a small-size demonstration in Beijing; the other is a real-world-size application in Shanghai. Both demonstrations use chemical absorption technologies, and were built by the China Hua Neng Electric Group.

Next, Chen discusses carbon capture and storage in natural gas-based power plants in China. As China begins to move away from coal-fired power plants, natural gas will be increasingly used in power generation. It is expected that carbon capture and storage processes will increase rapidly in natural gas-based combined heat and power combined cycle.

Finally, commercial CO2 utilization has recently been added as part of the U.S. Department of Energy’s research and development portfolio. In addition to making biofuels, algae can also be used to scrub CO2 from exhausts of power plants, digester gases, and so forth. Such a pilot project is under evaluation at the University of Cincinnati. CO2 generated from a food waste digester exhaust is being used as carbon source for microalgae. In their article, Thiansathit and Keener describe the pilot-scale food waste digester and algae reactor system that recently began operation.

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The reduction of carbon dioxide (CO₂) emissions from stationary sources has become a major factor in the environmental planning of the power sector and proposed regulations could severely impact fossil-driven power production. This trend is critical at a national level because almost 40% of total U.S. CO₂ emissions are presently from fossil fuel-fired power plants, most of which are coal-fired power plants. Because fossil fuels are expected to remain a dominant source of energy in the foreseeable future, post-combustion CO₂ capture (PCC) from large power plants is critical for reducing CO₂ emissions and meeting these proposed regulations.

The challenge from a separation perspective is that the flue gas from conventional fossil fuel combustion exhibits relatively low CO₂ concentrations.
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Research and development efforts have grown substantially for PCC in recent years.

(i.e., 10–15 vol% from coal-fired boilers and 4–7 vol% from natural gas combined cycles and boilers) and low pressures (i.e., near atmospheric pressure). This results in a low driving force for CO2 separation (i.e., low CO2 partial pressure) and a large volume of gas to be treated. As a result, PCC requires intensive energy use and tends to incur a large equipment footprint and a high cost.

The monoethanolamine (MEA)-based absorption process is presently an industrial benchmark for PCC. According to a recent U.S. Department of Energy (DOE) study,2 PCC at a pulverized coal-fired power plant equipped with MEA will impose an increase in the cost of electricity (COE) of approximately 80%. Of this COE increase, the majority is attributable to parasitic power loss (60%), followed by capital costs (30%), and then by operating and maintenance (O&M) costs (10%). Clearly, the intensive energy use and high cost of this process present enormous challenges for large-scale deployment of PCC.

**Energy of CO2 Separation and Compression**

The separation of a mixture into two or more products with different compositions requires work, heat energy, or both. The minimum work required for a separation process can be calculated according to the first and second laws of thermodynamics.3 Figure 1 shows the minimum work required for CO2 separation at 40°C and atmospheric pressure from a typical coal-fired flue gas containing 12 vol% CO2 and a natural gas-fired flue gas containing 6 vol% CO2. The minimum separation work increases as the CO2 concentration in the feed gas decreases and the CO2 recovery or product purity increases. For coal flue gas, 90% CO2 removal with 100% product purity requires a minimum separation work of 163.9 kJ/kg of CO2 separated (0.046 kWh/kg). In comparison, the benchmark MEA process consumes 3,600 to 3,900 kJ/kg of heat (from steam) for CO2 separation, resulting in a parasitic load loss of 0.22 kWh/kg. This is approximately five times the minimum separation work, suggesting that the present separation process is extremely inefficient.

The results in Figure 1 do not include energy use for CO2 compression. The compression of CO2 is necessary if the captured CO2 needs be transported and sequestered in geological formations or utilized for enhanced oil recovery. Assuming
that a pure CO₂ gas at 40°C and atmospheric pressure is compressed to a pressure ready for cooling condensation/liquefaction at 30°C, the minimum compression work is estimated as 251.5 kJ/kg of CO₂ compressed (0.070 kWh/kg). This compression work is a good estimate because in the liquid state, it takes minimal work to compress CO₂ to higher pressures. The work consumed for CO₂ compression with conventional multistage, intercooled compressors is approximately 0.1 kWh/kg, which is more than 40% greater than the minimum compression work.

According to the above analysis, the minimum work required for both CO₂ separation and compression at coal-fired power plants amounts to 0.116 kWh/kg of CO₂ captured. Given an average CO₂ emissions intensity of 0.9 kg/kWh in the United States, this translates to a 10.4% reduction in net plant output. In comparison, the parasitic loss for the benchmark MEA process is estimated at about 0.32 kWh/kg of CO₂ captured, resulting in a 29% reduction in net output. It is obvious that a huge potential exists for improvement in the energy efficiency of PCC.

Cost of CO₂ Capture
The state-of-the-art PCC technologies at new coal-fired power plants will result in a 60–80% increase in COE compared with plants without PCC. This translates to a CO₂ capture cost of $40–$70/MWh or $60–$80/ton of CO₂ avoided. The cost for PCC retrofitting at existing plants is generally expected to be higher than that at new plants. At present, the costs of PCC are approximately twice the DOE Carbon Capture Program’s cost goal of a 35% COE increase at 90% carbon removal.6

Figure 2 displays the trajectories for meeting DOE’s cost goal.6 The total cost of PCC consists of direct costs, which account for the capital and O&M costs, and indirect costs, which are associated with parasitic power losses attributable to PCC. The solid blue line in the figure depicts the costs corresponding to DOE’s cost goal. The dashed red line represents the costs corresponding to the minimum work required for carbon capture and compression, and the dashed green line outlines the lowest realistic capital cost. The PCC processes with direct and indirect costs that fall into the “feasible region” can meet or surpass the cost goal.6
The unique challenge of PCC at fossil fuel-fired power plants is to treat huge volumes of flue gas containing low partial pressures of CO₂.

As shown in Figure 2, points A and A¹, which represent the state-of-the-art amine-based process at new or existing coal-fired power plants, are far above the cost goal line. Note that the indirect costs are much greater than the direct costs at A or A¹, suggesting that reducing the parasitic losses from carbon capture should be a primary focus of research and development (R&D). However, the direct cost, especially the capital cost—which, depending on the technologies, is generally much higher than the O&M cost—cannot be ignored in future R&D efforts aimed at fulfilling DOE’s goal.

**Capture Technology Options**

Research and development efforts have grown substantially for PCC in recent years. A recent Electric Power Research Institute (EPRI) study reviewed 125 PCC technologies and assigned a Technology Readiness Level (TRL) to describe different development stages, from paper analysis (TRL1) to commercial deployment (TRL9). Among these technologies, 43% were absorption processes, 23% were adsorption processes, and 14% were based on membranes. Most of the reviewed projects were laboratory-, bench-, or small pilot-scale developments, and only four absorption projects were under sub- or full-scale demonstration.

Table 1 gives a comparison of the three primary technologies—absorption, adsorption, and membranes—with respect to technical characteristics, energy use, cost, equipment footprint, scalability, and maturity. In absorption processes, a chemical solvent, as opposed to a physical solvent, is used to obtain acceptable CO₂ uptake from flue gas with a low CO₂ concentration. The chemical solvents investigated covered advanced amines or amino acids, carbonate salts, ammonia, ionic liquids, their blends, and rate catalysts or promoters. A high CO₂ recovery rate (90–98%) and high CO₂ product purity (>99%) can usually be attained in chemical absorption processes. Amine-based absorption processes for removing CO₂ from gas streams have been practiced in the chemical and oil industries for more than 80 years and are expected to present few obstacles in scaling up for the PCC application. However, the state-of-the-art amine-based processes are still energy intensive and costly because of their intensive heat use for solvent regeneration and solvent degradation over time. Present R&D efforts for absorption are focused on addressing these issues by developing novel solvents, new stripping process configurations, high-pressure processes, and hybrid systems.

Adsorption is a dry process for PCC that has the potential for significant energy savings compared with wet absorption processes. Water is not used in adsorption processes, and they avoid the heat usage associated with heating and evaporation of water encountered during sorbent regeneration. Many sorbents, such as supported amines, molecular sieves, metal organic frameworks, and carbonate salts, have been investigated. Fixed-bed adsorption operates in batch modes, including temperature swing adsorption, pressure swing adsorption, and vacuum swing adsorption. Temperature swing adsorption is not generally suitable for PCC because a large number of absorbers and desorbers are required when adsorption—desorption cycling is slow, as limited by the rates of sorbent heating and cooling, and the actual CO₂ capacity of the sorbent is low. Pressure swing adsorption/vacuum swing adsorption may use rapid cycles of pressure change to compensate for the low-sorbent capacity, but it tends to have either low CO₂ recovery or low product purity. Fluidized-bed adsorption is a continuous process. However, operational problems arise in relation to heating and cooling management, sorbent attrition and degradation, and solids handling and transportation. Fluidization also causes strong back-mixing, significantly reducing the equilibrium capacity of the sorbent. Present R&D activities are attempting to address these technical challenges.

Membranes act as filters that allow CO₂ to pass through the materials faster than other species. The driving force for the separation is created either by compressing the gas feed or by creating a vacuum on the permeate side. Membranes under development for PCC are mostly polymers, carbons, inorganics, mixed matrices, and facilitated transport membranes. Selectivity and permeability are two important properties for membranes. High selectivity is required to produce a high-purity CO₂ product stream. To achieve high purity at an acceptable recovery rate, multiple stages, recycling
of one of the streams, or both may be necessary. Permeability determines the capacity of a membrane system, and low permeability translates to a large membrane area and high equipment cost. It has been reported that a CO₂/nitrogen gas (N₂) selectivity of greater than 70 and a CO₂ permeability of greater than 1,000 GPU are required for membranes to be economically competitive with amine-based absorption processes. However, the combined selectivity and permeability of membranes now available are far smaller than these target values. Membrane separation also has been used much less frequently in chemical industries compared with absorption or adsorption processes. Challenges associated with the need for high selectivity, large membrane areas, and low tolerance for flue gas impurities such as particulates remain to be addressed.

**Concluding Remarks**

The unique challenge of PCC at fossil fuel-fired power plants is to treat huge volumes of flue gas containing low partial pressures of CO₂. The thermodynamic minimum work required for CO₂ separation and compression corresponds to, respectively, 4.1% and 6.3% of the net plant output. The actual parasitic losses attributable to CO₂ separation with the state-of-the-art technologies are approximately five times the thermodynamic minimum, indicating the separation processes have great potential to improve energy efficiency. The state-of-the-art PCC technologies will result in a 60–80% increase in COE.

**Table 1. Comparisons of postcombustion carbon capture technologies (assuming technologies achieve ≥90% CO₂ capture with ≥95% purity of the CO₂ product).**

<table>
<thead>
<tr>
<th></th>
<th>ABSORPTION</th>
<th>ADSORPTION</th>
<th>MEMBRANE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separation driven by</td>
<td>Chemical properties of the solvent</td>
<td>Chemical &amp; physical properties of the sorbent</td>
<td>Chemical &amp; morphological structure of the membrane</td>
</tr>
<tr>
<td>Proposed location</td>
<td>Post FGD&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Post FGD</td>
<td>Post FGD</td>
</tr>
<tr>
<td>Probability of requiring a polishing step post FGD</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Probability of requiring modification of the boiler</td>
<td>Very low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Energy Use</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source of parasite power loss</td>
<td>Solvent regeneration</td>
<td>Sorbent regeneration</td>
<td>Compression on feed and/or vacuum on permeate</td>
</tr>
<tr>
<td>Primary energy source</td>
<td>Thermal</td>
<td>Thermal/vacuum</td>
<td>Compression/vacuum</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit equipment cost</td>
<td>Typically driven by cost of the column</td>
<td>Typically driven by cost of the column</td>
<td>Often driven by cost of the balance-of-plant</td>
</tr>
<tr>
<td>Operating cost</td>
<td>Driven by loss/degradation of the solvent</td>
<td>Driven by attrition/degradation of the sorbent</td>
<td>Driven by lifetime of the membrane</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Footprint</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major driver for equipment size</td>
<td>Driven by column height</td>
<td>Driven by column height</td>
<td>Driven by membrane area</td>
</tr>
<tr>
<td><strong>Waste Generation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste disposal</td>
<td>Used solvent and potential volatiles released</td>
<td>Used sorbent and potential fine particulate released</td>
<td>Used membranes</td>
</tr>
<tr>
<td><strong>Scalability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of scale-up</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Economy of scale</td>
<td>High</td>
<td>Medium</td>
<td>Medium-low</td>
</tr>
<tr>
<td><strong>Level of Experience</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degree of experience with technology in sectors related to power generation</td>
<td>Very experienced</td>
<td>Experienced</td>
<td>Experienced</td>
</tr>
</tbody>
</table>

<sup>a</sup> FGD = flue gas desulfurization.
a significant portion of which is due to parasitic load losses. To meet DOE's cost goal of a 35% increase in COE, reducing the parasitic losses from PCC should be a primary focus of R&D. However, the equipment capital cost still needs to be lowered to achieve the cost goal. Many PCC technologies are presently under development, most of which are laboratory-, bench-, or small pilot-scale developments that use absorption, adsorption, or membranes as the primary technology. Although absorption processes are less energy efficient and more costly, they have been widely practiced in the chemical and oil industries, and are expected to present fewer obstacles in scaling up for PCC. Adsorption, membranes, and hybrids of different separation processes may offer energy efficiency benefits, but still require more process and material development.

References
Overview

UKy-CAER Carbon Capture Research Projects

A summary of several University of Kentucky’s Center for Applied Energy Research (UKy-CAER) projects designed to capture carbon dioxide emissions using aqueous solvents.

Located in Lexington, the University of Kentucky’s Center for Applied Energy Research (UKy-CAER) focuses on energy-related technology research and development to meet increasing energy demand and maintain a sound environment. One active area of research focuses on overcoming the challenges posed by carbon dioxide (CO₂) capture from coal-fired power plant flue gas, such as large gas volume with relatively low CO₂ concentration.

by Heather Nikolic, Kun Liu, James Landon, Cameron Lippert, and Kunlei Liu, UKy-CAER

Heather Nikolic is a principal research engineer and Pilot-Scale CO₂ Capture Unit Project Manager; Kun Liu is an associate research engineer and Bench-Scale CO₂ Capture Unit Project Manager; James Landon is a principal research scientist and Catalytic Solvent Development Project Manager; and Kunlei Liu is the associate director for research, all with the University of Kentucky’s Center for Applied Energy Research (UKy-CAER). Kunlei Liu is also an associate professor in the Department of Mechanical Engineering at the University of Kentucky. E-mail: kunlei.liu@uky.edu.
There are several approaches to CO₂ emissions management, but post-combustion carbon capture via aqueous solvent absorption is among the most promising with the least commercialization risk due to an existing operational base in the industrial sector. In a typical post-combustion carbon capture system, the flue gas is routed through an absorbing column where CO₂ is transferred from the gas phase to the liquid phase when a chemical reaction occurs with the solvent. The solvent that absorbs the CO₂ is then regenerated in a typically, steam-driven stripping column.


**Technology Development**

Stemming from the early-stage researches under the support of the CMRG, several promising technologies were developed by UKy-CAER, including advanced solvent systems, synthetic catalysts, carbon enrichment processes, and integrated carbon capture processes. With the success from lab-scale research and the development of the heat-integrated process, some of these technologies were advanced to a small pilot plant in 2011 through a project with DOE for validating the efficiency improvements and the integration of carbon capture technology in an existing power station.

In 2013, UKy-CAER was awarded a grant by DOE to develop a catalytic solvent and carbon enrichment technology based on the success of a previous project funded by the Advanced Research Projects Agency-Energy (ARPA-E). By 2014, UKy-CAER has been the recipient, directly or indirectly, of seven such DOE-sponsored grants. In the meantime, UKy-CAER has worked with partners from both the United States and China in the U.S.–China Clean Energy Research Center, which aims to advance capture technologies from a global collaboration perspective. Scientists and engineers at UKy-CAER are actively working together to develop effective carbon capture technologies for commercial application with the balance of capital investment and operating and maintenance consumption resulting in a minimal cost of electricity increase (see Figure 1).

New process solvents that excel at high capture rates and lower energy consumption with high tolerances for higher processing temperatures and pressures are of great interest to UKy-CAER’s carbon capture research. Ammonium-based solvents have been considered by various technology developers for CO₂ capture due to their low-corrosivity and nondegradation characteristics. To take advantage of these characteristics, UKy-CAER has developed a hybrid process designed to reduce the energy penalty in the stripper resulting in an overall more efficient CCS.

**UKy-CAER’s Hybrid Process**

The hybrid process includes the traditional CCS absorber and stripper with the addition of a catalytic zeolite membrane separation unit operating between the two columns. This membrane has two functions: lowering the liquid volume needing treatment in the stripper column and catalytically regenerating the ammonia solution. The selective zeolite membrane can operate under harsher conditions and at lower feed pressure when compared to polymer-based membranes, making it well suited for commercial power plant operations. The goal of this project is to produce zeolite composite membranes using a range of support materials to
balance operation of the membrane with capital and operating cost considerations. With a specified membrane support, optimization of the separation was investigated including both the flux and selectivity of molecules through the membrane. The knowledge and experience gained from this project was the basis for our newly awarded DOE bench-scale catalytic hybrid project, which is discussed below.

The UKy-CAER hybrid CO₂ capture process utilizes a catalytic solvent coupled with a gas pre-absorber concentrating membrane and a membrane dewatering component, which was discussed previously for a heat-integrated post-combustion CO₂ capture process from utility flue gas, the “CAER Ad-CCS” capture technology. The key aspect of this technology system is the utilization of a homogeneous catalyst for enhanced absorber kinetics. This catalyst uses small molecule organometallic mimics of the enzyme carbonic anhydrase to facilitate the conversion of CO₂ into bicarbonate. The catalytic process has been shown to increase mass transfer rates 15–40% over the amine alone in a variety of CO₂ capture solvents, including primary amines. The increase in mass transfer from the UKy-CAER catalyst would translate to an estimated 30% reduction in the volume of the absorber tower for a 550-MW plant. The project is also leveraging the membrane research at Membrane Technology and Research (MTR) supported by DOE to increase the CO₂ concentration to approximately 30 vol%, which will generate a further reduction in capital and energy costs.

Figure 1. Scientists and engineers at UKy-CAER are actively working together to develop effective carbon capture technologies for commercial application.
UKy-CAER's Low-Enthalpy Solvent Research
Contributing to the high operational costs of CCS, steam that would otherwise be used for electricity generation is withdrawn from the steam turbine and directed to the CCS stripper reboiler for solvent regeneration. A traditional CCS operates with a high stripping temperature (approximately 300°F), this results in a decrease in the overall electricity generation efficiency. Along with project partners, Novozymes North America Inc. (Novozymes), UKy-CAER is working to study a low-enthalpy solvent that utilizes vacuum and low-temperature stripping. The major benefit resulting from low-temperature stripping is that low pressure steam extraction from the steam turbine is reduced, which allows greater electricity generation compared to a high-temperature steam extraction point. The downside of a low-enthalpy solvent is the low reactivity with CO₂. To overcome this problem, a thermally stable enzyme developed by Novozymes was used in this project to facilitate the CO₂ hydration reaction and increase the carbon capture rate.

To reach the project goals, a bench-scale integrated absorption/desorption testing unit was constructed. Parametric and 500-hr long-term campaigns were conducted to identify the process condition resulting in the lowest operational costs, while maintaining 85–90% CO₂ capture efficiency. Simultaneously, the enzyme performance and thermal stability were also assessed together with project partners.

Pilot Project: E.W. Brown Generation Station
To advance the development of the heat-integrated CCS process utilizing an advanced solvent, a pilot-scale facility is currently under construction at Kentucky Utilities’ E.W. Brown Generation Station in Harrodsburg, KY. This project will validate the novel technologies developed at UKy-CAER: an integrated liquid desiccant loop and a secondary air stripping system. The primary purpose of the desiccant loop is to recover heat generated from the CCS, and other waste heat from the power plant currently being rejected to the environment. In addition to providing effective heat management, the liquid desiccant loop is used provide cool, dry air to the cooling tower to achieve additional cooling of the water loop and efficiency improvement when integrated with a steam plant condenser. The liquid desiccant loop is also used to provide warm, saturated air to the secondary air stripper.

In this process, the solvent is regenerated first with a traditional steam-driven stripper, then with a secondary air-stripping column to recover additional CO₂. The gas stream exiting the secondary air stripper is recycled to the power plant boiler as secondary combustion air enriching the flue gas with CO₂, thus increasing the gas-phase CO₂ partial pressure in the bottom of the absorber. A greater amount of gas-phase CO₂ in the absorber and a lesser amount of liquid-phase CO₂ in the regenerated solvent work together to increase the solvent carbon loading, solvent working capacity, mass transfer, and ultimately to reduce capital costs. Finally, an advanced solvent—developed by project partner, Mitsubishi Hitachi Power Systems America (MHPSA)—with a lower solvent regeneration energy, higher CO₂ absorption capacity, and lower solvent degradation rate when compared to a traditional solvent, will be used.

Extensive studies are planned with project partner, Electric Power Research Institute (EPRI), to verify that the UKy-CAER process is effective in removing CO₂ from the flue gas, to quantify the energy input required, to establish the baseline for solvent and water management, and to determine ways the process can be integrated with an existing power plant at a commercial-scale to realize overall efficiency improvements. Finally, UKy-CAER has developed corrosion-resistant coatings, specifically designed for this application, which will be evaluated in effort to reduce capital costs related to materials of construction. Improved efficiencies associated with this unique UKy-CAER carbon capture system will result in reduced capital costs and a lower operational energy input required by an estimated 13%.

U.S.–China Clean Energy Research Center
In addition to work taking place in the United States, UKy-CAER is also involved in a joint project
with China in the U.S.–China Clean Energy Research Center (CERC), which was established in 2009. Through this project, members of UKy-CAER have been working with Chinese colleagues on a variety of enhancements to the post-combustion CO₂ capture process. These enhancements include new process solvents for use in the capture process, which have phase-separating components to aid in regeneration of the solvent; the development of an ionic liquid-functionalized polymer membrane for the direct separation of CO₂ gas; further development of catalytic mimics for increased rate of CO₂ absorption; and the use of electrochemical separations to aid in the regeneration of the process solvent. UKy-CAER has been specifically focused on the development of homogeneous catalysts and electrochemical separation processes at CERC. These rate increases and process separations can dramatically lower the cost of capital equipment and operating cost through lowering of the absorber tower size and decreasing the liquid processed in the stripper column, respectively. Scale-up of these CERC activities is currently ongoing.

**Summary**

The projects highlighted here represent only a portion of the research conducted at UKy-CAER. Funding for these projects is primarily provided by DOE’s National Energy Technology Laboratory, and additionally by the Carbon Management Research Group and the Kentucky Department of Energy Development and Independence. UKy-CAER is grateful for the funding received. The success of these DOE-funded projects will help set a pathway to achieve the ultimate goal of an effective, commercial-scale carbon capture technology with a minimal increase in the cost of electricity.

**Reference**

Each year just prior to the start of its Annual Conference, A&WMA offers an on-site review course that was developed to assist applicants in getting ready for the IPEP exams. You can register for A&WMA’s courses as part of your overall registration for the conference online at ace2015.awma.org.

Please keep in mind this course is meant as a review, and applicants should not depend on the course as the primary means of studying for the IPEP exams. The course was written using subject matter from the IPEP exams’ Bodies of Knowledge, which are publicly available on IPEP’s Web site, ipep.org, and many QEP and EPI applicants have found the courses very helpful in their preparation to take the exams.

IPEP exams will be offered on-site as well, in two three-hour sessions, on Wednesday, June 24. In addition to studying and review, to be prepared to sit for the exams, IPEP must have your completed applications received by May 15, 2015. Only approved applicants will be permitted to sit for the IPEP exams. Download applications at ipep.org.

If you work in the Raleigh, NC, area, and you are interested in scheduling a group review and exam session for the QEP/EPI with co-workers or colleagues, please contact me at 1-412-396-4094. This can be arranged in conjunction with conference scheduling or at another time. Group reviews and testing are great ways to build your knowledge, as well as your network of trusted professionals.

IPEP will also have a booth at the conference, so stop by and see us or attend our Annual Meeting, scheduled at 4:00 p.m. Thursday, June 25. We’ll see you there!
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The Engineering Application of CO₂ Capture by Chemical Absorption in China

As concentrations of carbon dioxide (CO₂) in the atmosphere have increased, the climate change issue has become more prominent and has been attributed to a series of climate-related disasters around the world. In China, an important aspect of reducing CO₂ concentrations is to decrease emissions from coal-fired power plants. This article discusses the engineering application of chemical absorption technology to reduce CO₂ emissions from the Beijing Gao Bei-dian and Shanghai Shi Dong-kou power plants.

Climate change is largely the result of the increase of greenhouse gases, such as CO₂. Global CO₂ concentrations increased from a pre-Industrial Revolution level of 280 parts per million (ppm) to 385 ppm in 2010, far higher than the natural variability of the past 65 million years. The main reason for its rapid rise is the extensive use of fossil fuels in energy generation, from which the annual emission of CO₂ is approximately 25.3–27.5 Gt.¹

Climate change has been found to have profound disastrous impacts, such as glaciers melting, species drastically deceasing, severe droughts, and fatal flooding. At present, CO₂ emissions from power plants account for more than 40% of total emissions. This rate will continue to increase if no control measures are taken. There are indications that fossil fuels will continue to be the main source of power in the coming decades and that worldwide electricity demand will increase significantly, especially in developing nations. According to recent forecasts by the U.S. Energy Information Administration (EIA) and the International Energy Agency (IEA), fossil fuel-derived power is likely to account for more than 60% of total world electricity by 2030. IEA also predicts that China will add 1.3 billion kW generation capacity in the coming 20 years, and that coal-fired power generation will account for more than 70% of this generation capacity.²
The development of safe and reliable carbon capture and storage (CCS) technology is one of the key ways to decrease carbon emissions, as proposed by the U.S. Department of Energy in 1999. The biggest obstacle to the application of CCS technology is the high cost of investment and, in particular, the high cost of energy consumption, which accounts for two-thirds of the total cost. Consequently, how to reduce the investment costs has become a noteworthy issue in the recent discussion of CCS technology. However, CO₂ capture data from a long-running power plant have been absent—until now. Installed in 2008, the CO₂ capture engineering demonstration designed by Xi’an Thermal Power Research Institute and built by Hua Neng Electric Group in China has been running successfully and trapping CO₂ from the Beijing Gao Bei-dian and Shanghai Shi Dong-kou power plants for several years and, as a result, a large quantity of reliable data have been obtained and evaluated.

**CO₂ Capture at the Beijing Gao Bei-dian Plant**

The Gao Bei-dian thermal power plant is located in the eastern suburb of Beijing and is funded and constructed by Beijing International Power Development & Investment Corporation and Hua Neng International Power Development Corporation. The coal-fired power plant is equipped with a selective catalytic reduction (SCR) system designed to remove nitrogen oxides (NOₓ) emissions, an electrostatic dust removal system, and a limestone-gypsum wet desulphurization system. The emission of CO₂ from a single unit in this power plant is estimated at 1.3 million tons per year. The CCS demonstration system captures only 3,000 tons per year, 0.075% of total CO₂ emissions, but nevertheless is the first engineering application in China.

**How It Works**

The decarbonization system is installed following the wet desulfurization system. The CO₂ absorption...
system is made up of an absorption tower and a regeneration tower. The absorption and regeneration tower both measure more than 30m in height, and are 1.2m and 1.0m, respectively, in diameter. Flue gas from the fan flows into the absorption tower and contacts with the chemical absorbent of organic amine countercurrent to remove CO₂. The flue gas then enters into the washing system. It is discharged from the top of the tower after being washed with water. The nearly saturated CO₂ moves through the poor-rich fluid heat exchanger and goes into the boiler, which is connected to the regeneration tower at the bottom. In the boiling device, the fluid that is rich in CO₂ is heated to 110°C by low-pressure vapor, it then returns to the regeneration tower. CO₂ over flowing from the fluid goes through the condenser and gas-liquid separator. Water and monoethanolamine (MEA) volatilized from the CO₂ is condensed and returned to the regeneration tower. At the same time, the extracted dry and pure CO₂ is captured. The depleted fluid returns to the absorption tower and continues to work.

The gas absorption system costs approximately US$59,000, the regeneration system costs approximately US$76,000, and all the other equipment costs approximately US$26,000. The proportion of staff costs and system maintenance fees decrease rapidly as the system size increases. But operating costs will not dramatically change as the system increases; it is directly related to the capture performance of the technology. The proportion of operating costs of this system is shown in the graph at left.¹⁰

Steam consumption is approximately US$15.3/t CO₂, which consumes the largest proportion in operation costs. Another major operation consumption is power. The pump power consumption is approximately 90kWhr/t CO₂, and if we add other power such as controlling and lighting, then the total power consumption is approximately 100kWhr/t CO₂ (or US$4.8/t CO₂); the chemical absorbent solution costs approximately US$7.2/t CO₂; and the remaining consumption costs approximately US$1.6/t CO₂, which increases the overall cost of power by 29%.

CO₂ Capture at the Shanghai Shi Dong-kou Plant

The Shanghai Shi Dong-kou power plant is located in the Baoshan District, a northern suburb of Shanghai on the south bank of Yangtze River. Two 600-MW supercritical coal-fired generating units are installed. Flue gas desulfurization and denitrification devices went to operation at the end of 2009. The CO₂ recovery unit, with the designed capacity of 66,000 standard m³/hr recovering 12.5t of CO₂ per hour, was put into operation with the main units simultaneously. The device operates 8,000 hours continuously each year under the rated capacity. This CO₂ capture project is the largest of its kind in China, and the CO₂ concentration trapped is higher than 99%. After refining, the concentration is greater than 99.9% to meet food grade standard and achieve resource reuse. The technology was developed by the Xi’an Thermal Power Research Institute, and it is especially suitable for the flue gas with low concentration and large flow.

The Basic Process

The basic process for CO₂ capture from flue gas consists of three parts (see schematic on page 21): (1) the absorption tower at the center is supported by a cyclone separator, gas and water separator, and pressurization equipment; (2) the regeneration tower and reboiler are supplemented by a cooler, gas separator, and recovering system; and (3) between parts (1) and (2), there is an absorption
solution enriched with CO₂ gas, heat exchanger, and filtration system.

The temperature of the flue gas is approximately 48°C after desulfurization, which is the ideal absorption temperature for MEA. Generally, the flue gas is pressurized by blower into the CO₂ absorption tower directly, after dust removal and the desulfurization process. To avoid solution evaporation and amine loss, some pretreatment, such as cyclone separation or gas and water separation, should be done before the flue gas is carried into the CO₂ recovery system, since the wet flue-gas desulfurization will introduce a large quantity of free and saturated water, which makes it difficult to achieve water balance. In addition, the blowers are mainly used to overcome the pressure drop while gas goes through the separator or absorption tower.

In the absorption tower, the flue gas flows from the bottom while absorbent from the top, which contact by counter-current to remove CO₂. Purified gas releases from the top. As the MEA has a higher vapor pressure, washing is usually done in the upper absorption tower to cut MEA vapor content in the gas in order to reduce the loss of MEA caused by flue gas emission. Washing water is recycled and supplied with deionized water as needed.

Fluid rich in CO₂ is pumped to the rich-poor solution heat exchanger to recover heat, and then it enters into the regeneration tower. The desorbed CO₂ and steam are then cooled together to remove water, so that CO₂ with a purity greater than 99.5% is captured. Rich liquid of nearly saturated CO₂ enters into the regeneration tower from the top by stripping. After stripping, the semi-lean solution goes into the boil to desorb further. The degassed CO₂ flows out of the regeneration tower from the bottom, then it goes through the rich-poor solution heat exchanger and poor fluid cooler, and the cooled liquid is recycled in the absorption tower.

To keep the solution clean, 10–15% is filtered through the activated carbon. This system sets an amine recovery heater to treat the degradation products. If necessary, part of the lean solution and sodium carbonate will be sent into the heater to recover the amine. The regeneration gas from the trapping zone goes into the refining area for further purification treatment.

The capital investment for this plant was approximately US$256 million. The operating costs of the decarbonization zone are approximately US$62/t CO₂. In addition, the CO₂ purification costs are US$12/t CO₂; the power unit costs are US$1.6/t CO₂; and the human capital costs are US$6.4/t CO₂. The total operating costs of this decarbonization project are approximately US$82/t CO₂.

**An Important Role**

Though the scale of the carbon capture demonstration project at the Beijing Gao Bei-dian plant is small, it greatly promotes the development of CO₂ emission reduction efforts in China. The power plant in Shanghai plays an important role in carbon capture in China. In this system, the absorption and regeneration towers are the most expensive equipment, accounting for 50% of the investment. Therefore, it is important to develop new internal structure with more gas-liquid exchange capacity to reduce the size of the tower. At the same time, research on new absorbents with low-corrosion and high-absorption rates will also help reduce costs. In addition, the development of an absorbent with low-regeneration heat and to further recover of the low-grade heat also are the important routes on the path to reducing the costs of CO₂ capture in power plants. 

Further research on new absorbents with low-corrosion and high-absorption rates will help reduce costs.

References

9. Huang, B. *CO₂ Capture Technology in Coal-Fired Power Plant* [D]; Xi’an Thermal Power Research Institute, 2008; 140-141.

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Carbon Capture and Storage in Natural Gas-Based Heat and Power Plants in China

Recent studies for global emissions scenarios suggest that global carbon dioxide (CO₂) emissions must peak before 2020 if the United Nations’ target of limiting global warming to no more than 2°C is still to be achieved. This means that emissions of CO₂—a greenhouse gas and key contributor to global warming potential—will have to decrease quickly. Carbon capture and storage is seen as an essential way to reduce global CO₂ emissions with relatively low costs compared to alternative technologies. In China, CCS is a crucial option because of the large amount of fossil fuel use and associated high CO₂ emissions. This article considers the Asian Development Bank–People’s Republic of China joint initiative, Study on Carbon Capture and Storage in Natural Gas-Based Power Plants.¹

Carbon capture and storage (CCS) technology is suitable for use in a variety of industries, including the power generation, cement, steel, petro-chemical, synfuel, and chemicals manufacturing sectors. All of these industries are in large scale production in China. Ultimately, China needs to assess the suitability of various CCS technologies for these sectors. Even for a similar type of manufacturing sector, there are different technologies available in order to utilize CCS. For example, the installation of CCS at a natural gas combined cycle (NGCC) power plant might be very different to that of a combined heat and power (CHP) NGCC, owing to different plant operation patterns.

Within the People’s Republic of China (PRC), the introduction of natural gas-based power generation is potentially attractive as a means to alleviate the pressures of low-carbon economic development and urban environmental protection.
At the same time, since natural gas is a fossil fuel, albeit with a lower CO₂ emission coefficient than coal, it is important to determine the applicability of CCS for use in gas-fired plants. One potential technology for CO₂ capture is post-combustion chemical scrubbing. Although this technique has been tested on several coal-fired units at various scales of operation in the PRC, with very promising results, its use at gas-fired plants will bring different challenges. Natural gas burning produces flue gases with lower concentrations of CO₂ (~7%) than flue gases from coal burning (~14%). As a result, it is more challenging to remove CO₂ from gas-fired units than from coal-fired units.

The Asian Development Bank (ADB)–PRC joint initiative, Study on Carbon Capture and Storage in Natural Gas-Based Power Plants, has been designed to address such issues. The overall aim is to provide the critical strategic analysis needed to compare various CCS options at this early stage of CCS development for gas-fired CHP in order to provide options for the feasibility of near-zero CO₂ emission gas-based plants in major urban locations within China.

**CCS for Natural Gas Development in China**

In China, natural gas CHP developed very quickly, as the country’s fast-paced electrical generation capacity increases significantly bolstered the CHP market. However, China’s power capacity growth is slowing, resulting in an essentially flat CHP market between 2007 and 2011.

At the same time, due to much stricter regulation on air pollution that has been introduced in China recently, natural gas CHP is expected to increase in the near future. By the end of 2011, discussions centered on fine particulate matter (PM₂.₅) brought attention both from public and government to push strong action on air pollution control.

At the beginning of 2012, Beijing announced that it would be the first city in China to be coal-free. NGCC CHP is booming in Beijing, as a dominant option in the process. This trend is expected to continue in other cities in China.
As middle class incomes increase in China, it is projected that CHP will increase due to a growing need for new buildings with associated requirements for space heating. The structure for CHP plants will change significantly in the future owing to technology progression and much tighter environment pollution control standards. High-efficiency coal-fired CHP will be utilized in the future in the form of supercritical units and ultra-supercritical units (see Table 1). Natural gas-fired CHP will develop at a rapid pace, mainly due to urban environment concerns, with corresponding increases in efficiency.

The use of CHP will result in a reduction in CO₂ emissions as increased efficiency units are introduced (see Table 2). At the same time, the potential use of CCS in CHP is very large in China. Even though now it is difficult to predict the diffusion rate, a 330-Mt CO₂ reduction is possible if CCS is utilized at CHPs in China. After 2030, it is estimated that gas-based CHP with CCS will increase rapidly, and the emission reduction from NGCC CHP with CCS could contribute more than half of the total CO₂ emission reduction in CHPs by CCS in China (see Table 3).

### Financial Support for CCS Projects in China

There are several international financing sources and domestic incentive mechanisms available to CCS-related projects. More financial incentive
mechanisms may become available once commercialization becomes foreseeable. The current funds backed mainly by governments and development institutions support CCS research activities and demonstration projects: General funding sources for projects (i.e., equity investment, commercial banks, multilateral sources, carbon financing, project risk mitigation support); ADB-managed funds; global environment facility funds; World Bank-managed climate investment funds; Clean Development Mechanism; and Financial Incentive Mechanism.

Recommendations for CCS in China

Even though there remains uncertainty in China, the importance for CO₂ emission is crucial; CCS is the key option for the reduction. For natural gas-based urban heat and power plants, the need is to establish some firm data on the likely impact of post-combustion CCS in order to compare with the information gathered already for coal-fired plants. For example, to ensure sustainable development, it has been suggested that the target net efficiency penalty for 90% CO₂ capture in a power plant should be less than 5 percentage points, compared with plants without CO₂ capture.

CCS for natural gas power and CHP plants needs a stronger national strategic approach to support its development and application in order to meet the 2°C target. It is recommended that pilot CCS demonstrations in natural gas-based power plants should be progressed as a matter of urgency in order to establish some firm data on the likely impact of post-combustion CCS, for comparison with the information gathered already for coal-fired plants. Once that position has been achieved, the scope to make improvements can be determined and research and development programs can be focused accordingly.

Reference

Microalgae Potential for Carbon Utilization
A brief overview of the development of microalgae production for renewable energy.

Climate change has been a growing global concern for the past several decades. A recent Intergovernmental Panel on Climate Change (IPCC) report indicated increases in the atmospheric concentration of the greenhouse gases (GHGs) carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O) over pre-Industrial levels of 40%, 250%, and 20% respectively. Annual average worldwide CO$_2$ emissions from fossil fuel combustion and cement production in 2002–2011 were 8.3 Gt of C, which is equivalent to 30.4 Gt of CO$_2$ with an average growth rate of 3.2%/yr.$^{1,1}$ CO$_2$ emissions from energy consumption continue to rise. If the trend continues in the same trajectory, energy use will increase by more than two-thirds (based on 2011 levels) by 2050; an average global temperature will rise approximately 6°C in the long term (by 2100).$^{2,3}$ Low-carbon energy technologies are required to significantly reduce CO$_2$ emissions. Carbon capture, utilization, and storage is one of the important measures to curb global CO$_2$ emission.

**Carbon Capture, Utilization, and Storage**

The term carbon capture and storage (CCS) is widely recognized as referring to the technology to reduce carbon emission by capturing CO$_2$ from major CO$_2$ emission point sources, such as power plants and industrial facilities, compressing and transferring, and then injecting into geological formation to permanently store it deep underground.$^{4,5}$ CCS evolved to carbon capture, utilization, and storage (CCUS) in 2012 by the U.S. Department of Energy to strategically drive the research and development to economically utilize CO$_2$ for commercial processes.$^{5}$ According to the 2012 United States Carbon Utilization and Storage Atlas—Fourth Edition (Atlas IV), there are at least 2,400 Gt of possible CO$_2$ storage resources in the United States. Current estimations of CO$_2$ emissions from power plants and industrial sources are 33% and 22%, respectively; the application of CCUS technologies at these facilities will greatly benefit the U.S. environment.
and economy in both preventing \( \text{CO}_2 \) release to the atmosphere and utilizing capture \( \text{CO}_2 \) in the industrial processes.\(^5\)

**CO\(_2\)** Utilization

\( \text{CO}_2 \) utilization has been introduced as a possible alternative and/or complement to the geological storage of \( \text{CO}_2 \) that could increase the economic value for captured \( \text{CO}_2 \). Current estimates of \( \text{CO}_2 \) sold annually for commercial application are 80–120 Mt.\(^2\) Example applications include use as chemical solvents, soft drinks carbonation, and fertilizer manufacture. Tertiary recovery (or enhanced oil recovery, EOR) is largest \( \text{CO}_2 \) consumption industry, mostly from natural sources. EOR techniques can ultimately increase 30–60% more production than the reservoir original oil. Gas-injection EOR currently accounts for nearly 60% of EOR production in the United States.\(^6\)

As of 2014, there were 113 \( \text{CO}_2 \) EOR projects in the United States, injecting 3.1 billion cubic feet per day (Bcfd) or 60 Mt per year of natural and industrial \( \text{CO}_2 \) for EOR. The EOR-associated crude oil production was 282,000 barrels per day in 2012. However, the growth of \( \text{CO}_2 \) EOR oil production has been limited in the past few years due to restrictions in accessibility to affordable supplies of \( \text{CO}_2 \).\(^7\) The current cost of utilizing captured \( \text{CO}_2 \) is 5–10 times higher than naturally occurring \( \text{CO}_2 \) from underground reservoirs.\(^8\) Other emerging applications, such as plastics production or enhanced algae cultivation for chemicals and fuels, are still in the developmental stages.\(^2\)

**Microalgae Production**

In the past decade, there has been increased interest in the development of microalgae production for renewable energy supply. Microalgae are photosynthetic microorganisms that can grow rapidly. With abundant solar energy, during photosynthetic activities, microalgae consume \( \text{CO}_2 \) to reproduce their cells and store energy in the form of oils, carbohydrates, and proteins. Advantages of microalgae biofuels are greater production yields per land area compared with terrestrial crops, such as corn and soybean. Microalgae production does not require arable land, hence it does not compete with food crops.

Algae biomass production is estimated to produce 2–10 times more biomass per unit area than the best terrestrial systems. The main reason for this is greater photosynthetic efficiency. Under ideal growth conditions, algae use most of their energy in cell division allowing for rapid biomass accumulation.\(^9\) Approximately 1.8 tons of \( \text{CO}_2 \) is required to produce 1 ton of algae. By contrast, some estimates have shown that 0.63 Gt of \( \text{CO}_2 \) is required to produce 1 million barrels of gasoline.\(^10\)

**Pilot Project**

A pilot renewable energy project has been designed and constructed at the University of Cincinnati to study the production of microalgae utilizing the \( \text{CO}_2 \) from biogas content. The biogas is derived from an anaerobic digester designed to convert food wastes from the University of Cincinnati’s cafeterias into usable energy. The microalgae production system was designed as closed system using continuous flow stirred tank reactor (CFSTR) with bubble column to transfer \( \text{CO}_2 \) into growth media. The system will demonstrate the economical setup.
of microalgae production in pilot scale, as shown in Figure 1. This setup can also be used with other CO2 source such as captured CO2 or can be constructed with any CO2 source with small area requirement.

**Conclusion**

In 2013, biofuels such as ethanol and biodiesels contributed to only about 5% of total energy used by the U.S. transportation sector. Large-scale production of microalgae as a source of biofuel will potentially be another technology utilized carbon captured from CCUS. However, many challenges remain in the research and development of microalgae production, including identifying fast growing and tolerance strains, enhancing photosynthetic efficiency, contamination control, recycle growth media and nutrients, lowering harvesting, and conversion cost.

**References**

Each year, the Federal Highway Administration (FHWA) and U.S. Environmental Protection Agency (EPA) jointly sponsor a transportation and air quality summit to assess the progress in improving the air quality related to the emissions of highway vehicles. The summit covers policies, programs and technical issues confronting transportation and air quality agencies as they try to improve their local air quality. In addition to the sponsorship by FHWA and EPA, these summits are co-sponsored by local agencies. The co-sponsors for the 2014 summit included the Pennsylvania Department of Transportation and the Southwestern Pennsylvania Commission. The meeting was held in the Southwestern Pennsylvania Commission’s offices located in Pittsburgh, PA, August 19 and 20. Highlights from the summit are summarized on the following pages.
Current Regulatory Issues

The meeting opened with a presentation discussing the FHWA version of a transportation reauthorization bill, titled “Grow America”. This bill is the FHWA’s proposal for replacing the current legislation known as Moving Ahead for Progress in the 21st Century (MAP-21), enacted July 2012. Elements that specifically address highway-generated emissions were briefly discussed, including changes to metropolitan and statewide planning practices and environmental review reform. It was noted that the popular funding program, known as the Congestion Mitigation and Air Quality Improvement Program (CMAQ), will likely continue although some modifications may be made.

EPA’s Advance Program and Tier 3 Rule were also discussed. The Advance Program encourages areas in attainment of the U.S. National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter to adopt practices and programs that will help them maintain their attainment status. Information on measures and programs that could be instituted included educational awareness, voluntary measures, mandatory ordinances, and supporting mechanisms, such as webinars and grant programs. A critical element for all areas—both in attainment and nonattainment—was the introduction of EPA’s Tier 3 Rule, which tightens the emission standards of newly manufactured light- and medium-duty vehicles and further limits sulfur content in gasoline. This rule assumes an operational vehicle life extending to 150,000 miles and significant emission reductions following engine start-up achieved by technologies, such as catalysts, new technologies, and reduced gasoline sulfur.

Pennsylvania’s implementation of the 2012 annual PM$_{2.5}$ NAAQS was discussed. The presentation provided information on the designation process, State Implementation Plan (SIP) requirements, emissions inventory, motor vehicle emission budgets, and the process by which areas demonstrate their compliance with the transportation conformity requirements. Pennsylvania expects vehicle activity (as measured by vehicle miles traveled, or VMT) to increase, since Pennsylvania is an important crossroad for diesel traffic. Increasing VMT could represent challenges for areas that have not attained the standards.

Mobile Source Air Toxic Compounds

Mobile source air toxic compounds (MSATs) are a concern in many areas. FHWA’s guidance document addressing MSATs was discussed and it was noted that several research studies have also been conducted and a research report recently published, “National Cooperative Highway Research Project (NCHRP) 25-25 Task 70,” outlining the

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requirements for performing an MSAT analysis. The report noted that projects can lead to increases or decreases in emissions, but that the differences between build and no-build is generally low. Figure 1 illustrates that although traffic volume is increasing, MSAT emissions are expected to continue to decline through 2030.

The Downtown Pittsburgh Diesel Study was discussed with its purpose to better understand the diesel emissions, their distribution around the city, the sources, and emission reduction strategies. The project involved rotating monitors during a sampling period—consisting of two summer and two winter periods—and analyzing the difference chemical species and time intervals to tease out sources. Preliminary analysis concluded that diesel emissions are not evenly distributed throughout city and not attributable to a single source.

The Pennsylvania Department of Transportation and Metropolitan Planning Organization’s implementation process for linking planning requirements and National Environmental Policy Act (NEPA) requirements were described. The planning and environmental linkage (PEL) concept defined by FHWA (referred to as LPN—Linking Planning and NEPA) defines the relationship between planning and environmental analysis as provided for in the Safe Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFE TEA-LU) legislation. The PEL/LPN process was explained using the Southwestern Pennsylvania Commission’s Transportation Improvement Program (TIP) as an example.

### Climate Change and Energy

Climate change and energy efficiency issues remain important topics for those working in the air quality field. Presentations on several tools for analyzing
the impact from transportation systems on climate change were described, including FHWA’s Greenhouse Gas (GHG) Analysis Toolbox and EPA’s Travel Efficiency Assessment Method (TEAM). FHWA’s GHG Analysis Toolbox includes the GHG Planning Handbook, the Performance-Based Planning Handbook, the Construction and Maintenance GHG Calculator, and the Energy Emission Reduction Policy Analysis Tool (EERPAT). Although there is no uniform approach to analyzing GHG emissions, these tools provide options for those needing to conduct climate and energy impact analysis related to highway projects.

EERPAT is a strategic policy tool for quantifying GHG reduction potential and is based on the GreenSTEP model developed by Oregon Department of Transportation. It has been pilot tested by four states, including the Vermont Agency of Transportation (VTRANS). Vermont projected changes using policies such as electrical vehicle penetration and a VMT tax. The strengths and weaknesses of the pilot were discussed as were VTRANS plans for evaluating future GHG policy considerations.

The session concluded with a discussion of EPA’s TEAM tool, which estimates GHG and criteria pollutant reductions from travel efficiency strategies. EPA’s TEAM approach is illustrated in Figure 2. Strategies including employer-based travel demand programs, land use policies, transit projects and policies, and pricing policies were evaluated using case studies conducted in Tucson, Kansas City, and Boston.

The CMAQ Program
Federal and local perspectives on the Congestion Mitigation and Air Quality Improvement Program (CMAQ) were presented. The CMAQ program’s purpose is to reduce air pollution and traffic congestion from transportation-related activities. The federal overview described an evolving program resulting from Moving Ahead for Progress in the 21st Century (MAP-21) legislation enacted in July 2012 and extended until through May of 2015. Elements include an emphasis on diesel retrofit programs, eligibility for natural gas and electric vehicle refueling infrastructure, and a PM$_{2.5}$ set-aside program. An overhaul of the CMAQ project database and public access system, development of project cost-effectiveness tables, a CMAQ assessment study, and project performance measures were discussed as additional efforts to meet the requirements of MAP-21.

The Southwestern Pennsylvania Commission presented the regional perspective on their CMAQ program describing their selection process, including project eligibility, the CMAQ evaluation committee, advertising, determining a project’s benefit, project prioritization, recommendations, and selections. Each step was described conveying the Commission’s understanding of CMAQ funding and how these projects support their TIP process. Fund matching restrictions were noted as was the Commission’s decision not to fund diesel retrofits, since contractors can move their equipment out of state.

Near-Road Monitoring and Travel Forecasting
Two presentations were made on EPA’s near-road monitoring network—one from the national program perspective and a second from the local experience perspective. In 2010, EPA initiated the development of this network in conjunction with revisions to the NAAQS for NO$_2$, CO, and PM$_{2.5}$. The network is designed to collect air quality data adjacent to major highways. Among the factors for determining the sites were population, traffic volumes, and diesel truck volumes. Specifics about the selection criteria outlined in EPA’s Technical Assistance Document (TAD) were discussed, including distance from the road, monitor probe inlet heights, traffic volume, and traffic types. A document describing several “pilot” site studies was briefly mentioned as was the data collection effort initiated in January 2014. Figure 3 is an illustration of siting and preliminary data from one location.

The local perspective on this network was provided for the Pittsburgh site. The Allegheny County Health Department maintains the monitor and described their selection process for siting the monitor. This included ranking the site by annual average daily traffic (AADT), heavy-duty vehicle counts and fleet equivalent AADT (which adds
weight to heavy-duty vehicle counts), and criteria for safety, unobstructed air flow, and utilities.

Traffic data are a major input in air quality analysis, so finding a method for acquiring accurate traffic data is essential. One method employed by Delaware Department of Transportation is known as the Tax Parcel Travel Modeling Process. The presentation described three levels of resolution for traffic analysis zones (TAZs)—peninsula, micro, and parcel—and noted that parcel-scale provided more accurate information about the travel in the TAZ. An example was presented showing how traffic volumes can be estimated using this method for Smyrna Delaware.

FHWA’s Travel Model Improvement Program (TMIP) provides research, training, and technical assistance to the public on travel models. The program provides this information through webinars, reports, the Travel Analysis Toolbox, a website for information exchange, and a community of practice. Information-sharing is provided by Workshops on the Web (WOW), Web Knowledge and Information Exchange (WKIE), and the Peer Review Program among others. Other travel and traffic issues focused on the linkage between traffic modeling, air quality modeling, and the integration of these two processes.

Regional Emission Analysis
Having covered the source of mobile emissions, traffic, the presentations shifted to the emissions generated by the traffic and EPA’s MOVES model. The MOVES 2014 model was released just before the summit meeting and so new elements of the MOVES2014 were described. Features included new science on vehicle emissions (e.g., fuel effect, temperature, and activity), new EPA rules (e.g., HD GHG Rule, LD GHG Rule, and Tier 3), and functional improvements to the model (e.g., interface with SMOKE Model, NONROAD Model, tool to convert MOVES 2010 files, starts, fuel wizard, local inputs, hoteling trucks, and idling). Changes resulting from modifications to traffic data and for processing input and output data using the MySQL program were also highlighted.

Information was presented on the sensitivity of the input variables. Preliminary results from an NCHRP project (NCHRP 25-38) described the variables and the influence they have on the model results. This project investigated the previous version of MOVES, but the findings are believed to hold true for the newly released version. Inputs for both regional and project applications were included. Some preliminary results are shown in Figure 4.

Additional information was provided on inputting data into MOVES as a prelude for explaining a tool for manipulating the data in the MOVES input database. The presentation covered input data requirements, creating spreadsheets for the required data and using an automated tool to insert the spreadsheet data into the MOVES input database, and bypassing the County Data Manager (CDM) input processor.

Emissions from truck traffic associated with drilling for natural gas are increasing throughout the country. Information was presented on the truck traffic emissions related to natural gas drilling in Pennsylvania, specifically in the Marcellus Shale region. Slightly more than half of the counties in Pennsylvania have active drilling and the associated truck traffic is playing an increasing role in mobile source emissions. Although the emissions associated with this additional truck traffic may not directly cause a violation of the NAAQS, emissions from related sectors may have an influence, and may result in decreasing the mobile source emission budget. Pennsylvania’s VMT forecasting process for SIPs includes special adjustments for shale drilling.
Project Emission Analysis
As noted in an earlier presentation, the sensitivity of some variables were evaluated to determine their impact on the emissions. This presentation focused on the emission factors generated by the MOVES model when MOVES was used in project level mode; it did not investigate the sensitivities of the dispersion models. The test studied the same variables as had been studied using MOVES in the regional analysis mode and included age distribution, vehicle age, and fleet mix. Some influencing factors included fuel economy, the use of the average speed method rather than operating mode method for vehicle speeds, the speeds tested (25 mph, 35 mph, and 45 mph), intersections, and level of service (LOS) B, D, and E.

Although not intended to be a comparison between the two difference dispersion models, the session included a presentation on the use of the CAL3QHCR model and a presentation using the AERMOD model. The CAL3QHCR model was used to evaluate the Elgin O’Hare-West Bypass Project, while the second study used EPA’s AERMOD model for a project on I-69. Either model could have been used for both projects, but familiarity with the models by the modelers was the reason each model was selected.

An important element of any project analysis is the selection of the background concentrations of existing pollutants. Since the goal in performing an analysis is to accurately predict how emission generated by the project will influence the ambient concentration of the existing air, determining the existing background concentration is critical. Two methods of determining the background concentrations—using historical ambient data and chemical transport modeling—were noted, however the historical ambient data method was described since this method is more frequently used.

Stakeholders Roundtable
The summit concluded with a panel of staff members from several state Departments of Transportation and Metropolitan Planning Organizations outlining the issues that they face and the support they would like from federal agencies tasked with resolving transportation-related air pollution. Topics included the expanded use of managed lanes its and its impact on air quality; the CMAQ program and its reporting requirements and availability of funds, allowing states to “self-certify” their CMAQ projects; the new MOVES model; excessive run times; travel model needs; and control strategies impact estimation using tools. The new O₃ NAAQS to be released in December was noted as was the need for closer cooperation between the federal, state, and local agencies for resolving the issues discussed.

Summary
In closing, it is worth noting some new items were introduced in this year’s meeting. Posters were accepted allowing those limited by travel restrictions to provide input to the meeting during breaks between sessions. This year’s meeting was also conducted in the offices of a public agency permitting greater control over certain arrangements, such as web-based interactions and webcasting of presentations. This also provided a method for those with travel restrictions to make presentations, albeit with limited interaction with participants. In testing some new options, the Northern Transportation and Air Quality Summit continues to provide a forum for sharing information on transportation-related air quality issues.

*Figure 4. Preliminary findings of the sensitivity of MOVES to certain inputs.*

<table>
<thead>
<tr>
<th>MOVES Input</th>
<th>VOC</th>
<th>NOₓ</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Very Substantial</td>
<td>Very Substantial</td>
<td>Very Substantial</td>
</tr>
<tr>
<td>Humidity</td>
<td>Modest</td>
<td>Substantial</td>
<td>Modest</td>
</tr>
<tr>
<td>Speed</td>
<td>Very Substantial</td>
<td>Very Substantial</td>
<td>Very Substantial</td>
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<tr>
<td>Age</td>
<td>Very Substantial</td>
<td>Substantial</td>
<td>Substantial</td>
</tr>
<tr>
<td>VMT</td>
<td>Substantial</td>
<td>Very Substantial</td>
<td>Very Substantial</td>
</tr>
<tr>
<td>Population</td>
<td>Substantial</td>
<td>Substantial</td>
<td>Substantial</td>
</tr>
<tr>
<td>Ramp Fraction</td>
<td>Modest</td>
<td>Modest</td>
<td>Substantial</td>
</tr>
<tr>
<td>Source Type Detail for Road Type Dist</td>
<td>Modest</td>
<td>Modest</td>
<td>Moderate</td>
</tr>
<tr>
<td>Source Type Detail for Speed Dist</td>
<td>Modest</td>
<td>Modest</td>
<td>Moderate</td>
</tr>
<tr>
<td>Month VMT Fraction</td>
<td>Modest</td>
<td>Modest</td>
<td>Moderate</td>
</tr>
<tr>
<td>Hour VMT Fraction</td>
<td>Modest</td>
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</tr>
</tbody>
</table>
Although we may develop detailed project plans that are intended to prevent problems, we are still likely to encounter problems. Project planning allows us to anticipate problems and take steps to prevent them from occurring. And should problems occur, our plans provide a framework for addressing them quickly and efficiently. Nonetheless, some problems arise from systemic failures that need detailed analysis to identify the root cause of the problem.

### Getting to the Root of the Problem

Although any structured approach that objectively characterizes the problem can be used to determine its root cause, many find the “Five Whys” approach both easy and effective. The first step in the process is to collect the facts and then define the problem. Once the problem is defined, the investigator, using an iterative process, asks why the problem occurred, focusing on operations, processes, behaviors, and policies. The goal is to identify the fundamental system or process that failed, thereby creating the problem. The model uses five iterations to drill down to the problem; however, more or less iterations may be appropriate for some problems. Once the root cause is identified, corrective actions can be identified and implemented.

To illustrate this approach to root cause analysis, consider the following case where repair work on a compressor motor resulted in a production shutdown at a manufacturing facility. Importantly, this compressor provided compressed air to a part of the facility that was subject to process safety management (PSM). Accordingly, the repair work was planned, scheduled, and managed as a project. The incident investigation yielded the following details:

- Production was unexpectedly terminated when an air compressor was being repaired.
- The electrician incorrectly wired the motor when attempting the repair.
- When the electrician closed the breaker to re-energize the compressor, it created a major fault.
- The main breaker in the substation opened, shutting down power to the air compressor plant. This shut down some production areas, including some covered by the facility’s PSM program.

### Root Cause Analysis

Now let’s use the Five Whys approach to determine the root cause of the problem:

1. **Why did the unexpected production shutdown occur?** Because circuit breakers serving production equipment tripped.
2. **Why did the circuit breakers trip?** Because a motor on the circuit had been rewired.
improperly resulting in a short.

3. **Why was the motor wired improperly?**
   Because this motor had a wiring configuration that differed from other motors in the plant and the electrician re-wired the motor based on his familiarity with other motors.

4. **Why was the electrician not familiar with the specialized wiring requirements for this motor?**
   Because the motor required infrequent and non-routine service preventing the electrician from properly preparing for this repair task.

5. **Why was the electrician not properly prepared for the task?**
   Because procedures for addressing non-routine repairs on production critical motors did not exist.

Thus the root cause of the production failure was determined to be a lack of procedures for addressing non-routine repairs on production critical motors. It is important to note that this facility used a sophisticated maintenance management program that was supported with standard operating procedures, work instructions, and recordkeeping systems. In this particular instance, specialized equipment, with infrequent service intervals and wiring configurations that differed from similar equipment, had been overlooked.

**A Corrective Action Plan**

Once the root cause had been determined, a corrective action plan was developed that included the following elements:

1. Facility management engineers would identify “mission critical” motors. Mission critical motors were defined as those that would shut down production if they failed.

2. For these motors, two electricians would be assigned to the repair work. The electricians would not be required to work together for the entire repair operation; however, they would have to work together during the disassembly phase and the post-repair check phase that occurs before the motor is restarted.

3. The lead electrician would be required to make a sketch of the wiring connection for the motor and the second electrician would be required to verify it. This sketch would have to be made before disconnecting the wiring. Repair work would then have to be checked against this sketch by both electricians assigned to the repair before the equipment could be restarted.

4. A standard operating procedure would be developed to identify mission critical motors and provides a checklist incorporating the foregoing tasks.

5. Additional preventative maintenance requirements would be developed for these motors to reduce the potential for failure, and hence, the need for complex repair operations.

Although the above tasks may be appropriate corrective actions, it is important to note that an effective corrective action plan will go beyond merely identifying corrective actions. An effective corrective action plan will clearly identify who is responsible for completing the tasks, as well as a schedule for completing the tasks, and will include training requirements to ensure that corrective action requirements are fully understood. Finally, an effective corrective action plan will include follow-up monitoring to establish that the corrective actions are being implemented as required and producing the intended results.

**A Change in Enforcement**

Interestingly, recently proposed U.S. Environmental Protection Agency (EPA) regulations that would require fenceline monitoring for refineries (Federal Register 79, 336879, 6/30/2014) establish requirements for a root cause analysis and development of a corrective action plan if established fenceline limits for benzene concentrations are exceeded. The facility would not be deemed out of compliance with fenceline limits, provided that the appropriate corrective action measures are taken according to the time-frame detailed in the corrective action plan. This approach signals a change in enforcement that holds the facility accountable for proper root cause analysis and effective corrective action plan development and implementation. We’re likely to find that root cause analyses and corrective action planning will become projects for all environment, health, and safety project managers in the near future.

by David Elam

David L. Elam, Jr., CIH, CMQ/OE, PMP, is a consultant with TRC Environmental Corp. E-mail: delam@trcsolutions.com.

The goal of root cause analysis is to identify the fundamental system or process that failed, thereby creating the problem.
Members in the News

E. Joseph Duckett, P.E., Ph.D., long-time member and A&WMA Fellow, has been selected to receive the 2015 Metcalf Award from the Engineers’ Society of Western Pennsylvania (ESWP).

Currently director of environmental engineering for SNC-Lavalin’s Pittsburgh Office, Dr. Duckett has over 35 years of professional experience in engineering management, regulatory/compliance, consulting, and applied research.

Dr. Duckett received a doctorate in environmental engineering and science from Drexel University and is a registered professional engineer in six states. He is a member and past chair of Pennsylvania’s Air Quality Technical Advisory Committee and a past chair of A&WMA’s Allegheny Mountain Section. In 2007, he served as general conference chair for A&WMA’s centennial conference in Pittsburgh. He also served as ESWP President in 1996.

The Metcalf Award is awarded annually to an outstanding engineer who is a resident of the United States and whose field of engineering accomplishment relates to those fields normally associated with Western Pennsylvania, such as steel, aluminum, power, coal, electrical equipment, chemical, glass, and construction.

A&WMA member J. Wayne Cropp has joined Baker Donelson as counsel and a member of the firm’s Corporate Mergers & Acquisitions group, where he will focus on public policy, economic development, and environmental law. He brings unique legal experience with respect to emerging manufacturing technologies and companies and represents clients on a full range of environmental law issues, including new source permitting, environmental enforcement, air and water quality, Superfund, brownfield redevelopment, and waste resource issues.

From 1979 to 1990, Cropp served as executive director of the Chattanooga–Hamilton County Air Pollution Control Bureau, where he developed the implementation strategies that put Chattanooga in the national spotlight for its environmental initiatives. Cropp also served as chair of the Chattanooga Technology Summit, of the Tennessee Valley Corridor. For 15 years, he served as chair of the Environment Committee for the Chattanooga Regional Manufacturers Association. He is an active member of the Chattanooga, Tennessee and American Bar Associations and served as chair of the Environmental Law Committee of the Tennessee Bar Association. He was also the recipient of the Air Conservationist of the Year Award from the Tennessee Conservation League in 1986.

In Next Month’s Issue...

Mobile Sources

The April issue will feature a discussion of the latest developments in mobile source emissions and dispersion modeling, including the recently released MOVES2014 model, covering on-road vehicle emissions and off-road equipment; and the new TRAQS model, covering dispersion models as a subsequent step from MOVES.

Also look for...

• Etcetera
• IT Insight
• YP Perspective
EPA Issues Fine Particulates Designations, Finds 14 Areas inViolation

The U.S. Environmental Protection Agency (EPA) is classifying 14 areas in six states, including the San Joaquin Valley and the Los Angeles–South Coast Air Basin, as being in violation of the 2012 National Ambient Air Quality Standards (NAAQS) for fine particulate matter.

EPA established air quality designations for the revised fine particulates standard based on certified air quality monitoring data from 2011 through 2013. The U.S. Clean Air Act requires EPA to make its area designations within two years of promulgating a revised standard. EPA in December 2012 revised the annual, health-based standard for fine particulates from 15 µg/m³ to 12 µg/m³.

EPA said it is initially classifying all of the non-attainment areas for the 2012 fine particulate matter standards as being in moderate nonattainment. The 14 areas that will be designated as nonattainment areas are spread out over six states: California, Idaho, Indiana, Kentucky, Ohio, and Pennsylvania. Those states will be required to submit state implementation plans within 18 months of the effective date of the designations. The plans will outline the steps states and local governments will take to bring the nonattainment areas into compliance with the national air quality standard.

D.C. Circuit: Extension of 2008 Ozone Compliance Deadline Unlawful

The U.S. Environmental Protection Agency (EPA) unlawfully extended the deadline for states to comply with revised air quality standards for ozone issued in 2008, federal appellate judges have ruled. “Even assuming EPA could adequately justify choosing a trigger date other than the designation date, it has failed to do so here,” the U.S. Court of Appeals for the District of Columbia Circuit said in a 2-1 decision. That decision means states will have six months less to demonstrate compliance with the National Ambient Air Quality Standards (NAAQS) for ozone.

The court also overturned EPA’s decision to revoke the requirement for some states to maintain transportation conformity plans for the 1997 ozone standards, which were superseded by the standards set in 2008.

The NRDC had challenged EPA’s May 21, 2012, rule to implement the ozone NAAQS, which were revised to 0.075 parts per million in 2008. The EPA rule set the compliance period beginning December 31, 2012, but the NRDC argued the compliance period should have begun July 20, 2012, when nonattainment designations took effect. That would mean states designated as marginal nonattainment areas would have to demonstrate compliance by July 20, 2015. EPA’s extended deadline would have given states until December 31, 2015, to comply with the standards.

Farm Groups Challenge Proposed Grain Elevator Standards

The U.S. Environmental Protection Agency (EPA) doesn’t have the authority under the U.S. Clean Air Act to issue standards covering particulate matter emissions from new and modified grain elevators, according to a coalition of agricultural groups.

The groups, in joint comments on EPA’s proposed new source performance standards for grain elevators, said the agency didn’t “provide a rational basis” for concluding that emissions from future construction events at grain elevators present a significant risk to human health and welfare. The comments were filed jointly by the Corn Refiners Association, National Council of Farmer Cooperatives, National Grain and Feed Association, National Oilseed Processors Association, North American Millers’ Association, and USA Rice Federation.

EPA in July 2014 issued a proposed rule that would establish new requirements for grain elevators on which construction, modification, or reconstruction commenced after July 9, 2014. The proposal, which would set new emissions limits and additional testing, recordkeeping, and reporting requirements for those grain elevators, is projected by EPA to reduce particulate matter emissions by 31 tons per year.
To Frack or Not to Frack in Yukon?

The Yukon legislative committee charged with reporting on the risks and benefits of hydraulic fracturing has failed to reach a consensus on key issues.

Four issues confounded the committee: whether hydraulic fracturing can be done safely, whether hydraulic fracturing should be allowed in Yukon, whether social license from the Yukon public is necessary before considering hydraulic fracturing in Yukon, and whether to proceed with specific regulatory development of hydraulic fracturing.

The committee did reach consensus on 21 points, the sum of which presents a high hurdle for the government to leap should it choose to court the unconventional oil and gas industry. Recommendation number 1, for example, is that the government obtains the support of the Yukon First Nations, whose traditional territories are affected before allowing hydraulic fracturing. Many of the suspected hydrocarbon-rich lands in Yukon are either settled or disputed Aboriginal lands, and First Nations presenting before the committee were unanimous in their opposition to hydraulic fracturing.

The bulk of the remaining recommendations call on the government to undertake a wide range of research into social and economic impacts, as well as in the collection of baseline data for environmental monitoring. The final decision rests with the Yukon government. —By Mark Sabourin, EcoLog

New Report Argues the Merits of Low-Carbon Growth

Over the next 15 years, governments around the world will invest some US$90 trillion in infrastructure, according to The Global Commission on the Economy and Climate. If those governments can direct investments into low-carbon infrastructure, the commission says, the planet will have taken a big step toward arresting the advent of climate change.

The Global Commission on the Economy and Climate consists of 24 leaders from government, business, and finance in 19 countries. Leading research institutes from China, India, the United States, Brazil, Korea, Europe, and Africa conducted a year-long study, and the resulting report, “Better Growth, Better Climate,” was launched at an event at the University of Toronto’s Munk School of Global Affairs on January 13, 2015.

The report challenges the often-cited argument that carbon-conscious policies will strangle economies emerging from recession, arguing instead that governments and businesses can improve economic growth and reduce their carbon emissions at the same time. “Better Growth, Better Climate” sets out a detailed 10-point Global Action Plan of practical recommendations that could achieve greater prosperity and a safer climate. —By Mark Sabourin, EcoLog

Pembina Institute: Natural Gas’ Impact on GHG Emissions Overstated

Natural gas may serve as a bridge fuel to a low-carbon economy, but the Pembina Institute argues that its impact on global greenhouse gas (GHG) emissions is overstated. In a January 22, 2015 webinar based on “LNG and Climate Change: The Global Context,” a 2014 Pembina Institute report, Pembina British Columbia (BC) Director Josha MacNab took particular issue with the BC government’s assertions that exporting liquefied natural gas will be a significant contribution to global GHG reduction because it will displace coal in markets such as China.

That’s not necessarily the case, said MacNab. There are uncertainties about the lifecycle GHG contribution of natural gas. If natural gas is to play an important role in the transition to low-carbon energy, investment in new technologies, such as methane management, will have to be made.

MacNab argued that if coupled with strong climate policy, including a price on carbon and an end to fossil fuel subsidies, natural gas will displace coal and will eventually be replaced by renewables. But in the absence of strong climate policy, natural gas will simply retain its place in the energy mix. —By Mark Sabourin, EcoLog
States and utilities said Jan. 29 they lack the time and resources needed to meet the interim carbon dioxide emissions targets for the power sector proposed by the U.S. Environmental Protection Agency (EPA) in its Clean Power Plan.

The Clean Power Plan requires states to achieve the bulk of the mandated carbon dioxide reductions during an interim compliance period between 2020 and 2029, which is unrealistic, power companies and state regulators said during a Jan. 29 forum sponsored by the Bipartisan Policy Center.

Some states said they are further hampered by EPA’s unrealistic assumptions about how quickly they can make the necessary policy changes and infrastructure improvements necessary to meet that interim target.

“Most states don’t even have the infrastructure in place to meet that target,” Quinlan Shea, vice president of environment at the Edison Electric Institute, said.

States and utilities said EPA will need to extend that interim deadline, revise the near-term targets or scrap the interim target entirely and focus solely on helping states meet the final carbon dioxide emissions rates set out for 2030 to make the rule workable.

“Most states don’t even have the infrastructure in place to meet [EPA’s] target.”

— Quinlan Shea, Edison Electric Institute
EPA’s Clean Power Plan (RIN 2060-AR33), proposed in June 2014, sets a unique carbon dioxide emissions rate for each state. States would develop their own plans to comply with the rule. EPA expects the proposal will reduce carbon dioxide emissions from existing power plants by 30% from 2005 levels when it is fully implemented in 2030.

**Reductions Front Loaded**

Some state regulators said EPA’s proposal requires as much as 80% of their emissions reductions to be achieved during that 2020 through 2029 interim period. They doubted that states would be able to craft the policies necessary to encourage the investment in cleaner or renewable generation necessary to meet that target in the time EPA has allowed.

“That interim goal presents a logical virtual impossibility because of all the different moving parts that need to be addressed,” Robert Kenny, chairman of the Missouri Public Service Commission, said.

Regulators and power companies both said EPA’s rule is heavily reliant on natural gas displacing coal-fired generation, but the proposal does not provide adequate time to develop the infrastructure needed to accommodate the anticipated increase in demand for natural gas.

Henry Darwin, director of the Arizona Department of Environmental Quality, said the proposed rule unrealistically assumes that a state could wean itself entirely off of coal-fired electricity by 2020. “For EPA to assume we can be off coal for those summer months is a really a false assumption and can’t be achieved by 2020,” he said.

Rather than a single interim compliance target to be met between 2020 and 2029, Derek Murrow, director of federal energy policy at the Natural Resources Defense Council, said EPA could set two different five-year interim compliance targets that could ease the burden on states. “If EPA adjusts targets, depending on how they did that, you might see more of a glide path of the targets,” he said.

**Early Action Not Credited**

States and utilities were also concerned that EPA’s proposed rule does not sufficiently credit them for steps they took prior to the proposed 2012 baseline to reduce carbon dioxide emissions from the power sector. That results in emissions rates that are more stringent than realistic while leaving states and utilities with fewer options for achieving the necessary reductions, they said.

Bob Martineau, commissioner of the Tennessee Department of Environment and Conservation and president of the Environmental Council of the States, said EPA’s decision could create incentives for utilities to delay investment in beneficial pollution controls in the future because they might fear they will not be credited in upcoming regulations.

“Why would any industry make an early reduction on anything they think EPA will eventually regulate?” he said.

Jack Ihle, director of environmental policy at Xcel Energy, said his company has taken steps to reduce its investment in coal-fired generation, but the company’s efforts were not credited in EPA’s proposal. Xcel reduced its greenhouse gas emissions by 18% between 2005 and 2012 and plans to reduce its emissions by 30% by 2020. “We felt the rule didn’t fairly treat us,” Ihle said.

Lisa Edgar, a member of the Florida Public Service Commission and president of the National Association of Regulatory Utility Commissioners, said ratepayers have already been asked to pay for those early investments in new pollution controls but they do not receive credit as part of EPA’s rule.

“The investment our utilities made and our ratepayers paid for to move us forward and have cleaner emissions should not be such that we’re penalized in the goals moving forward,” she said.

Rather than adjusting the 2012 baseline, Kenny said, EPA could revise its emissions rate targets for states to incorporate the steps some have already taken, though that could lead to less stringent standards overall. —By Andrew Childers, Bloomberg BNA
Several industry and public health groups used a public hearing to push for changes in the U.S. Environmental Protection Agency’s (EPA) proposal to revise the National Ambient Air Quality Standards (NAAQS) for ozone.

Representatives of the American Lung Association, Sierra Club, and other environmental and public health groups urged EPA to set the standards at 60 parts per billion (ppb), a level which they said is needed to offer an adequate level of health protection for children and other at-risk populations.

The agency also heard from representatives of the American Petroleum Institute, U.S. Chamber of Commerce, and other industry groups, who raised concerns about the high costs of revising the ozone standard and urged the agency to retain the current standard of 75 ppb.

EPA in November 2014 proposed (RIN 2060-AP38) to revise the current standard to somewhere in the range of 65 ppb to 70 ppb.

EPA Administrator Gina McCarthy told reporters when the proposal was released that there is uncertainty on the data of health effects at the 60-ppb level supported by public health groups, but said that level is still “on the table” for EPA consideration. The agency is soliciting comments on both a 60-ppb standard and retaining the current 75-ppb standard, set in 2008.

The hearing in Washington was one of three public hearings EPA scheduled to complement the written comment period, which ended March 17. The agency also held a Jan. 29 hearing in Arlington, TX, and a Feb. 2 hearing in Sacramento, CA.

Hundreds Push for Stronger Standard

Mary Ann Hitt, director of the Sierra Club’s Beyond Coal Campaign, told Bloomberg BNA Jan. 28 the environmental group had organized hundreds of people to attend the public hearings in support of a more stringent ozone standard.

In addition to medical professionals, environmental groups also focused on getting individuals who suffer from asthma and other ozone-related health effects to present testimony before EPA. “The public input here is really important because it is such a big public health issue,” Hitt said.

The Sierra Club also is collecting thousands of written comments that will be submitted to EPA, and will work to make sure that the White House Office of Management and Budget (OMB) hears from medical experts and people who suffer from ozone pollution when the final rule on the ozone standard is sent to OMB for review, she said.

Proposed Range Called Inadequate for Health Protection

The agency officials at the Washington hearing heard from many individuals who said the proposed range of 65 ppb to 70 ppb is still not protective enough of public health.

Many people who testified on behalf of public health groups referenced the conclusion by the Clean Air Scientific Advisory Committee, an independent advisory panel that recommended EPA consider revising the ozone standard to somewhere between 60 ppb and 70 ppb.

That committee advised EPA to set the ozone standard at a more stringent level than 70 ppb, citing “substantial evidence” of adverse health effects at that level.

Samantha Ahdoot, a member of the American Academy of Pediatrics Council on Environmental Health, told EPA officials that their proposal was “a step in the right direction,” but said there was “clear and compelling scientific evidence” supporting a standard of 60 ppb.
When asked by EPA staff about that evidence, Ahdoot said her written comments on the ozone proposal will reference studies that support a 60-ppb or lower standard.

**Industry Cites Economic Effects**

EPA also heard from several industry and business groups, who raised concerns about the economic effects of the agency’s proposal to set a more stringent ozone standard.

Mary Martin, energy, clean air, and natural resources policy counsel for the U.S. Chamber of Commerce, said businesses are concerned about the “potentially devastating economic and employment impacts” of revising the ozone standard.

A more stringent ozone standard would place more areas of the United States into nonattainment, a designation that is viewed as a “death knell” for economic development in an area, Martin said.

Businesses seeking to build or expand facilities in nonattainment are subject to tougher permitting requirements under the New Source Review program. Martin said a nonattainment designation makes it “substantially harder” for communities to attract new businesses.

**Could Affect 45 of Lower 48 States**

Howard Feldman, director of regulatory and scientific affairs at the American Petroleum Institute, said during his testimony that an ozone standard of 65 ppb could lead to the designation of nonattainment areas in 45 of the lower 48 states.

He argued that EPA should give states and businesses more time to achieve progress under the 2008 ozone NAAQS, which are still being implemented. Feldman noted that the implementation rule for those 2008 standards has yet to be finalized and is still under review at OMB.

The American Fuel & Petrochemical Manufacturers (AFPM) also won’t support a tightening of the ozone standard while the current standard is still being implemented, according to David Friedman, vice president for regulatory affairs at the AFPM.

“EPA should not move the goal posts in the middle of the game,” he said.

**EPA Estimates Criticized**

Anne Smith, senior vice president at NERA Economic Consulting, criticized EPA’s cost estimates that accompanied the ozone proposal, which she said the agency “greatly underestimated.” EPA estimated that a 70-ppb standard would cost $3.9 billion to implement annually, while a 65-ppb standard would cost $15 billion annually.

NERA Economic Consulting is the firm that prepared a 2014 report, commissioned by the National Association of Manufacturers, that estimated a 60-ppb ozone standard could cost the United States as much as $270 billion in annual economic output and force the closure of one-third of the nation’s coal-fired power plants.

**Environmental Groups Criticized Economic Study**

The Natural Resources Defense Council and other organizations were critical of that economic study, specifically NERA Economic Consulting’s decision to use the Car Allowance Rebate System, an economic stimulus program commonly known as “Cash for Clunkers,” to estimate the cost of unknown controls needed to meet a more stringent ozone standard.

Smith said the 2014 report included several recommended evidence-based techniques for quantifying the costs of unknown controls. Instead of using those techniques, EPA retreated to a “less-informed” method for estimating the costs of unknown controls, according to Smith.

She acknowledged that EPA says it’s not allowed to consider costs in its review of NAAQS, but said the costs of revising those standards “are not irrelevant to the public.”

The U.S. Supreme Court in 2001 ruled that the U.S. Clean Air Act prohibits EPA from considering implementation costs when setting national ambient air quality standards (Whitman vs. American Trucking Ass’ns, 531 U.S. 457, 51 ERC 2089 (2001)).
**Need for Accurate Information Cited**
Several public health commenters said the agency’s Air Quality Index (AQI) is providing the public with inaccurate information on the quality of air where they live because the index is based on a standard that isn’t strong enough to be protective.

The AQI calls for “code orange” alerts on days when ozone levels would affect at-risk groups and “code red” alerts on days when ozone levels could cause adverse health effects in all people.

Hitt of the Beyond Coal Campaign told EPA staff-ers that those alerts aren’t providing parents with accurate information on whether the air is safe for their children to breathe. “Those alerts are based on outdated medical science,” she said.

**Bad Information Being Disseminated**
Paul Billings, senior vice president for advocacy and education at the American Lung Association, agreed that the 75-ppb standard is resulting in the dissemination of bad information on air quality. “The current standard misleads all of us about bad air,” he said.

Billings also reiterated that the U.S. Clean Air Act only asks one question of EPA: “At what level does ozone harm health?”

He said the agency is once again hearing “outrageous claims” from industry on costs—arguments that have been proven false in the past when air quality standards have been lowered.

“A strong ozone standard will not block a new hospital from being built,” Billings said.

**Agencies Call for Timely Guidance**
A coalition of state and local clean air agencies praised EPA for proposing to update its AQI at the same time as finalizing the ozone standards.

“The effectiveness of the AQI as a public health tool will be undermined if EPA undertakes regula-tory changes to the ozone [national ambient air quality standard] without simultaneously revising the AQI,” said Nancy Kruger, deputy director of the National Association of Clean Air Agencies, which represents air regulatory agencies in 42 states, the District of Columbia, and 116 metropolitan areas.

Kruger said her members also would like to see EPA “commit to and follow through on” proposing the implementation rule for the revised ozone standards at the same time as the standards are finalized. Implementation rules address various issues related to national ambient air quality standards, including requirements for attainment demonstrations and New Source Review permitting.

**Timetable for Implementation Rule**
Kruger said EPA should issue its final implementa-tion rule for the expected 2015 ozone standards within one year of their issuance.

EPA often fails to issue implementation rules and guidance until years after a national air standard is revised. Representatives from several state and local air pollution control agencies told Bloomberg BNA in 2014 that they would be able to more readily process pre-construction permits if EPA issued its guidance on ambient air standards in a more timely manner. —By Patrick Ambrosio, Bloomberg BNA

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<table>
<thead>
<tr>
<th>EM Advertiser (www)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Public University System (apus.edu)</td>
<td>17</td>
</tr>
<tr>
<td>Lakes Environmental Software Inc. (weblakes.com)</td>
<td>Back Cover</td>
</tr>
<tr>
<td>Newell Rubbermaid Commercial products LLC (rubbermaidcommercial.com)</td>
<td>3</td>
</tr>
</tbody>
</table>

**EM Advertiser (www) | Page**

- Tri-Mer Corp. (tri-mer.com) 7
- UL-DQS Inc. (ul-dqsusa.com) 19


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