Gasification
Combined Heat and Power
From Coal Fines

DE-FE0031520

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University of Kentucky, Center for Applied Energy Research
http://www.caer.uky.edu/powergen/home.shtml
Power Generation and Utility Fuels Group

Using Fossil Resources to Produce Clean Electricity

- About 35 researchers (engineers, scientists, technicians and students)
- 10-18 peer reviewed publications, annually
- 5-7 invention disclosures, annually
- 5-10 project proposal submitted, annually
Outline

1. Project Background and Purpose
2. UKy-CAER Coal-based Polygeneration Philosophy
3. Market and Economic Benefits
4. Alignment with Fossil Energy Objectives
5. Project Status
6. Technical Challenges, Next Steps and Outside Interest

Take Away

1. Small Scale Polygeneration is Applicable to Remote Areas like Appalachia, Economically and Environmentally
2. UKy-CAER Polygeneration Philosophy Supports the REMS Initiative through Standardization, Modularization, Fuel Flexibility and Simplification
3. Remote Polygeneration is of Interest to Local Governments and OEMs
Project Purpose

- Complete a FEED study for a 5 MWe equivalent polygenerating unit to be located at an industrial park in Hazard, Eastern KY utilizing nearby waste coal fines as the feed
- Identify appropriate main components (technology selection and operating conditions)
- Components included in FEED study

Project Goals

- Utilize local waste: refuse coal fines
- Develop a model for widespread application
- Develop cross-industry synergy in a rural, remote area
- Model for future economic development in depressed regions

Objective: Complete FEED Study for an Eastern KY 5 MWe Polygen Unit

Design Basis

Preliminary Design

Cost Estimation and Comparison

EH&S Assessment

Social and Economic Assessment

BOP, Logistics & Execution Guidelines

Model for Application throughout Coal Communities

Site Determination Template

Technology Selection Procedure

Method for Implementation and Deployment
Background

Appalachian Coal Fields

EXPLANATION
- Producing oil wells
- Producing gas wells
- Producing oil and gas wells
- Active coal mine
- Coal-fired power plant
- Preparation plant
UKy-CAER Coal-based Polygeneration

Standardization + Modularization + Fuel Flexibility + Simplification = Distributed Power Success

Configuration for Small Modular Coal to Value-added Products
UKy-CAER Coal-based Polygeneration

Local heat and power generation with modular coal gasification and optional F-T synthesis

Three useful products: power, heat and liquid hydrocarbons

- • Use a commercially available ASU ~2400 Nm³/hr O₂ consumption
- • Design power generation unit based on coal with lower heating value
- • Excess syngas will go to F-T unit
- • For power generation, meet EPA requirements, remove H₂S, minimal CO₂ and minimize AGR size
- • Second stage H₂S removal bed before the F-T unit

- • Design the burner based on O₂ available
- • Outside chamber and burner sized fixed
- • Size inside chamber tubes to accommodate different kinds of coal

Three useful products: power, heat and liquid hydrocarbons
Project Partnerships

Center for Applied Energy Research

Beijing Baoju Energy Science & Technology Co. Ltd

Trimerc Corporation

Aqq

Gay Brothers Lumber

Fourth Generation Lumber Company

BLACKHAWK MINING, LLC

Coal Fields Regional Industrial Authority
Eastern, KY is a remote, coal dependent area.

### Perry County, KY Coal Preparation Plants

<table>
<thead>
<tr>
<th>Company</th>
<th>Plant</th>
<th>Nearest Town</th>
<th>Capacity (tph)</th>
<th>Fine Coal Recovery Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitaker/Perry Co/ICG</td>
<td>#4 Plant</td>
<td>Hazard</td>
<td>750/950</td>
<td>HM Cyclone, Spirals</td>
</tr>
<tr>
<td>KEM/Pads Branch</td>
<td>Plant #25</td>
<td>Hazard</td>
<td>400</td>
<td>HM Cyclone, Spirals</td>
</tr>
<tr>
<td>Blue Diamond/Blackhawk</td>
<td>Leatherwood</td>
<td>Leatherwood</td>
<td>800/1600</td>
<td>Concentrating Tables, Spirals, HM Cyclones</td>
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<tr>
<td>Lost Mountain</td>
<td>Harris Branch</td>
<td>Bulan</td>
<td>900</td>
<td>HM Cyclone</td>
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<tr>
<td>Kodak</td>
<td>Chester</td>
<td>Allock</td>
<td>350</td>
<td>Hydrocyclone</td>
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<tr>
<td>River Processing</td>
<td>Dunraven</td>
<td>Dunraven</td>
<td>350</td>
<td>Concentrating Tables, Hydrocyclone</td>
</tr>
<tr>
<td>Sunfire</td>
<td>#2 Plant</td>
<td>Combs</td>
<td>175</td>
<td>None</td>
</tr>
<tr>
<td>River Coal</td>
<td>Indian Head</td>
<td>Ned</td>
<td>180</td>
<td>None</td>
</tr>
<tr>
<td>Tesora</td>
<td>Wahoo</td>
<td>Bonneyman</td>
<td>420</td>
<td>None</td>
</tr>
</tbody>
</table>

### Market Benefits

- Pads Branch Impoundment Site in Hazard, KY
Economic Benefits

- Suffering from poor economy and job loss
- Local polygeneration units will
  - Encourage industry location in industrial parks
- Provide jobs
- Provide secondary environmental benefit
  of recovering coal fines and capping impoundments
- Use local sites in Perry County as representative of sites throughout Eastern, KY and Appalachia
Project Alignment to Fossil Energy Objectives

- 5 MWe energy conversion technology
- Will produce power, heat and liquid hydrocarbons at relatively small scale
- Economically compared to large scale state-of-the-art technology
- Technology can be scaled up by modular expansion
- Modules to be pre-fabricated and deployed in remote areas, while maintaining advantages in cost and flexibility
- Supports Radically Engineered Modular Systems (REMS) Initiative

Technology to Market Path

- Establish future partnership with General Electric Power, who expressed interest in a microgrid demonstration
- Establish build, operate and transfer (BOT) relationship for the F-T part of this application
## Project Status

### Impoundment Survey

<table>
<thead>
<tr>
<th></th>
<th>Moisture (wt%)</th>
<th>VM (wt%)</th>
<th>FC (wt%)</th>
<th>Ash (wt%)</th>
<th>C (wt%)</th>
<th>H (wt%)</th>
<th>N (wt%)</th>
<th>O (wt%)</th>
<th>S (wt%)</th>
<th>GCV (Btu/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impoundment 1</td>
<td>2.07</td>
<td>14.5</td>
<td>14.36</td>
<td>69.06</td>
<td>22.44</td>
<td>2.16</td>
<td>0.31</td>
<td>5.47</td>
<td>0.56</td>
<td>1483</td>
</tr>
<tr>
<td>Impoundment 2</td>
<td>1.85</td>
<td>13.37</td>
<td>14.83</td>
<td>69.95</td>
<td>22.29</td>
<td>2.08</td>
<td>0.31</td>
<td>4.93</td>
<td>0.44</td>
<td>563</td>
</tr>
<tr>
<td>Impoundment 3</td>
<td>1.58</td>
<td>15.22</td>
<td>15.89</td>
<td>67.31</td>
<td>23.49</td>
<td>2.14</td>
<td>0.38</td>
<td>5.87</td>
<td>0.81</td>
<td>2294</td>
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<tr>
<td>Impoundment 4</td>
<td>1.86</td>
<td>16.7</td>
<td>16.66</td>
<td>64.79</td>
<td>25.45</td>
<td>2.27</td>
<td>0.35</td>
<td>6.63</td>
<td>0.52</td>
<td>1862</td>
</tr>
</tbody>
</table>

### Impoundment Particle Size Distribution

- +150 µm
- -150+75 µm
- -75+45 µm
- -45 µm

### Impoundment Ash Content

- Location 1
- Location 2
- Location 3
- Location 4
Project Status

Coal Recovery

Density Separation

+ Litium Metatungstate (LMT)

\[ \rho = 1.6 \text{ g/cm}^3 \]

> 150 µm

LMT Recovery

Coarse Recovered Coal

< 150 µm

LMT Recovery

Reject Solid Material

Particle Size Separation

+ methyl isobutyl carbinol (MIBC) and collector

Stable Froth

Fine Recovered Coal

Froth Flotation

Tailings

2019 Gasification Systems Project Review Meeting
Project Status

Recoverable Coal

Target feed slurry of < 15% ash

Proximate, Ultimate and Heating Value Analysis Results from the Recovered Coal Product (Dry Basis)

<table>
<thead>
<tr>
<th></th>
<th>VM (wt%)</th>
<th>FC (wt%)</th>
<th>Ash (wt%)</th>
<th>C (wt%)</th>
<th>H (wt%)</th>
<th>N (wt%)</th>
<th>O (wt%)</th>
<th>S (wt%)</th>
<th>GCV (Btu/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel for Proposed CHP</td>
<td>27.8-29.8</td>
<td>56.9-61.2</td>
<td>11.0-13.3</td>
<td>69.4-75.3</td>
<td>4.3-4.6</td>
<td>1.3-1.4</td>
<td>7.2-10.0</td>
<td>0.8-0.9</td>
<td>12,500-13,000</td>
</tr>
</tbody>
</table>
Project Status

Coal-Water Slurry

Design Basis CWS

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Concentration (wt%, Air Dried)</td>
<td>56</td>
</tr>
<tr>
<td>Dispersant Concentration (wt%)</td>
<td>0.5</td>
</tr>
<tr>
<td>Bulk Density (g/mL)</td>
<td>1.15</td>
</tr>
<tr>
<td>Apparent Viscosity (cP)</td>
<td>365</td>
</tr>
<tr>
<td>Flowability</td>
<td>A</td>
</tr>
<tr>
<td>Stability</td>
<td>A</td>
</tr>
</tbody>
</table>

Coal-Biomass-Water Slurry

Sawdust had to be dried, shredded and re-saturated with water
Particles < 250 um were used
50.3 wt% (dry basis) Recovered Coal
0.6 wt% (dry basis) Sawdust
0.5 wt% Surfactant
# Project Status

## Ash Analysis

<table>
<thead>
<tr>
<th>Proposed CHP Gasification Unit Design Basis Design Basis Coal Feedstock AFTs</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing Environment, Bulk Impoundment Material Ash Fusibility Temperatures</td>
<td></td>
</tr>
<tr>
<td>Initial Deformation Temperature</td>
<td>2478</td>
</tr>
<tr>
<td>Softening Temperature</td>
<td>2701</td>
</tr>
<tr>
<td>Hemispherical Temperature</td>
<td>2716</td>
</tr>
<tr>
<td>Flow Temperature</td>
<td>2737</td>
</tr>
</tbody>
</table>

Options to tuning the ash flow T to ~2280 °F
- Blending with another type of coal
- Addition of ~2 wt% (dry basis) CaCO₃
Project Status

Leachate Analysis

<table>
<thead>
<tr>
<th>RCRA Regulated Element</th>
<th>As</th>
<th>Se</th>
<th>Ag</th>
<th>Cd</th>
<th>Pb</th>
<th>Ba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Hazardous Material Limit by TCLP (ppm)</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Expected Pads Branch Recovered Coal Product Slag Leachate Concentrations (ppm)</td>
<td>0.001</td>
<td>0.017</td>
<td>7E-05</td>
<td>0.007</td>
<td>0.016</td>
<td>0.131</td>
</tr>
</tbody>
</table>
Project Status

Initial EH&S Assessment

The following Regulations need to be considered:

1. Clean Air Act (CAA) Potential Requirements
2. Clean Water Act (CWA) Potential Requirements
3. Comprehensive Environmental Responses, Compensation and Liability Act (CERCLA) Potential Requirements
4. Mine Safety and Health Act (MSHA) Requirements
5. Occupational Safety and Health Act (OSHA) Requirements
7. Surface Mine Control and Reclamation Act (SMCRA) Requirements
8. Toxic Substances Control Act (TSCA) Potential Requirements
11. Regional Transmission Organization (RTO) Potential Requirements
12. Federal Aviation Administration (FAA) Potential Requirements
Project Status

Technology and Major Component Selection

**Entrained Flow Gasifier**
- Maximum fuel and operation flexibility

**Aqueous amine (MDEA) to concentrate the acid gas stream followed by a solid scavenger (Schlumberger’s Sulfa Treat Technology)**
- Using just a solid sorbent at the gasifier outlet has a very high cost because the saturation point is low
- Merichem’s LO-CAT® liquid redox technology may be a more economical process option, but increases process complexity and ExxonMobil’s Flexsorb™ may be a potential alternative to MDEA

Project Status

Technology and Major Component Selection

Once-Through at 60% F-T

- Recirculation is complicated
- Fe catalyst does not require WGS

Reciprocating Internal Combustion Engines for Power Generation

- GE Jenbacher engines
- Likely three engines required

Gas engine basic components

Project Status

Gasifier, AGR, F-T FEED

- Aspen Plus and HYSYS® models complete with H&MB stream tables
- Process Design Package is complete including PFD and P&ID sets
- Technologies selected for gasifier and F-T systems
- Utilities and waste streams estimated
## Project Status

### Major Equipment and Power Consumption

Reactors, Heat Exchangers, Columns, Vessels, Tanks, Pumps, Agitators, Filters, Mixers, Separators and a Mill

Medium, Operating Conditions, Design Conditions, Size, Weight, Material of Construction and Recommended Spares

| HEAT EXCHANGERS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. | TAG NO. | NAME | MEDIUM | OPERATING CONDITION | DESIGN CONDITION | SIZE | HEAT | HEAT | MATERIAL | METAL | ALLOY |
| | | | | TEMPERATURE | PRESSURE | TEMPERATURE | PRESSURE | DIAMETER | LENGTH/HEIGHT | LOAD (KW) | MATERIAL | WEIGHT (TOTAL) | |
| | | | (IN/OUT) (℃) | (MPaG) | (℃) | (MPaG) | (mm) | (mm) | | | |
| 1 | E-2201 | Burner cooling water heat exchanger | Shell - CW/CWR | 25/35 | 1.5 | 60 | 2 | 450 | Shelf 5370 | 134 | 38 | CS | 2000 |
| | | | Tube - cooling water | 45/35 | 0.4 | 80 | 0.7 | 325 | Tube 4500 | 300 | 10 | CS | 700 |
| 2 | E-2204 | Lock hopper circulating water cooler | Shell - CW/CWR | 25/35 | 0.4 | 60 | 0.7 | 325 | Tube 4500 | 300 | 10 | CS | 910 |
| | | | Tube - black water | 150/70 | 3.52 | 200 | 4.5 | 300 | Tube 4500 | 304 | 210 |
| 3 | E-2203 | Raw Gas Cooler | Shell - Raw gas | 182/40 | 2.8 | 310 | 3.5 | 650 | Tube 4500 | 304 | 1820 |
| | | | Tube - CW/CWR | 25/35 | 0.4 | 80 | 0.7 | 650 | Tube 4500 | 304 | 210 |
| 4 | E-2301 | HP flash gas cooler | Shell - CW/CWR | 25/35 | 0.4 | 80 | 0.7 | 650 | Tube 4500 | 304 | 1820 |
| | | | Tube - Flash gas | 135/40 | 0.4 | 170 | 0.3 | 650 | Tube 4500 | 304 | 210 |
| 6 | E-2304 | Waste water cooler | Shell - CW/CWR | 25/35 | 0.4 | 80 | 0.7 | 400 | Tube 4500 | 304 | 1820 |
| | | | Tube - Waste water | 61/40 | 0.5 | 80 | 0.7 | 400 | Tube 4500 | 304 | 1820 |
| 7 | E-2302 | Vacuum Cooler | Shell - CW/CWR | 25/35 | 0.4 | 80 | 0.7 | 400 | Tube 4500 | 304 | 1820 |

| TOWERS | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NO. | TAG NO. | NAME | MEDIUM | OPERATING CONDITION | DESIGN CONDITION | SIZE | MATERIAL |
| | | | | TEMPERATURE | PRESSURE | TEMPERATURE | PRESSURE | DIAMETER | T-T | TOTAL METAL | WEIGHT (T/ TOTAL) | ALLOY |
| | | | (℃) | (MPaG) | (℃) | (MPaG) | (mm) | (mm) | | | |
| 1 | T-2201 | Water Scrubber | Raw gas / Black Water Raw Syngas | 210 | 2.8 | 280 | 4 | 1200 | 4200 | 4.8 | 13MMNMo | 3400 | 1000 |

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2019 Gasification Systems Project Review Meeting

April 10, 2019
Project Status

BOP Systems

- PFD set complete
- Technologies selected for sulfur removal and power generation systems
- Steam system analysis complete
## Project Status

### Project Success Criteria

<table>
<thead>
<tr>
<th>Date</th>
<th>Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/5/18</td>
<td>Acceptable feed slurry demonstrated for design basis.</td>
</tr>
<tr>
<td>6/30/19</td>
<td>Completed preliminary design package for polygeneration unit to be located in Eastern KY.</td>
</tr>
<tr>
<td>6/30/19</td>
<td>Demonstration that the polygeneration unit can be modularized.</td>
</tr>
<tr>
<td>9/30/19</td>
<td>Demonstration of economically viable option of CHP with small scale, locally installed polygeneration units throughout Eastern KY.</td>
</tr>
</tbody>
</table>

### Task Details

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Project Management and Planning</td>
<td>Wed 12/6/17</td>
<td>Wed 6/6/19</td>
</tr>
<tr>
<td>2 Project Design Basis</td>
<td></td>
<td></td>
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<tr>
<td>2.1 Host Site Visit</td>
<td>Wed 12/6/17</td>
<td>Mon 3/6/18</td>
</tr>
<tr>
<td>2.2 Coal Fines Impoundment Site(s) Visit</td>
<td>Wed 12/6/17</td>
<td>Mon 3/6/18</td>
</tr>
<tr>
<td>2.3 Biomass Site Visit</td>
<td>Wed 12/6/17</td>
<td>Mon 3/6/18</td>
</tr>
<tr>
<td>2.4 Project Management and Planning</td>
<td>Thu 1/18/18</td>
<td>Thu 4/19/18</td>
</tr>
<tr>
<td>2.5 Coal Feedstock Characterization</td>
<td>Thu 1/18/18</td>
<td>Thu 4/19/18</td>
</tr>
<tr>
<td>2.6 Biomass Feedstock Characterization</td>
<td>Thu 1/18/18</td>
<td>Thu 4/19/18</td>
</tr>
<tr>
<td>2.7 Slurry Prep and Characterization</td>
<td>Tue 3/6/18</td>
<td>Tue 5/6/18</td>
</tr>
<tr>
<td>2.8 Fuel Mix Optimization</td>
<td>Tue 3/6/18</td>
<td>Tue 5/6/18</td>
</tr>
<tr>
<td>2.9 Coal and Biomass Ashing and Leach Testing</td>
<td>Tue 3/6/18</td>
<td>Tue 5/6/18</td>
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<tr>
<td>2.10 Milestone: Project Design Basis Complete</td>
<td>Tue 6/5/18</td>
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<tr>
<td>3 Basic Engineering Design Elements</td>
<td></td>
<td></td>
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<tr>
<td>3.1 Process Engineering</td>
<td>Thu 7/19/18</td>
<td>Wed 6/5/19</td>
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<tr>
<td>3.1.1 Milestone: Polygeneration Process Basic Engineering Design Complete</td>
<td></td>
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<tr>
<td>3.2 Technology Cost and Schedule Estimate</td>
<td>Wed 11/21/18</td>
<td>Wed 2/20/19</td>
</tr>
<tr>
<td>3.2.1 Milestone: Polygeneration Process Cost Estimation Complete</td>
<td></td>
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<tr>
<td>3.3 Initial Environmental, Health and Safety (EH&amp;S) Assessment</td>
<td>Wed 7/19/18</td>
<td>Wed 2/20/19</td>
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<tr>
<td>3.3.1 Milestone: Polygeneration Process EH&amp;S Assessment Complete</td>
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<tr>
<td>3.4 Social and Economic Impact Assessment</td>
<td>Wed 3/6/19</td>
<td>Wed 6/5/19</td>
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<tr>
<td>3.4.1 Milestone: Polygeneration Process Social and Economic Impact Assessment Complete</td>
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<tr>
<td>3.5 Technology Execution and Management Guidelines and Procedures</td>
<td>Thu 7/19/18</td>
<td>Wed 6/5/19</td>
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<tr>
<td>3.6 Logistical Summary</td>
<td>Thu 7/19/18</td>
<td>Wed 6/5/19</td>
</tr>
<tr>
<td>3.7 Balance of Plant Requirements</td>
<td>Thu 7/19/18</td>
<td>Wed 6/5/19</td>
</tr>
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</table>
Results Apply to Strategic Goals

1. Supports Radically Engineered Modular Systems (REMS) Initiative
2. Site Determination Template
   - Economic, environmental and social assessments
   - Proximity to and logistics of recovering waste coal fines
   - Local energy demands
3. Technology Selection Procedure for Niche Applications
   - Gasification, acid gas cleanup, F-T synthesis, and combined heat and power (CHP) production
   - Address each niche application and the regional demands of Eastern KY
   - Small, modular equipment and processes for easier deployment
4. Deployment Method throughout Coal Communities
   - Environmentally sound
   - Supported by local governments
   - Motivates private business participation
Next Steps

1. Cost Estimation and Comparison
2. EH&S Assessment
3. Social and Economic Impact Assessment

Technical Challenges

1. Safe Method Removing Impoundment Material
2. Permitting Associated with Returning Solid Material to the Impoundment
3. Sulfur Recovery for a Usable Product
4. Maintaining the Feed Slurry Heating Value with Reasonable Flowability with Biomass Included
Outside Interest

Other Impoundment Locations

Calla Refuse and Impoundment Site in Irvine, KY

Hazard Perry County Economic Development Alliance

General Electric Power
Owning the system, using GE turbine technology and selling heat and power

Sanju Material and Environmental Co.
Build, operate and transfer (BOT) relationship for the F-T part of this application
Take Away

1. UKy-CAER has plan for distributed power success
2. At this scale, use of recovered impoundment coal is feasible for gasification and also offers a secondary environmental benefit
3. The project team is ready to continue the design and work with DOE toward demonstration in Eastern KY
Acknowledgements

U.S. DOE-NETL: David Lyons and Steve Markovich
UKy-CAER: Jack Groppo and Moushumi Sarma
BJST: Xiangkun Ren, Ting Cao, Edward Wu and Yankun Song
Trimeric: Andrew Sexton, Brad Piggot, Austyn Vance and Anne Ryan
SMG: Clay Whitney and Steward McCollam
Coal Fields Regional Industrial Authority, Blackhawk Mining, Arq and Gay Brothers Lumber

The Power Generation Team