Transforming the Nation’s Energy Future – Allam Cycle

A next generation carbon solution

National Coal Council Fall Meeting
Bill Sawyer – Minnesota Power / ALLETE
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Coal is......

• #1 fuel for electric generation in the United States.
• #1 fuel for electric generation in the World.
Until...it is Not

Figure ES-1. Net electricity generation from coal, natural gas, and renewables in the AEO2016 Reference case, 2013–40 (billion kilowatthours)

Figure ES-2. Net electricity generation from coal, natural gas, and renewables in the No CPP case, 2013–40 (billion kilowatthours)

ES-2
Energy Industry Challenges – Why are we Here?

• Low-cost, reliable, coal-fired generation is challenged in today’s regulatory environment.

• Natural gas use for generation is growing, but has variability in pricing and is also challenged under long-term environmental regulations.

• Renewable generation options are expanding, but intermittency is challenging.
Energy Industry Challenges – Why are we Here?

According to recent EIA data, there is a long-lasting supply of coal and gas in the U.S.:

• Based on U.S. coal production in 2014, the U.S. estimated recoverable coal reserves would last about 250 years.

• Based on U.S. natural gas usage in 2014, the U.S. estimated recoverable gas reserves would last about 85 years.

Source: www.eia.gov
Our Vision and Call to Action

**Our Vision:**
A next generation energy solution for North Dakota and the utility industry.

**Our Call to Action:**
The United States, and the State of North Dakota, need a transformational technology to meet these challenges and to forge the future of the energy industry.
Our Answer → The Allam Cycle

A new opportunity for truly clean, low-cost, coal power

Patented, oxy-fuel, high-pressure, supercritical CO₂ cycle invented and developed by 8 Rivers Capital – the Allam Cycle is next generation technology.

Major performance, cost, and environmental benefits vs. existing systems and other new energy system designs.

• The turbine is driven by supercritical CO₂.

• **Near-zero emissions** - 100% of the CO₂ available for utilization at pipeline pressures.

• **Efficiency estimates nearing 50%** - 1.4x higher than the U.S. coal fleet average.

• **Economic Power Generation**
  • $0.04-$0.05 /kWh with sale of CO₂
  • $0.06-$0.07 /kWh without the sale of CO₂

• **Smaller Footprint** - 20% of a traditional coal-based plant.
Allam Cycle Process Diagram

Coal Gasification System (in gray)

Core Power Block (in yellow)
**Allam Cycle is Competitive with Traditional Technologies that don’t have Carbon Capture**

<table>
<thead>
<tr>
<th>Technology Type</th>
<th>LCOE ($/MWh)</th>
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<tr>
<td>NGCC</td>
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<td>NGCC w/CCS</td>
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<tr>
<td>First-of-a-kind Allam Cycle NG (NET Power)</td>
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<td>Allam Cycle NG (NET Power)</td>
<td>$140 million natural gas Allam Cycle demonstration program underway by NET Power, 8 Rivers, CB&amp;I and Exelon</td>
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<tr>
<td>SCPC</td>
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<td>SCPC w/CCS</td>
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<td>IGCC</td>
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<td>IGCC w/CCS</td>
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<td>Allam Cycle Coal</td>
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- LCOE calculated using EPRI methodology
- Assumes natural gas at $2.85/MMBtu and coal at $1.73/MMBtu
- Every move of $1 in natural gas moves LCOE $6
- Cost ranges represent range of data combined from: EIA (2013), Parsons Brinkerhoff (2013); Black & Veatch (2012); DOE NETL (2012)

In climates with less O₂ per volume of air (higher altitudes and/or higher temperatures), Allam Cycle power output stays relatively stable, while output of traditional cycles falls sharply.
Our Solution → A Broad Vision

A sustainable solution for coal coupled with a sustainable solution for additional oil recovery:

• Demonstrate the Allam Cycle technology, then develop and build a commercial electric generation plant in North Dakota using local lignite.

• Transport CO$_2$ from electric plants to the Bakken for Enhanced Oil Recovery and sequestration (in conventional oil fields).

• Develop a solution for utilization of the CO$_2$ in the Bakken shale formations (tight oil fields).
Our Partnership – Working Together to Create a Pathway for Carbon Solutions
Strong Support for Preserving the Coal Option

• Research and development on key challenges has been successfully conducted.

• A 25 MWe natural gas-fired demonstration plant is currently being constructed in Texas.

• Further development creates a path forward for continued utilization of coal.

• Substantial investment already committed from federal, state, industry, and international partners.
  ~ $15 million of coal design, research, and testing work through 2017.
  ~ $140 million of core cycle design, testing, and demonstration.

• World-class research and development leaders at the University of North Dakota, Energy and Environmental Research Center.
Initial Demonstration Underway

Core natural gas Allam Cycle is being demonstrated by Net Power

50-MWth natural gas demonstration plant located in La Porte, TX.

- Mirrors design of commercial plant to ensure scalability.
- Includes all components of the Allam Cycle.
- Oxygen will be pulled from a pipeline as opposed to a dedicated ASU.

Plant will undergo full performance evaluation.

- Construction under way, equipment arriving.
- Commissioning begins end 2016.
- Full operations begin in Q2 2017.
- Will test performance, reliability, controllability, and safety.

Program is fully funded.

- $140 million raised for engineering, construction, and testing.

300-MWe commercial plant under development.

- Pre-FEED study completed on full commercial plant.
- Beginning FEED and early development work.
- Toshiba well progressed on commercial turbine design.
- Working with customers in power, oil and gas industries on development opportunities.
Allam Cycle Coal Development – What We’ve Done So Far

1. Identified and began to address the key technology challenges for coal.

2. Initiated steps to design pilot testing and scale-up to commercial plant.

3. Identified partnership and funding pathways to support full project development.
Our Path Forward

Lignite-Based Allam Cycle Technology Development Road Map

**PHASE 1a** – Addressing Technical Challenges, $3.18 million
- June 2016 – December 2017
- Additional Follow-Up R&D Identified in Phase 1a
- Syngas Combustor Pilot Test

**PHASE 1b** – Key Development Pathways, $5 million–$10 million*
- August 2016 – July 2019
- Preliminary Engineering of Commercial Plant
- Engineer, Procure, Construct, and Operate Pilot Plant
- 5–10-MWe System

**PHASE 2** – Pre-Feed and Pilot Testing, $20 million–$50 million*
- August 2019 – July 2020
- Up Through Preliminary Design and Estimates of Commercial Operation

**PHASE 3** – FEED for Commercial Plant, $10 million–$30 million*
- July 2020–2024
- 100–300-MWe System
- Detailed Engineering, Procurement, Construction, and Operation

**PHASE 4** – Commercial Demonstration, $500 million–$900 million*
- Detailed Engineering, Procurement, Construction, and Operation

*Costs are estimated and include matching support from federal and industrial sponsors.
Thank You!

Questions?