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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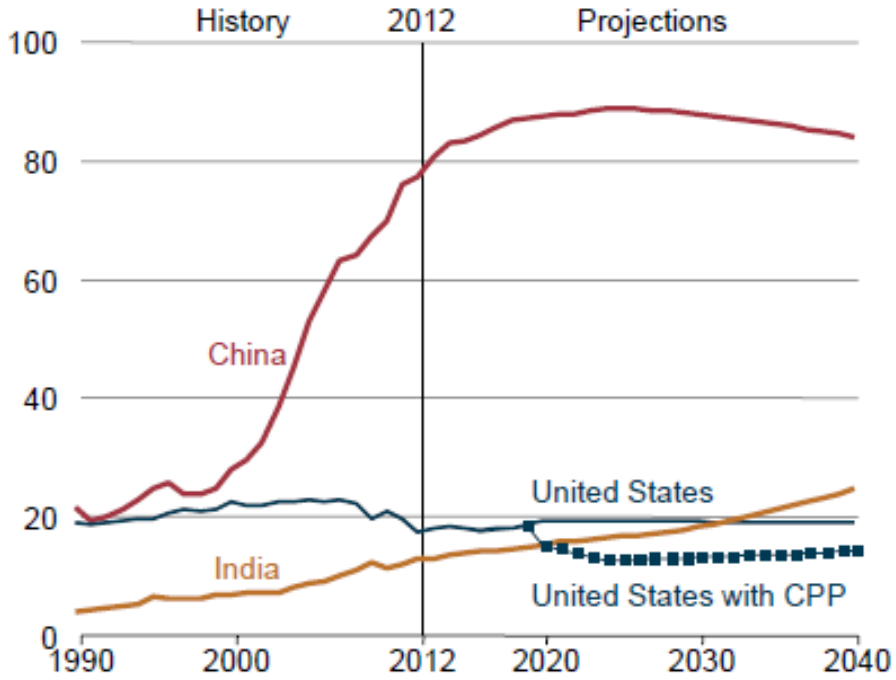
Coal is.....

- #1 fuel for electric generation in the United States.
- #1 fuel for electric generation in the World.

Figure ES-5. Coal consumption in China, India, and the United States, 1990–2040 (quadrillion Btu)



Note: Dotted line for U.S. coal consumption shows projected effect of the U.S. Clean Power Plan.

U.S. Energy Information Administration | Annual Energy Outlook 2016

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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)

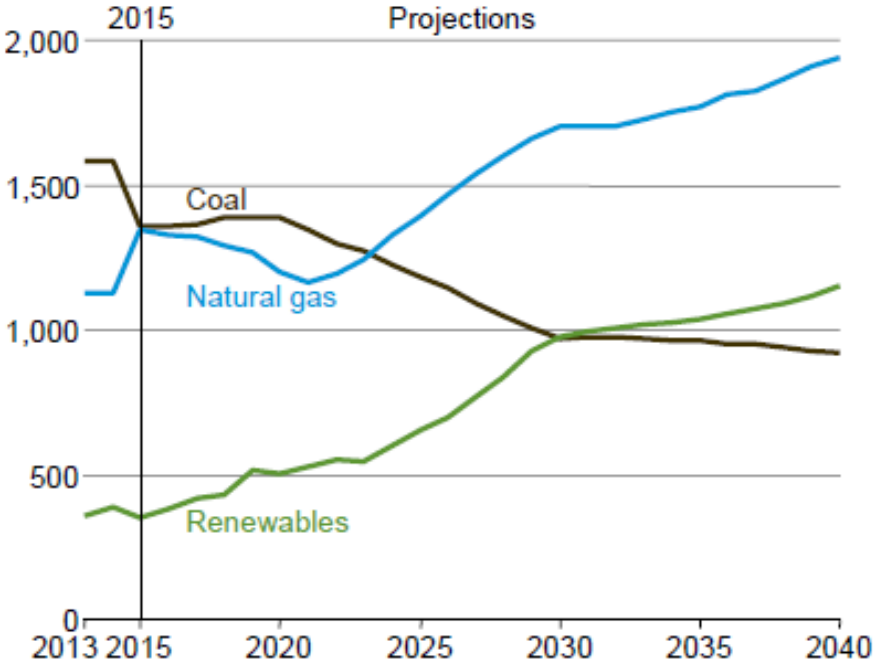
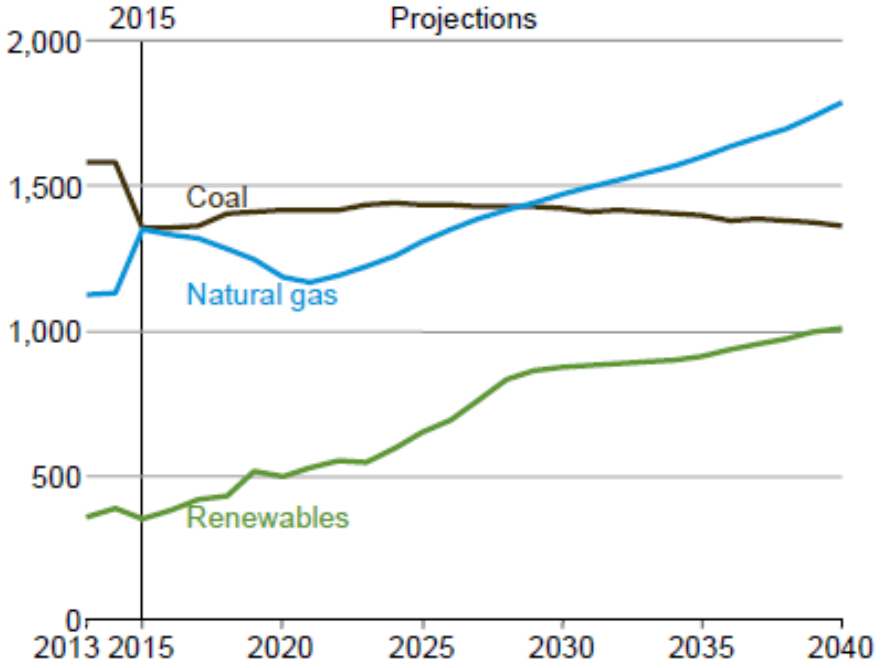


Figure ES-2. Net electricity generation from coal, natural gas, and renewables in the No CPP case, 2013–40 (billion kilowatthours)



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

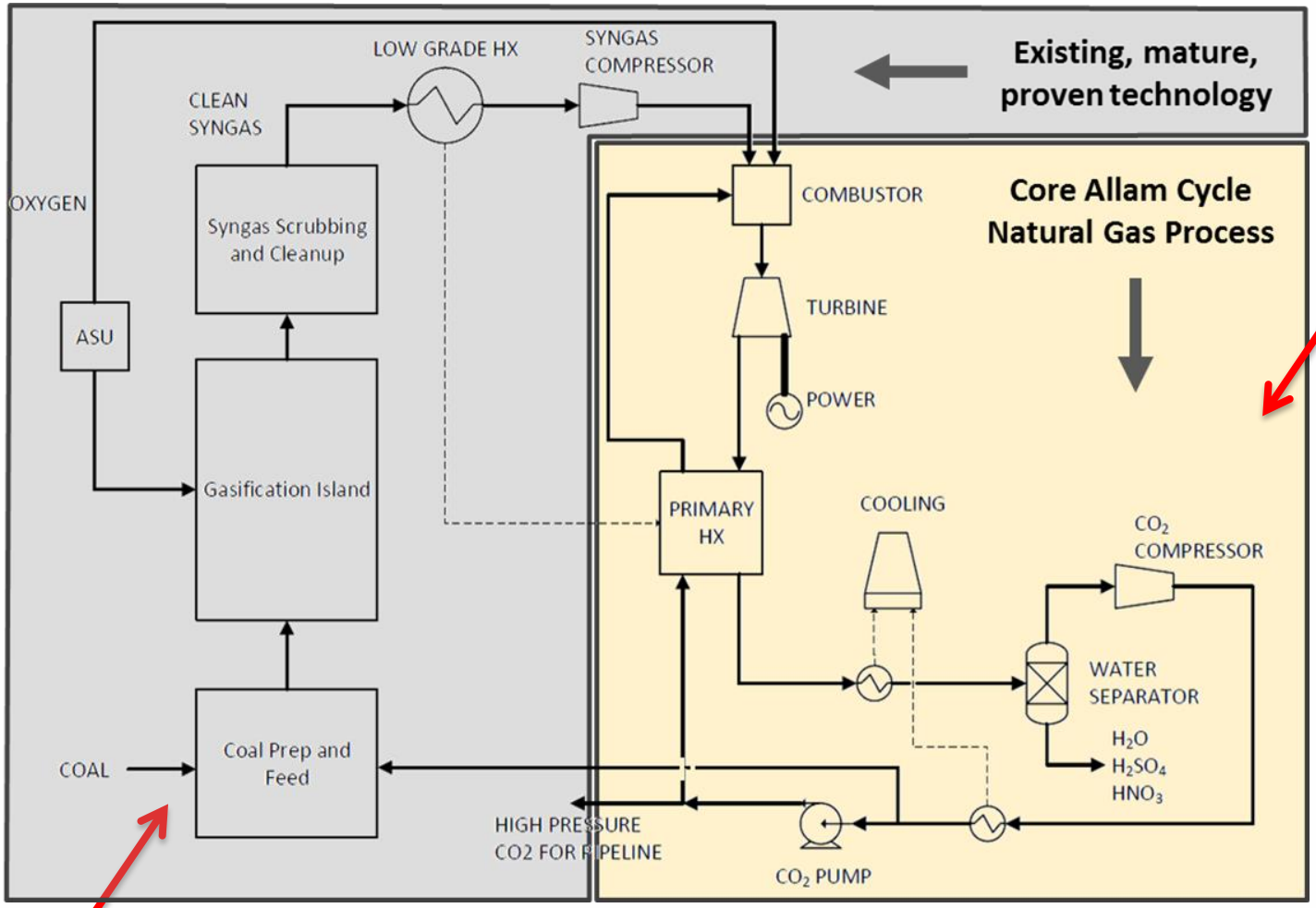
A new opportunity for truly clean, low-cost, coal power

Patented, oxy-fuel, high-pressure, supercritical CO_2 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 CO_2**.
- **Near-zero emissions -** 100% of the CO_2 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 CO_2
  - $0.06-$0.07 /kWh without the sale of CO_2
- **Smaller Footprint** - 20% of a traditional coal-based plant.

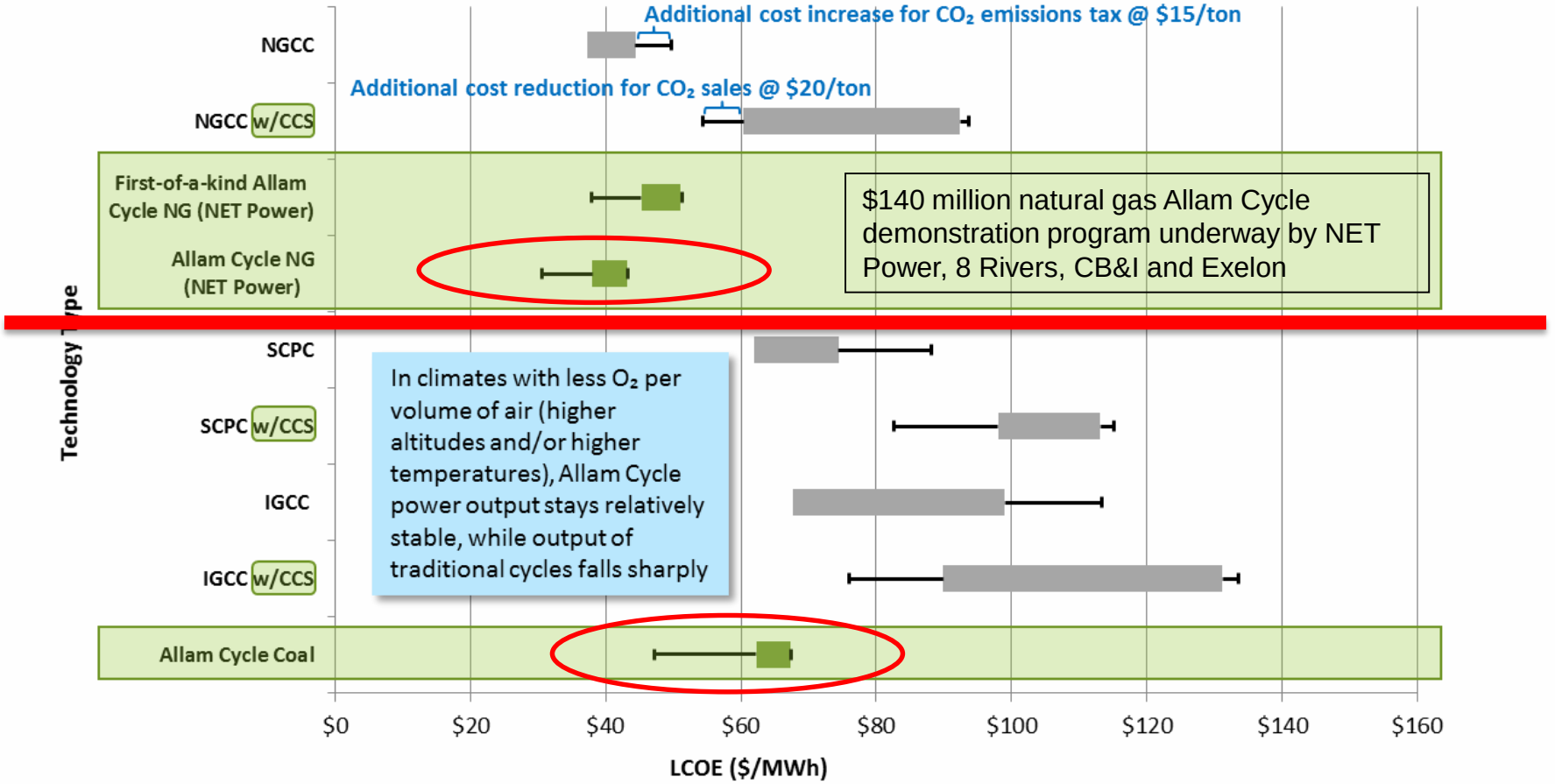
Allam Cycle Process Diagram



Core Power Block (in yellow)

Coal Gasification System (in gray)

Allam Cycle is Competitive with Traditional Technologies that don't have Carbon Capture



- 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)

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

DAKOTA GASIFICATION COMPANY

BASIN ELECTRIC POWER COOPERATIVE
A Touchstone Energy® Cooperative

BNI energy
AN ALLETE COMPANY

minnesota power
AN ALLETE COMPANY

8 RIVERS

ALLETE

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

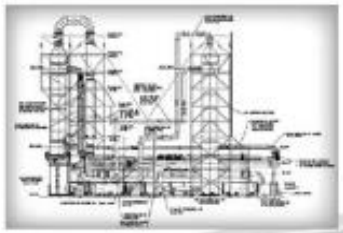
1. Identified and began to address the key technology challenges for coal.

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
- January – November 2016

PHASE 1b – Key Development Pathways, $5 million–$10 million*
- June 2016–December 2017
- Additional Follow-Up R&D Identified in Phase 1a
- Syngas Combustor Pilot Test

PHASE 2 – Pre-FEED and Pilot Testing, $20 million–$50 million*
- August 2016 – July 2019
- Preliminary Engineering of Commercial Plant
- Engineer, Procure, Construct, and Operate Pilot Plant
- 5–10-MWe System

PHASE 3 – FEED for Commercial Plant, $10 million–>$30 million*
- August 2019 – July 2020
- Up Through Preliminary Design and Estimates of Commercial Operation

PHASE 4 – Commercial Demonstration, $500 million–>$900 million*
- July 2020–2024
- 100–300-MWe System
- Detailed Engineering, Procurement, Construction, and Operation

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

EERC JS51631.AI

Thank You!

Questions?