8 University of Kentucky

Regional Energy Innovation Forum

Lexington, Kentucky • April 21, 2016

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Post-Forum Report

Contents

Opening Remarks, President Eli Capilouto

Thank you. It's a pleasure to be here this morning and welcome our guests from out of town to Lexington and the University of Kentucky.

I'd also like to introduce some of the members of the UK family who have built the foundation for UK's strong relationships with the Department of Energy: Lisa Cassis, our Vice President for Research, and a highly regarded scientist with a large research portfolio funded by NIH; Larry Holloway, Chair of the Department of Electrical and Computer Engineering, Director of the Power and Energy Institute of Kentucky, and state director of Kentucky's DOE EPSCoR (Experimental Program to Stimulate Competitive Research) program; and Rick Honaker, Chair of UK's Mining Engineering Department, who is helping lead our partnership with DOE's National Energy Technology Laboratory to develop a mobile pilot-plant facility for the recovery of rare earth elements from coal.

Because of the extraordinary talent on our campus, we were honored – but not surprised – when our Center for Applied Energy Research (CAER) was asked to spearhead and help lead this Forum. Led by Director Rodney Andrews, CAER is one of the nation's leading energy research and development centers.

CAER is home to researchers like Kunlei Liu, who helped create the Carbon Management Research Group, an industrial, academic and government consortium that has partnered to develop cost-effective technologies for reducing and managing carbon dioxide emissions at coal-fired power plants, and Mark Crocker, who – thanks to DOE-grant support – is seeking an algae-based platform to reuse carbon dioxide emission from power plants. Dr. Crocker's algae work has been scaled from the bench to a field demonstration here in Kentucky. And he recently partnered with a company in China to utilize CO_2 at a power plant.

Finally, I want to welcome and thank our friends, colleagues and collaborators at the Department of Energy who helped make this Forum a reality. It is my pleasure to welcome our distinguished guest and keynote speaker, Secretary Ernest Moniz of the U.S. Department of Energy.

As U.S. Secretary of Energy, Dr. Moniz is tasked with implementing critical Department of Energy missions in support of a comprehensive energy strategy that supports the economy, enhances security, protects the environment, and positions the United States as a global leader and collaborator on these important priorities.

Prior to his appointment, Dr. Moniz was the Cecil and Ida Green Professor of Physics and Engineering Systems at MIT where he has been a faculty member since 1973. At MIT, he helped lead the development of multidisciplinary technology and policy studies on the future of nuclear power, coal, nuclear fuel cycles, natural gas and solar energy in a low-carbon world.
His background includes critical policy development and leadership on nuclear weapons stockpile stewardship, the disposition of Russian nuclear materials, the President's Council of Advisors on Science and Technology, the DoD's Threat Reduction Advisory Committee, and the Blue Ribbon Commission on America's Nuclear Future. Dr. Moniz is a member of the Council on Foreign Relations and is a Fellow of the American Association for the Advancement of Science, the American Academy of Arts and Sciences, the Humboldt Foundation, and the American Physical Society.

Please welcome Secretary of Energy, Dr. Ernest Moniz.

Secretary Moniz remarks:

Today's meeting is part of a larger conversation that we are having across the country around how low carbon energy can ensure energy security, reduce energy costs and help American companies remain competitive in the global economy. The *2016 Economic Report* of the President notes that one half of the growth in productivity between 1948-2014 came from improvements in productivity associated with innovation.

Looking at energy more specifically, the American Energy Innovation Council noted that, "*Public investment is critical to generating the discoveries and inventions that form the basis of disruptive energy technologies. Private companies cannot capture the full economy-wide value of new knowledge and thus systematically underinvest in research and development relative to the benefits it produces.*"

Abundant, diverse and affordable domestic energy also adds to our security. Since 2008, the United States has reduced oil imports by nearly 60 percent, but we still import seven million barrels of crude oil every day. Continued investments into biofuels, electric vehicles and efficient transportation are critical to reduce our oil dependence and can open new transportation horizons.

We also need to drive down the costs of shale oil production and expand the use of enhanced oil recovery (EOR) to simultaneously reduce carbon emissions from coal-fired power plants while increasing domestic oil recovery. It's a win-win for our economy and our security.
Last year, President Barack Obama joined 19 other world leaders to launch Mission Innovation, a commitment to double each government's investments in low carbon energy research and development over the next five years. This represents a major expansion of the global innovation pipeline, since Mission Innovation nations account for more than 80 percent of the world's public clean energy investment.

In February, President Obama released the Administration's budget request for fiscal year 2017, which makes good on the U.S. Mission Innovation commitment with $7.7 billion across 12 agencies for clean energy research and development, including $5.9 billion at the Department of Energy. Which puts us on pace to double funding by 2020.

Doubling our RD&D funding will allow us to take advantage of a lot of opportunities currently being "left on the table." A good example is the ARPA-E program, which received a 12 percent budget increase in the bill that just passed in the Senate. ARPA-E started in 2009 and became operational (awarding projects) in 2010. To date, 200 projects have been completed and have received $1.25 billion in private sector funding on top of federal investments. Results include 36 companies formed and 10 commercial products. But – only 2% of proposals from last year's open call were able to be funded at ARPA-E, meaning we are leaving a lot of great ideas out.
While Mission Innovation incorporates every source of clean energy, including new advances in energy efficiency, renewables, energy storage and transportation, smart and resilient infrastructure, and cutting-edge technologies in nuclear energy, and advanced manufacturing, it will also focus on a range of fossil fuel technologies.

Smart investment by governments will need to be matched by smart investments from the private sector to move technologies to the market. Mission Innovation is complemented by a significant private sector-led effort. Led by Bill Gates, 28 investors from 10 countries created the Breakthrough Energy Coalition to mobilize substantial capital to capture the fruits of Mission Innovation by investing with heightened risk tolerance, patience and a willingness to carry the most promising technologies all the way to the marketplace.

We need a breadth of energy solutions that will serve the varied needs and resources in different regions, in concert with expanded innovation ecosystems of researchers, entrepreneurs, investors and companies in all parts of the country. The National Research Council's 2012 Report, Rising to the Challenge, articulated the rationale: "*Historically, federally funded R&D has not been connected to state and regional industrial development. Bridging that gap can create the local talent and technology base needed to convert these U.S. investments into domestic companies, industries, and jobs.*"

Coal can serve as an innovation case-study. Recently, sustained low prices for natural gas, combined with the appeal of its lower carbon emissions, have helped natural gas challenge coal's longtime dominance in electricity generation. For coal to remain competitive in this environment, efficient, low-cost, large-scale carbon capture technologies are needed. Within the broader DOE efforts tied to Mission Innovation, we have reinvigorated our efforts on carbon capture with an initiative we are calling Innovation CCS.

Panel I: Innovation, Combustion and CCS - David Mohler, Deputy Assistant Secretary, Office of Fossil Energy, Moderator

Dr. Jeff Phillips, Senior Program Manager, EPRI

Supercritical CO2, Brayton Power Cycles – Potential and Challenges

Coal power plants have become increasingly efficient over time, but efficiency has capped at ~33% since the 1970s, while natural gas power plant efficiency continues to improve. Part of the problem is the conventional Rankine Cycle, which has reached temperature limits when using ferritic steels. DOE is funding work to address that through the use of nickel alloys. Another way to improve the situation is to use a Closed Brayton Cycle and use supercritical CO2 instead of air as a working fluid. Closing the cycle reduces heat loss and improves efficiency by ~5%. Even higher efficiencies could be attained by integrating coal gasification with a closed Brayton Cycle. To make it happen, need compact and efficient heat exchangers. (Net Power is developing this approach for natural gas plants).

Dr. Kunlei Liu, Center for Applied Energy Research, University of Kentucky

Chemical Looping and Oxy Combustion

Both chemical looping and oxy combustion are mature technologies, but have some challenges that make adoption difficult. (1) Ash oxygen carrier separation is difficult, (2) slow kinetics of a solid fuel on solid oxygen carrier combustion, (3) affordable oxygen carrier – current cost is $20- 200K/ton, and (4) oxygen carrier agglomeration in the fluidized bed configuration, which is terrible for unit operation. Benefits for C capture include the fact that oxy combustion produces high purity CO2, removing the need to separate and concentrate CO_2 after combustion. To make oxy combustion affordable, we need a carbon tax. To make chemical looping competitive, need the cost of oxygen carrier needs to be less than $2,000/ton as compared to $50/ton for coal. A 500 MWe CLC requires 200 tons coal/hr @ η=35% and 1,200 Btu/lb Coal and 10,000 – 20,000 tons of oxygen carrier in circulation.

Kiln may work as a means to produce oxygen carrier particles with chemical looping and oxy combustion. The kiln is widely used in making cement and batteries.

Roxann Laird, Director, National Carbon Capture Center

Advancing Capture Technologies

Carbon capture, use and storage (CCUS) is an integrated suite of technologies that can capture up to 90% of the carbon dioxide emissions produced from coal fired power generation plants. Capture technologies separate carbon dioxide from gases produced in electricity generation by one of three methods:

- Pre-combustion capture
- Post-combustion capture
- Oxy-fuel combustion

Carbon capture technology is key to reducing carbon dioxide emissions from coal-fired power generation plants but current technology have higher capital and operating costs as well as lower efficiencies than conventional power plants without capture.

National Carbon Capture Center (NCCC) is located in Alabama and is a partnership with Southern Company, EPRI, Luminant, American Electric Power, Cloud Peak Energy, and Duke Energy. It is also a part of the international test center network, a place where knowledge about carbon capture can be shared for everyone's benefit.

Post-Combustion Accomplishments:

- PC4 operation supported 40,000 hours of technology testing
- Over 6,000 hours under natural gas conditions
- More than 20 developer projects completed
- Tested enzymes, membranes, sorbents, solvents, and associated systems
- Continued relationship with technology developers to achieve scale-ups and process enhancements
- PSTU operation for more than 13,000 hours
- Demonstrated near 100% mass and energy balance closures
- Supported commercial developers and DOE Carbon Capture Simulation Initiative
- Several solvents progressed to further testing at other facilities
- Facility construction and upgrades
- PC4 constructed in under three years
- Plant capacity more than doubled from 12,000 to 30,000 lb/hr flue gas
- Added systems (SSTU, air dilution, etc.) and enhanced instrumentation, sampling methods, and analysis systems

George Koperna, VP, Advanced Resources International

Storage and Subsurface

Traditional storage reservoirs have high porosity or are depleted oil and gas reservoirs, which are not uniformally distributed across the US. Some non-traditional reservoirs are on the horizon and have the potential to substantially increase storage opportunities.

From a subsurface perspective, early CCS efforts have taken advantage of decades of CO_2-EOR experience in industry as well as natural gas storage. Existing technologies for tacking CO_2 are from those industries and are not sufficiently rigorous for permitting and to address stakeholder concerns. Seismic technologies lose resolution at depth, geophysical logging protocols do not identify small-scale and inter-well geologic heterogeneity, and pressure gauges require frequent maintenance. However, there are technologies in development that address many of these concerns.

A great deal of work has gone into the geologic assessment of reservoirs for CO_2 storage. However, most projects that have advanced are connected with the economic benefits of CO_2-EOR. Ultimately, a portfolio approach will be required to meet long-term storage needs. In addition to saline and depleted O&G reservoirs, greenfield ROZs show promise, with 4 Permian basins counties accounting for 11 gigatonnes of potential storage resource (Australia, the Middle East, the North Sea, South America, and Lithuania). Co-injection of nitrogen with CO_2 may arrest swelling in coalbed reservoirs and reduce the cost of capture.

As long as there have been CO_2 injection projects, conforming the flood has been the number one challenge. Many of these challenges will be relevant to storage operations as operators will attempt to maximize the use of the storage space and limit area of review and/or surface rights exposure. Techniques include:

1. Engineered completions, including select perforating, stacked storage reservoirs, smart well completions.
2. Vertical (top-down or bottoms-up) flooding, and possibly into/from a saline leg.
3. CO_2-soluble diverting agents.
4. Brine withdrawal and injection strategies to create space and/or “steer” the CO_2 plume.

In addition to conforming the injection project, a number of next-generation technologies are available for tracking the CO_2 in the subsurface. They are:

1. S-wave seismic: UT Austin is able to migrate p-wave data into higher resolution s-wave data. Still quantifying improvement.
2. Real-time subsurface flow imaging: Seismos Technologies is using k-waves (acoustic generated) to monitor well-to-well flow.
3. Distributed acoustic sensing: Deployed fiber optics have the capability to act as permanently deployed geophones, with 1 meter resolution.
4. Resistivity/Gravity: E&P exploration techniques deployed to monitor the plume with downhole sensors
5. Surrogate modeling: Reservoir training provides real-time tools for subsurface plume development.

The next phase of monitoring innovation still draws upon mineral/hydrocarbon exploration technologies, However, many of the techniques and advancements are pre-commercial requiring significant *field testing* to advance. Only CO_2-EOR in the U.S. has moved beyond the large pilot scale. The flow and dynamics of CO_2 in EOR is pressure dominated, while it is buoyancy dominated in saline storage. As such, the pressure field, plume development, and trapping mechanisms within saline storage projects are very different than those exhibited in CO_2-EOR. This necessitates a dedicated saline test site, injecting significant CO_2 volumes over significant time frames. The single largest hurdle to saline storage technology development is the lack of large-scale, long-term, commercial storage site(s) that could provide access for R&D technology developers.

Q&A

Q: How do we advance storage in KY?

George Koperna: Use shale gas wells to inject utilize existing pipe infrastructure. Note that in KY, the saline reservoirs do not have great permeability and do not constitute a great resource. Suggested the Big Sandy gas field (in eastern KY?) as potential CO_2 storage test site.

Q: How do developers pay for testing at NCCC?

Rosann Laird: They pay fees

Q: Boundary Dam update
Roxann Laird: Lessons learned document under prep.

NCCC tested >30 technologies to date, and enzyme catalysis showed a lot of promise, especially to bring the cost of capture down.

Q: CO_2 + N_2 co-injection – what is the recommended ratio?

George Koperna: It depends on the coal rank (1:1 is low, 3:1 is high)

Q: Agreement with China on sequestration, what should we do?

A: Permeability varies across China and saline projects have not taken off in China as a result. China geology needs to be further characterized.

Q: Can supercritical be a retrofit?

A: Maybe as a combined cycle, but would need a new boiler and other new infrastructure, so its not a strong candidate for retrofit. Better for new plants.

Broad comments:

The biggest challenge for CCS is funding. Projects search for additional income streams, including EOR. These projects need extreme patience (there is no strength to fund longterm R&D right now). Utilities are very conservative with their funding and willingness to take on longterm projects and funding risk. On the storage side, infrastructure is vastly insufficient. There is also a need for public outreach and regulatory understanding.

Panel II: New Value Creation from Coal - Grace Bochenek, Director, NETL, Moderator

Dr. Rick Honaker, University of Kentucky

Rare Earth Elements: New Value Creation from Coal

Rare earth elements (REEs) is a plural term because you often find several elements together in the same deposits. REE concentrations vary geographically, as do the prices they fetch, but the value of total REEs are equivalent to average gold and metal sulfide deposits. In Central Appalachia, maximum values come up to $156/ton, relative to northern Appalachia at $93/ton. REE prices are volatile. Heavy REEs have a high value and coal has a lot of heavy REES, especially in the residues and ash, which contain the highest value ($/tonne of feed - $20-172/tonne). Light REES such as neydymium, cerium, lanthanum, and ytrrium fetch $40-250/kg, while heavy REES such as dysprosium, terbium, and europium are $500-3500/kg. This helps explain the demise of Molycorp, which mined largely light REEs in a volatile market.

REE value is typically greater than copper deposits. In one seam in eastern KY that has volcanic ash, there was value across the whole chain, with middlings (50% coal and 50% rock) at $16-90/tonne and fine reject with similar values. Fine reject REE recovery can fetch up to $80/ton and with additional coal recovery, up to $120/ton. Getting REEs out of coal as part the process can double the revenue for a mining operation. REEs in pre-combustion sources may be recovered by physical and ion exchange processes, in contrast to post-combustion requiring hydrometallurgical processes.

Dr. Sally Greenger, Center for CO2 Utilization and Reduction, University of Illinois

Creating a market for captured CO2

- Global energy demand in 2040 will be 25% higher than in 2014, with oil, natural gas and coal accounting for nearly 80% of total energy consumption.[1]
- CO_2 generated by human activity last year: 35 billion metric tons
- CO_2 generated by coal-fired power plants last year: 14 billion metric tons
- Cost of capturing and storing CO2: $50-100/ metric ton
- Number of CCU technologies in development worldwide: >250

Steps in building a market for captured CO2 include a combination of partnerships, technologies, and interest in economic development.

- Find a Power Generator willing to host large scale pilot
    - Abbott Power Plant at University of Illinois
    - Traditionally evaluates new technologies and shares with other plants
- Assemble a "bondable" team with a proven capture technology (Phase I)
    - Linde/BASF provides proven technology
    - Linde/BASF; Affiliated Engineers Inc. experienced in large projects
- Obtain financing for project
    - Proposal to DOE for 25 MW large scale capture pilot
    - $75 MM; $60 MM DOE funds; $15 MM cost share
- Construct and test a large scale pilot system at the power generator (Phase II)
- Large scale pilot evaluations of technologies for utilization of captured CO_2 (Phase III)
    - Forming Center for CO_2 utilization
    - Capitalizes on 500 Tons/day of CO_2 generated

Example: Abbott Power Plant at the University of Illinois and Linde (1.5MWe capture plant tested at the NCCC). Phase I for the project has been accepted by DOE for 15-25 MWe capture facility and awarded October 2015. Phase II (build and test) is a $75 million project, with $60 million from DOE, starting in 2017.

A Center for CO_2 Utilization has the goal of bringing together university researchers and industry partners to examine large scale pilots to UTILIZE the captured CO_2 and the center is currently looking for partners to test, develop, and build capacity. The center is looking for partners throughout the value chain, i.e. CO_2 users and CO_2 generators, and also looking for international partners willing to test large scale systems and share information. The center will include educational and workforce development components and is developing research thrust areas now.

CO2 utilization falls into the following categories:

- Streams with low concentrations of CO_2
    - e.g. energy production from coal and natural gas combustion
- Streams with medium concentrations of CO_2
    - e.g. anaerobic processes or cement manufacture
- Streams with high concentrations of CO_2
    - e.g. breweries or fuel ethanol plants

Uses include transportation fuel, agriculture (algae), chemicals (methanol, formic acid, manufacturing – cooling, solvent extraction, refiguration – replacing CFCs and HCFCs, EOR, and biochar – soil storage).

Richard Horner, Carbon Management Center, University of Wyoming

UW's carbon engineering initiative: converting coal to high-value carbon products and chemicals

Caveat: We are talking about new markets for coal; low-carbon technologies for Btu value (high efficiency, CCUS) all remain in the mix, and remain cornerstones

Near Term (<10yrs): Grow Exports Overseas

- Beholden to neighboring states cooperating
- Environmental opposition - International carbon regulation/commitments and actions
- Volatile coal prices in Asia
- New Asian import tariffs/local free trade agreements
- Financial sentiment for funding projects

Medium Term (>10yrs): Develop CO_2 Capture &Utilization Solutions (CCUS)

- Present technologies not proven at scale, with the economics of retrofit constraining coal fired electricity generation & power industry profitability
    - Focus on EOR plus saline research (Rock Springs Uplift)
    - Wyoming Integrated Carbon Capture Test Center (ITC)

Long Term (15 yrs +): Convert Coal into High Value Carbon-Based Products & Chemicals

- New research required to develop the technologies that meets the demands for and the constraints on the full utilization of coal in a carbon-constrained world
    - Creates new jobs and investment in the State
    - Significant investment in research and technology required – University of Wyoming leading pursuit of Carbon Engineering
    - Attracting industry interest and investment are key
- Use coal as source for manufacturing non-metals and chemicals

Captures value beyond coal's btu value

Turns CO_2 generated during conversion into products … or does not make it in the first place

- Coal-to-chemicals plants are being built or planned in China, Germany & India
- Demand for carbon-based materials is rising
    - Light-weighting
    - Substitution for metals (Existing Markets)
    - New Markets for (carbon) material classes
    - Superior functional performance of carbon materials over metals
    - Rising growth in non-metallic materials & industrial chemicals > GDP Growth Projections
- Maximize Yield of carbon-based intermediates & finished products
- Product slate worth is > coal btu value
- Full conversion of primary (PRB) coal feed
    - Include other feeds - /gas/LNG/shale oil/biomass feeds only to support this prerequisite
- Maximize the liquid intermediate product yields from primary coal processing
- Extraction & complete process use of water extracted from coal
- Zero or minimal pure stream CO_2 emissions
- Optimal energy consumption
    - exothermic rather than endothermic processing
- Zero effluent discharge & water consumption neutrality

Petroleum and coal refineries have common product families (gasoline, diesel, naptha, aromatics, base oil and lubes) but there are some new carbon conversion techniques that can convert coal chemicals (pitch, activated carbon, carbon composites, aerogels, graphene) to petrochemicals.

Value versus volune: On average 1 ton of coal contains about 21 gigajoules of energy. Assuming full-conversion, 1 ton of coal could make 159 gallons of gasoline. A 100,000 crude oil bbl/day full conversion integrated (fuel & chemicals) refinery manufactures 586,200 Giga-joules of product. On an equivalent basis this equates to 28,000 tons of coal /day or about 4% of Wyoming daily coal production from Powder River Basin or ~ 20% from Rock Springs area (coal is of an inferior quality).

At the University of Wyoming, 2 Year Research & Technology Development Plan (Appraisal & Evaluation), with three activity thrusts:

Converting Wyoming coal to intermediate liquids and solids

- solvent systems and extraction to maximize liquid and solid product yields
- co-processing Wyoming coal and biomass
- super-critical coal processing
- coal intermediate characterization
- solid (carbide) products from coal – high temperature route

Identifying products that can be made from coal intermediates and derivatives

- carbon based nano /fibre/ engineered composites
- nano-carbon nitrogen structures for thermal and electrical duties
- amorphous diamanoids and derivative products
- syngas and CO_2 derived products
- 'Winterized' Asphalt Paving
- 'green' Building Materials
- additives for fixing nitrogen in soil

Establish commercial & techno-economic viability of coal refinery

- Complete stage 2 coal refinery configuration model
- Determine the compelling business case (facility scale and scope)
- Attract investors to want to make the coal refinery happen in Wyoming

Don Stevenson, Executive Director, Gas Technology Institute

New value creation from coal

What changed the market for natural gas? Technology. The resource was always there (in shale formations), but technology was needed to unlock it at low cost. Something similar is needed for coal.

Modularization is advantageous because it increases speed to market, increases plant ROI, improves plant construction safety performance, minimizing disruption to existing operations, and minimizes risk.

R-GAS Advanced Coal Gasification – commercialization happening in China

- 90% reactor size reduction enables modularization
- Lower capital cost
- Higher availability
- Reduces product cost by 15-25%
- Reduces water use by up to 30%
- High efficiency (99+% carbon conversion)
- Lower oxygen use
- Able to gasify all ranks of coal, petcoke
- Environmentally friendly waste
- Lower disposal costs

Zero Emissions Power and Steam – has carbon capture built in

- Captures 98% of CO2
- Reduce capital and electricity costs by 27%
- 14% greater efficiency than USC plants with post-combustion capture
- 31% greater efficiency when combined with supercritical CO2 power cycle
- Reduced turbomachinery size enables modularization and distributed power generation

In summary, transformational technologies are emerging, with great hope in modularization, advanced gasification, oxy, and super critical CO_2 power cycles

Q&A

Q: How much CO_2 can be utilized?

Sallie Greenberg: current utilization options take tiny amounts of CO_2

Q: Is REE extraction environmentally safe?

Rick: ion exchange on the clays is an exciting technology and initial results show 40% extraction using ion-solvent extraction methods.

Broad comments:

Need a market pull to make these things happen

Scale up is a significant challenge

Need diverse partnerships to move utilization forward

Grace Bochenek – how can partnerships move forward?

(1) Need diversity
(2) Regional approach is effective – ex: regional carbon sequestration partnerships have been successful
(3) Need tangible benefits for all the stakeholders
(4) Partnerships are effective at bringing people together, but need a way to keep everyone engaged through the much of developing projects and finishing years later because the "valley of death" is demoralizing
(5) Patience in investment is critical and that's where consistent funding from government can play a key role, as well as pulling in international participants (10% cost share from DOE is not enough)

Panel III: Technology Innovation as a Driver for Regional Energy and Economic Development - David Foster, Department of Energy, Moderator

US is the second biggest manufacturing powerhouse in the world and manufacturing supports 75% of private R&D, along with 90% of patents.

Summary from the Moderator:

The manufacturing panel, entitled Manufacturing Innovation, included panelists representing the Aluminum Association, the ORNL Lab Director, Chair of the Appalachian Regional Commission, and the CFO of the Department of Energy. The panel was facilitated by a DOE Senior Advisor who provided introductory remarks, citing the importance of manufacturing to the KY economy and the close relationship between manufacturing and sources of cheap, reliable energy. The panelists from the Aluminum Association and ORNL demonstrated that interdependence with examples of innovation in energy and manufacturing technologies that have reduced energy consumption in motor vehicles through development of new materials and alloys and technologies for multi-material welding. The Chair of ARC provided important input on the role of economic development agencies in the Commercialization of new technologies. ARC has been working for 40 years to eliminate poverty and create economic opportunity in Appalachia. The direct connection between economic development and innovation was poignantly noted by the ARC Chair when he highlighted that one benchmark of success in their region was the number of interns placed at NETL and ORNL, a coveted steppingstone to success in Appalachia. The panel was effectively rounded out by the DOE CFO who provided an historical context for how regional partnerships could provide context and direction to Mission Innovation by harnessing local talent, resources, and identifying key local challenges and needs in our energy ecosystem. The panel demonstrated how each regional partnership needs to support the manner in which energy production and distribution are tied to the broader regional economy."

Earl Gohl, Federal Co-Chair, Appalachian Regional Commission

Technology, innovation, and economic development in Appalachia

Appalachia is the next great investment opportunity in the US (report "Investing in Appalachia's Future, 2016-2020). The Appalachian Region's economy has historically been dominated by a few industries, including mining, textiles, tobacco, and timber. Dependence on these industries as economic drivers and employers has left many communities, particularly those in the most economically distressed counties, vulnerable to economic fluctuations as their businesses face increasing competition, specialization, and market changes. Recently, the nation's fast-changing energy mix is impacting the Region in enormous ways. Compared to 1960's, when share of poverty was much higher and coal share of electricity generation was also a lot higher, things are better today. But poverty is largely concentrated in Appalachia in the US today.

As is widely known, reductions in natural gas prices because of technological innovations (fracking) has helped lead to an increase in the energy generation from natural gas, and conversely, a reduction in the energy generation from coal. At the same time, renewable energy generation is on the upswing, especially via solar and wind, but those production levels remain relatively modest compared to other sources.

Figure represents the amount and share of electricity generation by source in the U.S. from 2000 to 2013, along with projections to 2040. Coal generation fell from 52 percent of electricity generation in 2000 to 39 percent in 2013 and is expected to see a further decrease in share over time. Natural gas, on the other hand, increased its share from 16 percent to 27 percent from 2000 to 2013 and is likely to see even more market share in the future, with renewables (hydroelectric, wind, solar, etc.) on a steady growth path. These future projections from the EIA are based on more or less status quo conditions. Various factors could easily precipitate a more rapid decline in coal for electricity generation in the future.

Coal losses have been felt acutely in Appalachia for the past 4-5 years. US economy is always changing. This region was salt, lumber, coal, and now some known for gas. This is not the last time an economic shift will happen. The question is - how do we prepare for the future?

Energy generation from coal on downward trend starting in 2009 (recession), down to 39% with natural gas and renewables increasing. ARC electricity generation from coal varies greatly by state – over 95% in KY and WV; 69% in OH, 39% in PA, just 3% in NY. There are many recent/planned coal power plant retirements in Region – OH, PA, KY, WV. Coal also plays a huge role in rail shipments nationally (43% of tonnage), and an even larger role in Region (over 60% of rail movements originating in WV, PA, KY, and OH are coal). Coal projected to lose market share in electricity generation (39% to 34%) but coal from Region expected to decline and shift to lower cost regions – some scenarios show major future loss.

Another challenge is workforce development and education levels. ARC is focused on investment in human capital, community colleges, and supporting broadband connectivity. This is all with the goal of fostering entrepreneurial activity and grow industry clusters.

These are ARC's priorities
-- Competitive workforce – workforce training for quality, in-demand jobs; support existing and new businesses in the region
-- Access to and application of broadband communications
-- Foster entrepreneurial activity – requires a host of supports and facilities to have a healthy entrepreneurial ecosystem

-- Grow industry clusters – both new and existing

The Power Initiative has 4 key components:

1. Two new refundable investment tax credits to new and retrofitted electric generating units (EGUs) that deploy carbon capture technology.
2. Support for UMW Legacy costs of Health and Welfare funds
3. RECLAIM Act provides $200 million a year from the Abandoned Mine Trust Fund for Economic Development
4. Targeted investments – This is the ARC & EDA and federal response. Supporting economic diversification and job creation

The Obama Administration's comprehensive POWER Plan to bring federal resources and programs to revitalize coal communities nationwide includes $66.8 million available for economic diversification, workforce development and job creation in coal impacted communities:

- $45 million through ARC to support implementation efforts in Appalachia
- $1.2 million through ARC for technical assistance support in Appalachia
- $19.6 million through the Economic Development Administration (EDA) to support implementation efforts nationwide

Thom Mason, Director, Oak Ridge National Lab

Advancing innovation in carbon fiber-reinforced polymer composites

Low cost labor offshore is becoming less important because of concerns over IP, timelines for development to market (shorter here because of proximity to where things are being developed and made is helpful), designer material and instrument development at academic research hubs and labs, and the ability to run model simulations to in product design (labs). DOE has a central role to play as the global push for clean technology continues. Clean tech in the US should also be manufactured in the US.

Advanced Manufacturing (EERE) IACMI regional partnership between the public and private sector has three areas of active research:

1) Wind turbines
2) Compressed gas storage
3) Vehicles – fuel efficiency and light-weighting, with the goal of bringing the cost down

As a model for future clean energy regional partnerships, IACMI is a 501c3 to manage research activity and distribute funds.

AMIE (Additive Manufacturing Integrated Energy) is another partnership, this one focused on 3D printing and integration with building systems. This could also include microgrid, distributed generation, and the incorporation of intermittence.

Joe Quinn, Aluminum Association

Aluminum impact on manufacturing

Aluminum production has a substantial environmental footprint, high energy use, and a large carbon footprint, though there has been a decline over the last 20 years (26% decline in energy use and 37% reduction in carbon emissions). The industry is driving to continue the decline, with the goal of using 92% less energy, 15% reduction in carbon emissions, all through increasing energy efficiency, updating computer technology, and switching to hydropower where possible. Aluminum use in vehicles has seen a steady increase over the last 50 years and today, we are using 500 lbs of aluminum per vehicle.

There are a lot of aluminum plants in Kentucky and more are on the way. The US aluminum industry is a major part of today's manufacturing economy, with 161,000 direct jobs, $12 billion going to support workers, and $75 billion contribution to the US economy. The goal is to grow jobs and wages.

Joe Hezir, Office of the CEO, Department of Energy

Models for regional clean energy innovation partnerships

The National Research Council's 2012 Report, Rising to the Challenge, articulated the rationale:

> "Historically, federally funded R&D has not been connected to state and regional industrial development. Bridging that gap can create the local talent and technology base needed to convert these U.S. investments into domestic companies, industries, and jobs."
>
> "Private businesses and local education institutions and economic-development agencies are in the best position to identify opportunities, gauge competitive strengths, and mobilize wide community support for regional cluster initiatives."
>
> "Regional innovation cluster initiatives should be built upon existing knowledge clusters and comparative strengths of a geographic region."

Existing regional ecosystems in New England, the Chicago region and Silicon Valley have led the way in creating the template for regional partnerships.

There are models for how to set up partnerships. They can go from be federally led and funded to self-organized, industry led, cost shared models. Examples include DOE regional offices, Regional Carbon Sequestration Partnerships, RPSEA (Research Partnership to Secure Energy for America), NNMI (National Network of Manufacturing Institutes), and self-organized consortia.

Regional partnerships can complement DOE programs:

Direct leadership from non-federal stakeholders
- Non-federal stakeholders: Key priority setters and funders (in addition to federal input, funds)
- Direct connection to end-user and market: Stronger connection to end-to-end activities, including investment, scale-up, deployment decision-makers
- Upfront pooling of funds: Longer-term portfolio engagement than project-specific cost-sharing

Closer interactions at local/state/regional levels
- Greater integration of localized strengths, preferences, initiatives, leaders, institutions
- Stronger connection between innovation ecosystems, local/state policy, and regional investment/market opportunities
- Co-location with existing ecosystems

More flexible funding mechanisms and processes
- Flexibility: Expanded potential range of RD&D activities, mechanisms, criteria

Speed: Smaller, flatter organizations with faster decision-making, procurement processes

Diversity of approaches

Inherently cross-sectoral: Activities not organized/directed by fuel type/technology

Broader scope: Multiple regions will likely select more, different focus areas and activities than what conventional DOE programs/platforms

Q&A

Q: How can these partnerships be self-sustaining? How can they be funding stable?

Comment from the audience: Good idea to move decisions to regions rather than the federal level

Q: Why isn't coal being converted to other things? Why is it just electricity/power?

Poster Session:

During the lunch, student attendees presented a number of posters on energy and energy-related topics. The following organizations provided posters:

- 1 from NSF-Experimental Program to Stimulate Competitive Research
- 3 from UK CAER's Power Generation Group
- 8 from UK's Electrical Engineering Dept
- 1 from UK's Chemistry Dept
- 1 from UK CAER's Biofuels Group
- 1 from UK's Mining and Engineering Dept
- 1 from UK CAER's Carbon Group
- 1 from Washington University
- 1 from West Virginia University

Appendix A: Program Booklet

Regional Energy Innovation Forum

April 21, 2016

Presented by the University of Kentucky
Center for Applied Energy Research,
in association with the U.S. Department of Energy

Introduction and Welcome

8:30 AM - 9:30 AM

Ernest Moniz
U.S. Secretary of Energy

Eli Capilouto
President, University of Kentucky

Panel Session I

9:30 AM - 10:45 AM — Innovation, Combustion and CCS

Moderator: David Mohler
Deputy Assistant Secretary for Clean Coal and Carbon Management

Jeffrey Phillips
Senior Program Manager, Electric Power Research Institute

Kunlei Liu
Associate Director for Research, UK Center for Applied Energy Research

Roxann Laird
Director, National Carbon Capture Center

George Koperna
Vice President, Advanced Resources International, Inc.

10:45 AM - 11:00 AM — *Break*

Panel Session II

11:00 AM - 12:15 PM — New Value Creation from Coal

Moderator: Grace M. Bochenek
Director of the National Energy Technology Laboratory (NETL)

Rick Honaker
Chair of Mining Engineering, UK College of Engineering

Sallie Greenberg
Associate Director, Advanced Energy Technology Initiative, Illinois State Geological Survey

Kipp Coddington
Director, University of Wyoming Carbon Management Institute

Don Stevenson
Executive Director, Gas Technology Institute

12:15 PM - 1:15 PM — *Lunch and Poster Session*

Panel Session III

1:15 PM - 2:30 PM — Technology Innovation as a Driver for Regional Energy and Economic Development

Moderator: David Foster
Senior Advisor on Industrial and Economic Policy

Earl Gohl
Federal Co-Chair, Appalachian Regional Commission

Thom Mason
Laboratory Director, Oak Ridge National Laboratory

Joe Quinn
Vice President of Public Affairs, Aluminum Association

2:30 PM - 3:00 PM — *Wrap up and Rapporteur*

Ernest Moniz

FEATURED GUEST

U.S. Secretary of Energy

As United States Secretary of Energy, Dr. Ernest Moniz is tasked with implementing critical Department of Energy missions in support of President Obama's goals of growing the economy, enhancing security and protecting the environment. This encompasses advancing the President's all-of-the-above energy strategy, maintaining the nuclear deterrent and reducing the nuclear danger, promoting American leadership in science and clean energy technology innovation, cleaning up the legacy of the cold war, and strengthening management and performance.

Prior to his appointment, Dr. Moniz was the Cecil and Ida Green Professor of Physics and Engineering Systems at the Massachusetts Institute of Technology (MIT), where he was a faculty member since 1973. At MIT, he headed the Department of Physics and the Bates Linear Accelerator Center. Most recently, Dr. Moniz served as the founding Director of the MIT Energy Initiative and as Director of the MIT Laboratory for Energy and the Environment where he was a leader of multidisciplinary technology and policy studies on the future of nuclear power, coal, nuclear fuel cycles, natural gas and solar energy in a low-carbon world.

Appendix B: Attendee List

First Name	Last Name	Job Title
Eric	King	Director, Federal Relations
Karen	Kelly	District Director
Kunlei	Liu	Associate Director
cameron	lippert	principle research scientist
Grace	Bochenek	Director
Don	Stevenson	Executive Director
Tiffany	Bailey	Energy Development Specialist
Heather	Nikolic	Principal Research Engineer
Daniel	Henderson	Director of Research & Advanced Engineering
Pankaj	Sharma	Managing Director
Tamara	Zelikova	AAAS Fellow
Kipp	Coddington	Director
Jeffrey	Phillips	Senior Program Manager
Rick	Honaker	Professor and Chair
Roxann	Laird	Director, National Carbon Capture Center
David	Link	Manager Research and Development
Nicholas	Jewell	Research Engineer III
George	Koperna	Vice President
Doug	DURST	Technology Development Mgr
Mike	Manahan	R&D Engineer
Ryan	Hines	Engineering Co-op
Ben	Kumfer	Research Asst. Professor
Thom	Mason	Director
Kate	Shanks	Director of Public Affairs
Michael	Kennedy	Assistant Director
Bill	Bissett	President
Rick	Bender	Executive Advisory
Rodney	Andrews	Director
Cliff	Eberle	Director, Materials & Processing
Fazleena	Badurdeen	Associate Professor
Rusty	Ashcraft	Manager, Government Affairs & Environmental Policy
Jingxin	Wang	Professor
Matthew	Hall	Co-op Research Assistant
Ethan	Witt	Field Representative
Yongqi	Lu	Research Chemical Engineer
Chad	Harpole	Director of Government Affairs
Jesse	Thompson	Scientist
Don	Challman	Senior Director Assistant
Teresa	Eppeson	Administrative Assistant
Alice	Marksberry	Webmaster & Conference Planner
David	Foster	Senior Advisor
David	Melanson	Assistant Director for External Affairs and Develo
Don	Colliver	Professor / Director
Larry	Holloway	Director, Power and Energy Inst. (PEIK)
Mark	Crocker	Associate Director
Christopher	Swartz	senior research scientist

Joanna	Mroczkowska	Visiting Scientist
Stephen	Lipka	Associate Director
Michael	Wilson	Senior Research Engineer / Grad Student
HONG	LU	Chemical/Environmental Research Engineer
Wencai	Zhang	Graduate Research Assistant
Xinbo	Yang	Graduate Student
Courtney	McKelphin	Student
Samantha	Jones	Research Assistant
Tao	Chen	PhD student
Xiangqing	Jiao	Teaching Assistant
Dan	Ionel	Professor and L. Stanley Pigman Chair in Power
Matt	Weisenberger	Associate Director for Carbon Materials
Vandana	Rallabandi	Post doctoral Scholar
Sallie	Greenberg	Associate Director - Energy and Research
John	Voyles	Vice President, Transmission & Generation Services
Obinna	Igwe	Master's Student
Xiang	Li	Graduate Student
Xiao	Liu	Research Assistant
Narges	Taran	PhD student
Jonathan	Wood	President
Douglas	Mynear	Chief Operations Officer
Gay	Dwyer	Lobbyist
Donald	Ryan	Mgr., Product & Materials Technology
Jinhua	Bao	Post doctorate
Zachary	Lippay	Student Auditer
Dean	Adams	Student
Sarah	Edrington	Student
David	Mohler	Deputy Assistant Secretary for Clean Coal and Carb
Kimberly	Rasar	Panelist
Eben	Burnham-Snyder	Deputy Director of Public Affairs
Lisa	Cassis	Vice President for Research
Riley	Coulthard	Student (collaborates with Jim Hower)
Earl	Gohl	Federal Co-Chair
Joe	Quinn	VP of Public Affairs
Guy	Land	Chief of Staff
Sora	Kim	Assistant Professor
James	Hower	Senior Scientist
Clayton	Whitney	Vice President
Ben	Corwin	Videographer
Tyler	White	District Director
Christopher	Crumrine	University Relations Officer
Roe-Hoan	Yoon	University Distinguished Professor
Mahong	Fan	Professor, Chemical and Petroleum Engineering
David	Freibert	Director of External Affairs
Andi	Johnson	VP, Public Policy and Government Relations
Lillie	Ruschell	Associate Producer
Alan	Lytle	News Director

Jenny	Wells	Senior Information Specialist
Stu	Johnson	Reporter/Producer
Josh	James	Reporter/Webmaster

Company
University of Kentucky
US Congressman Hal Rogers
CAER
University og Kentucky
National Energy Technology Laboratory
Gas Technology Institute
WV Division of Energy
University of Kentucky Center for Applied Energy Research
Caterpillar Inc.
Purdue University
DOE Fossil Energy
Carbon Management Institute, University of Wyoming
Electric Power Research Institute
University of Kentucky/Mining Engineering
Southern Company Services
LG&E and KU Energy
LG&E and KU
Advanced Resources International, Inc.
Duke Energy
LG&E and KU Energy
University of Kentucky Center for Applied Energy Research
Washington University
Oak Ridge National Laboratory
KY Chamber of Commerce
Kentucky Energy and Environment Cabinet
Kentucky Coal Association
Dept of Energy Development
University of Kentucky
The Composites Institute
University of Kentucky
Alliance Coal, LLC
West Virginia University
University of Kentucky Center for Applied Energy Research
Senator Mitch McConnell
University of Illinois
Century Aluminum
UKy-CAER
University of Kentucky
University of Kentucky
University of Kentucky
Department of Energy
UK Center for Applied Energy Research
Univ of KY / KY Industrial Assessment Center
University of Kentucky
UK Center for Applied Energy Research
University of Kentucky Center for Applied Energy Research

UK/CAER
CAER University of Kentucky
University of Kentucky Center for Applie
University of Illinois at Urbana-Champaign
University of Kentucky
University of Kentucky
University of Kentucky
University of Kentucky Center for Applied Energy Research
University of Kentucky
University of Kentucky
University of Kentucky
UK Center for Applied Energy Research
University of Kentucky
Illinois State Geological Survey
LG&E and KU Energy, LLC
The University of Kentucky Department of Electrical Engineering
University of Kentucky
University of Kentucky
University of Kentucky
CoalBlue Project
ECSI, LLC
Century Aluminum
The Babcock & Wilcox Co.
University of Kentucky, Center for Applied Energy Research
Kentucky Industrial Assessment Center (KIAC)
University of Kentucky
University of Kentucky
Department of Energy
Department of Energy
Department of Energy
University of Kentucky
Yale University
Appalachian Regional Commission
Aluminum Association
Appalachian Regional Commission
Univ. of Kentucky
Univ Kentucky CAER
Smith Management Group
UK Research Communication
Congressman Andy Barr's office
UK President's Office
Virginia Tech
University of Wyoming
LG&E and KU Energy, LLC
CommerceLex
Media - KET
Media - WUKY

Media - UK-PR
Media - WEKU
Media - WUKY