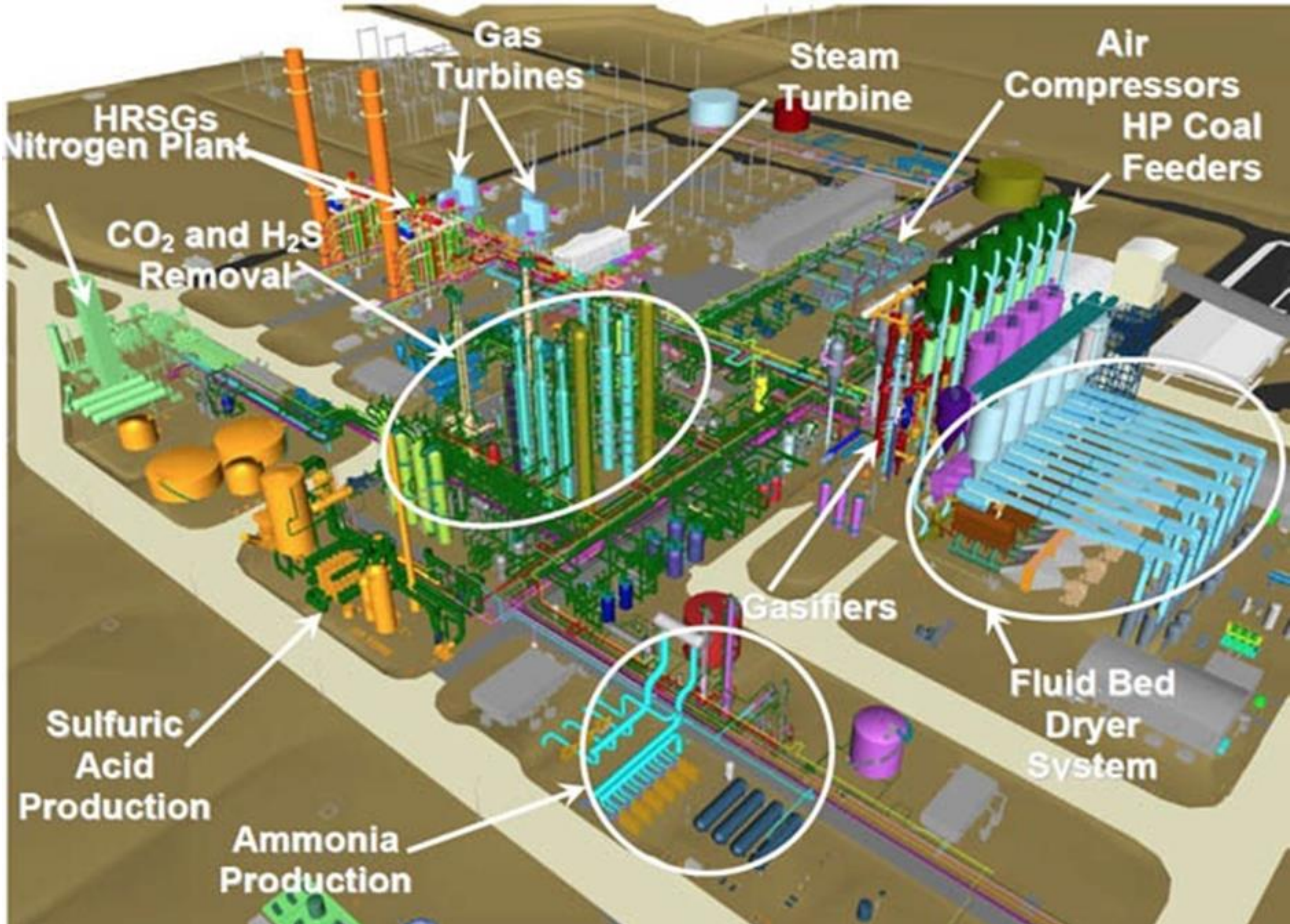
Reflections from the Kemper IGCC site visit

Commissioner John Quackenbush


Gas
Turbines
Steam
Turbine
Air
Compressors
HP Coal
Feeders
HRSGs
Nitrogen Plant
CO2 and H2S
Removal
Gasifiers
Fluid Bed
Dryer
System
Sulfuric
Acid
Production
Ammonia
Production

- A hydrogen sulfide (H2S) absorber being delivered to the plant
- 238 feet long, 21 feet wide, weighs 1,425,730 lbs
- Came 75 miles on a 160 axle Goldhofer modular transporters

- A CO_2 absorber being delivered
- 210 feet long and weights in at 700,000 lbs
- 65% of the CO_2 will be used for enhanced oil recovery

- Hydrogen sulfide (H2S) absorbers help reduce sulfur emissions
- largest pieces of equipment delivered fully constructed to the site

- Part of the gasifier – the core of the IGCC process.
- Gasifiers are assembled section by section

- Zero Liquid Discharge facility
- The town of Meridian effluent water is piped 31 miles

Lignite storage dome


SCHADE


CATERPILLAR 700
CAT
CAT


785D
CAT

Transforming North Dakota's Energy Future

NARUC Clean Coal Subcommittee

February 15, 2016

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 2013, the U.S. estimated recoverable coal reserves would last about 260 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.

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 & gas power

Patented, oxy-fuel, high-pressure, supercritical CO_2 cycle invented and developed by 8 Rivers Capital

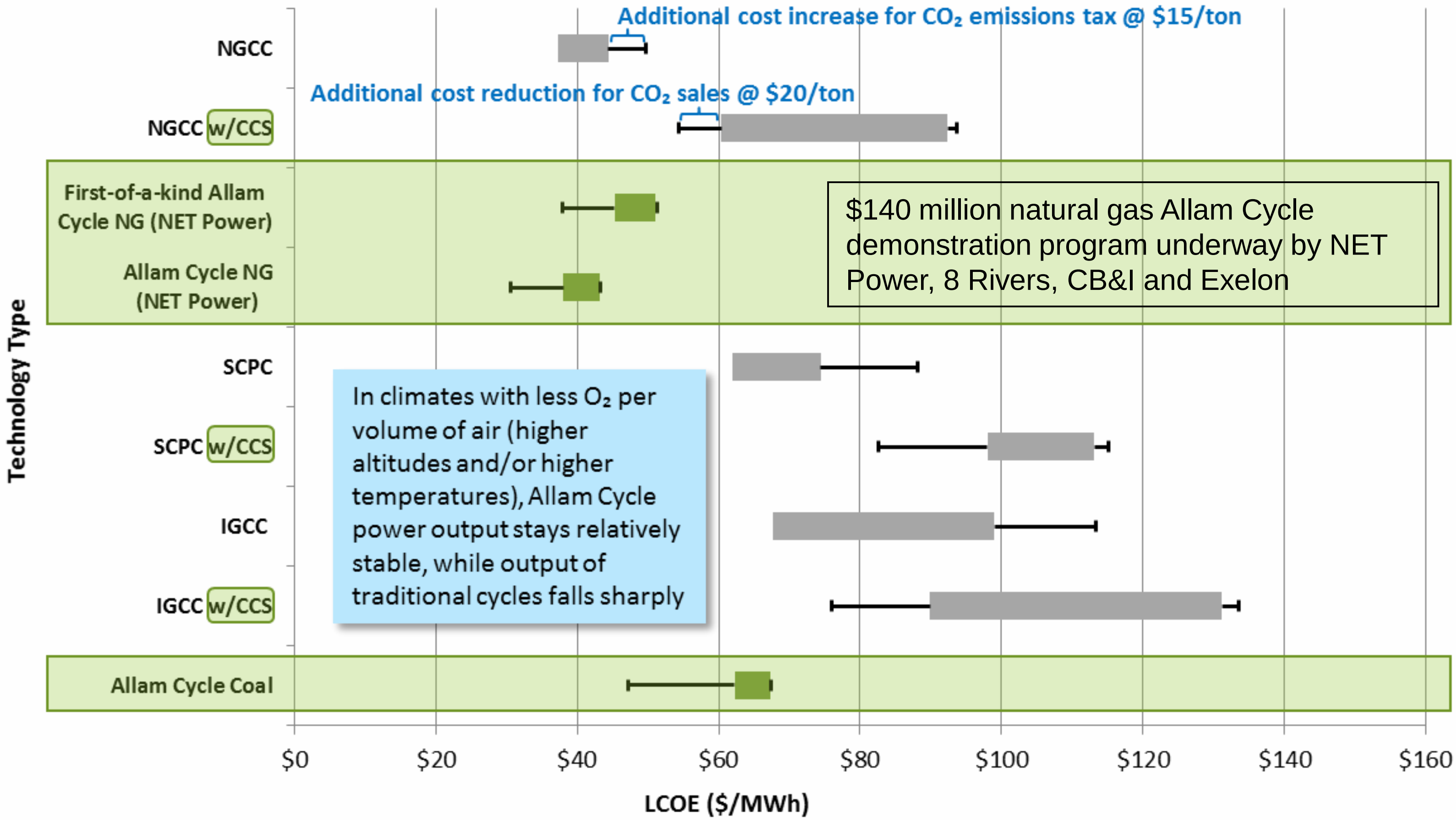
Major performance, cost, and environmental benefits vs. existing systems and other new energy system designs

- Higher gross output leads to **high net efficiencies** with full carbon capture.
- Simpler cycle significantly **reduces cost.**
- **No air emissions.** Carbon capture at pipeline conditions is inherent to the process.

Why Allam?…Coal plant efficiencies nearing 50%, or about 1.4 times higher than the U.S. coal fleet average, with near-zero emissions and full carbon capture.

ALLETE

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

Sustainable Solution for lignite married with a sustainable solution for tertiary oil recovery in the Bakken:

- *Demonstrate the Allam technology, then develop and build a commercial electric generation plant in North Dakota using local lignite*
- *Develop a solution for tertiary oil recovery in the Bakken using CO2*
- *Transport CO2 from electric plants to the Bakken for Enhanced Oil Recovery and sequestration*

ALLETE.

Our Partnership

PATHWAY TO NORTH DAKOTA ENERGY TRANSFORMATION

LIGNITE Energy COUNCIL

NETL

ALLETE

BASIN ELECTRIC POWER COOPERATIVE
A Touchstone Energy® Cooperative

8 RIVERS

EERC
UND UNIVERSITY OF NORTH DAKOTA

GREAT SEAL STATE OF NORTH DAKOTA

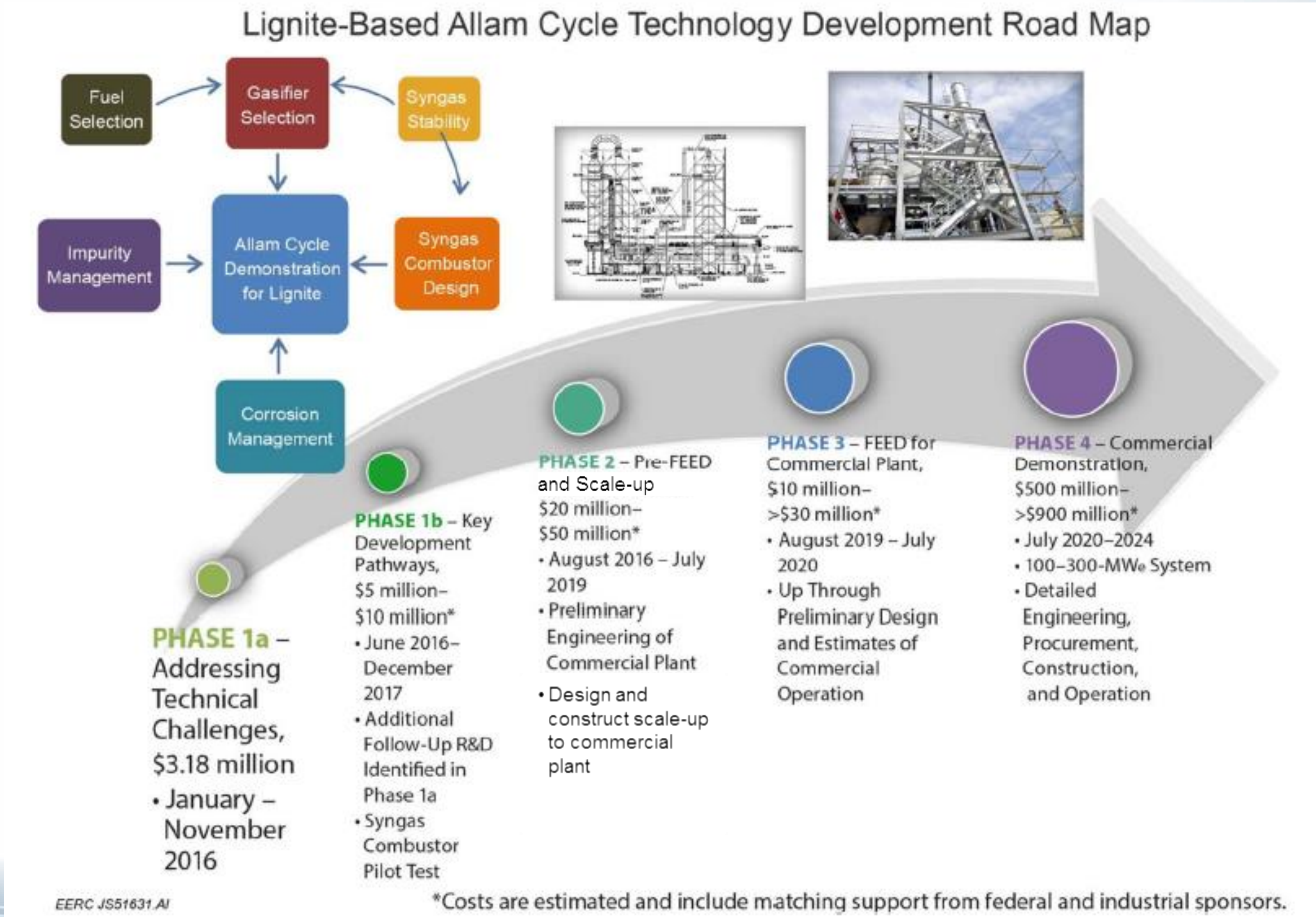
Strong Support for this Vision

- $5 million approved by the North Dakota Legislature to date.
- $1.5 million allocated by the Department of Energy for current activities.
- World-class research and development leaders at the University of North Dakota, Energy and Environmental Research Center.
- North Dakota Lignite and Oil & Gas Industries.
- Leverages Net Power gas cycle development

What We've Done So Far

1. Identified key technology challenges.
2. Began the steps to address these challenges.
3. Initiated steps to design scale-up to commercial plant.
4. Identified partnership and funding pathways to support full project development.

Our Path Forward



THE OHIO STATE UNIVERSITY

CHEMICAL LOOPING PROCESS FOR ELECTRICTY

Andrew Tong

Research Assistant Professor

Department of Chemical and Biomolecular Engineering

NARUC Winter Committee Meeting | February 15, 2016

Professor Fan’s Chemical Looping Credentials

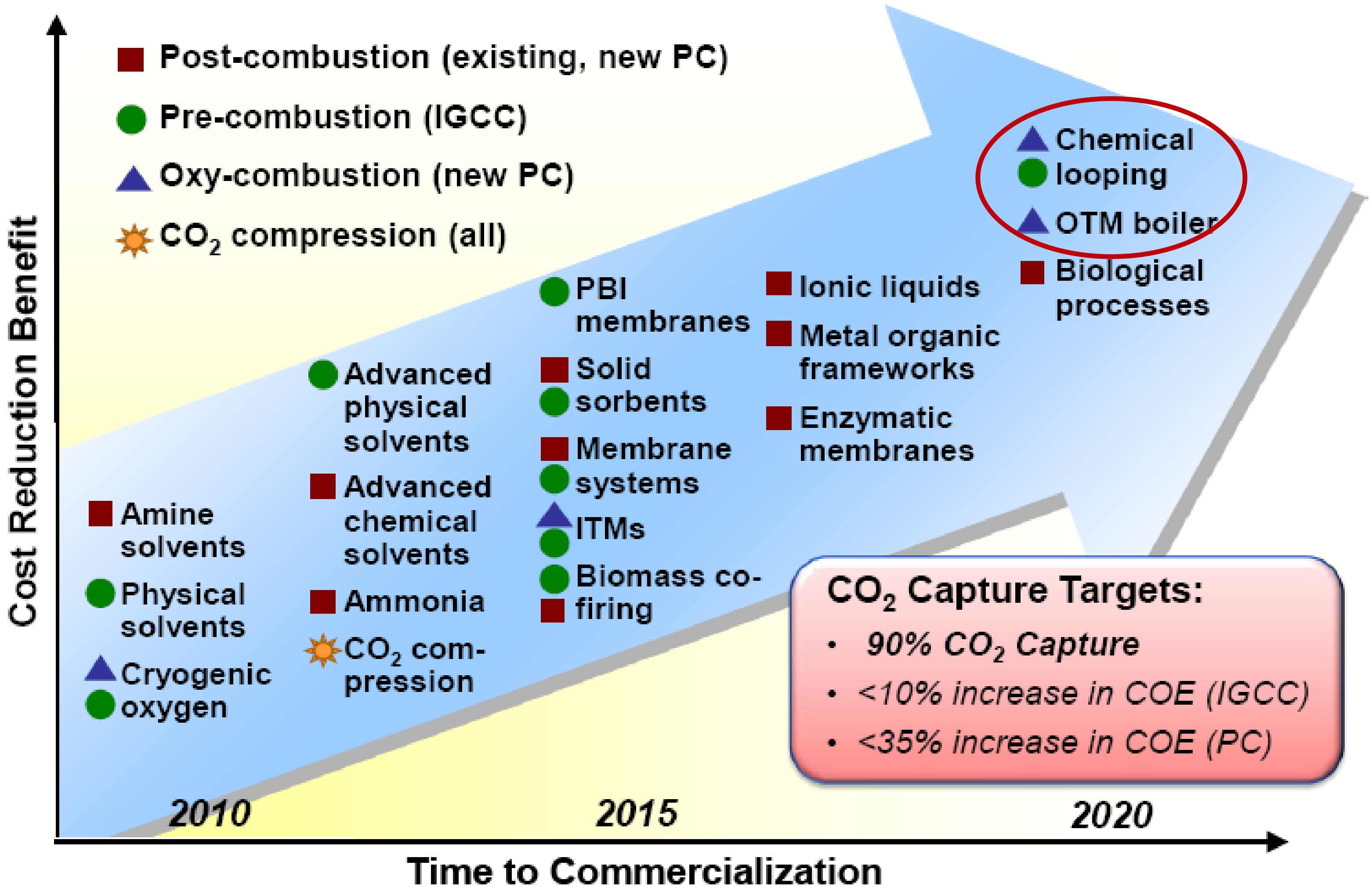
- **Over 40 plenary lectures including the following:**
  - 2009 U.S. - Korea Conference, Raleigh, North Carolina, July 16-19, 2009.
  - 2009 AIChE Plenary Session on “Energy Policy and Technology”, Annual Meeting, Nashville, Tennessee, November 9, 2009.
  - 12th International Symposium on Chemical Reaction Engineering (ISCRE-21), Philadelphia, June 13 – 16, 2010.
  - 1st International Conference on Chemical Looping, Lyon, France, March 17 – 19, 2010.
  - 2010 Sustainable and Green Technology Symposium, National Taiwan University, July 3, 2010.
  - 13th Asian Pacific Confederation of Chemical Engineering Congress (APCChE 2010), Taipei, October 5-8, 2010.
  - National Energy Technology Laboratories (NETL), U.S. Department of Energy Workshop on Fossil Energy Flows and Reaction Engineering, August 16-18, 2011.
  - 14th Asian Pacific Confederation of Chemical Engineering Congress (APCChE 2012), Singapore, February 21 – 24, 2012.
  - 11th International Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering (in conjunction with the 9th World Congress of Chemical Engineering), Seoul, Korea, August 19 – 22, 2013.
  - 2013 Ohio Coal Association Annual Meeting, Columbus, Ohio, September 26, 2013.
  - 7th World Congress in Particle Technology, Beijing, China, May 19-22, 2014.
  - 2014 International Pittsburg Coal Conference, Pittsburgh, PA, September, 2014.
  - International Conference on Engineering Science and Technology (ICEST) 2014, organized by the Chinese Academy of Engineering and the International Council of Academies of Engineering and Technology Sciences (CAETS), Beijing, China, June 2-3, 2014.
- **Over 20 Published Articles/Books:**
  - “Coal Conversion Processes: Progress and Challenges,” with F. Li, *Energy and Environmental Sciences*, 1, 248-267 (2008).
  - “Chemical Looping Technology and Its Fossil Energy Applications,” with Fanxing Li, *I&EC Research*, 49, 10200 - 10211 (2010).
  - “Biomass Direct Chemical Looping Process; A Perspective,"with N. Kobayashi, *Biomass and Bioenergy*, 35, 1252-1262 (2011).
  - **“**Activation Strategies for Calcium-Based Sorbents for CO2 Capture – A Perspective,” with Fu-Chen Yu, Nihar Phalak and ZhenChao Sun, *I&EC Research*, 51, 2133-2142 (2012).
  - “Chemical Looping Processes – Particle Characterization, Ionic Diffusion-Reaction Mechanism and Reactor Engineering,” with Liang Zeng, Siwei Luo and Deepak Sridhar. *Reviews in Chemical Engineering*, 28, 1-42 (2012).
  - “Chemical Looping Processes for CO2 Capture and Carbonaceous Fuel Conversion – Prospect and Opportunity,” with Zeng, L. and Luo, S. *Energy & Environmental Science,* 5 (6), 7254 – 7280 (2012).
  - “Some Remarks on Direct Solid Fuel Combustion Using Chemical Looping Processes,” with Liang Zeng, Mandar Kathe and Elena Chung, *Current Opinion in Chemical Engineering*, 1 (3), 290-295 (2012).
  - “Chemical Looping Technology and Its Applications in Fossil Fuel Conversion and CO2 Capture,” with Liang Zeng, Siewei Luo, and Fanxing Li, *Scientia Sinica Chimica*, 42(3), 260 – 281 (2012).
  - “Chemical Looping Technology: Oxygen Carrier Characteristics,” with Siwei Luo and Liang Zeng, *Annual Review of Chemical and Biomolecular Engineering, (*2015).
  - “Chemical Looping Combustion and Gasification,” with Elena Y. Chung, Samuel C. Bayham, Mandar V. Kathe and Andrew Tong, *Handbook of Clean Energy System*, AICHE/Wiley publication (2015.)
  - ”Chemical Looping Technology Platform” with Liang Zeng and Siwei Luo, AIChE Journal (Perspective Article, 2015);CEP (May issue , 2015)
  - “Chemical Looping Technology” WIRES Energy and Environment, with Andrew Tong, Elena Chung and Sam Bayham (Perspective Article, 2015)

Outline

- **Chemical Looping Overview**
- **OSU Process:** Unique Advantages
- **Pilot Demonstration Results**
- **Where Do We Go From Here?**

CO_2 Capture from Fossil Energy

Technological Solutions



Figueroa, J.D. *International Journal of Greenhouse Gas Control.* 2008.

OSU Chemical Looping Platform Technology

Feedstock
- Coal
- Natural Gas
- Oil
- Petcoke
- Biomass
- Waste
- Syngas
- F-T light hydrocarbon

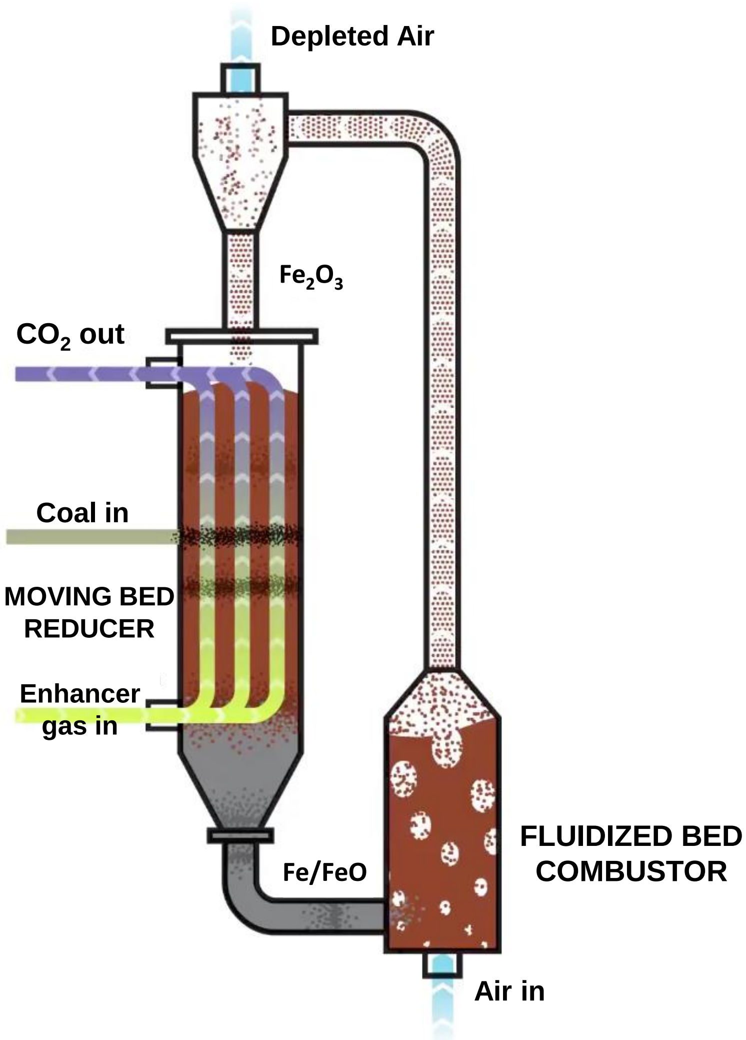
Driver
- Chemical Looping Combustion (CLC)
- Chemical Looping Gasification (CLG)
- Carbonation-Calcination Reaction (CCR)
- Calcium Looping Process (CLP)
- Direct Chemical Synthesis (with EcoCatalytic)

Applications and Products
- CO_2 Capture/Emission Control
- Electricity/heat
  - Retrofit to PC
  - New Plant
  - Combined Cycle
  - SOFC
- Hydrogen
- CLG Syngas
- Liquid fuel
  - F-T Synthesis
  - CO_2 Hydrogenation
  - Olefins to Liquid Fuel
- Chemicals
  - Olefins
  - Ammonia

Metal Oxide Development

Thomas, T. J., Fan, L.-S., Gupta, P., Velazquez-Vargas, L.G. U.S. Patent 7,767,191.

OSU Coal Direct Chemical Looping Process



Main reactions:

Reducer: Coal + Fe_2O_3 → Fe/FeO + CO_2 + H_2O

Oxidizer: Air + Fe/FeO → Fe_2O_3 + Spent Air

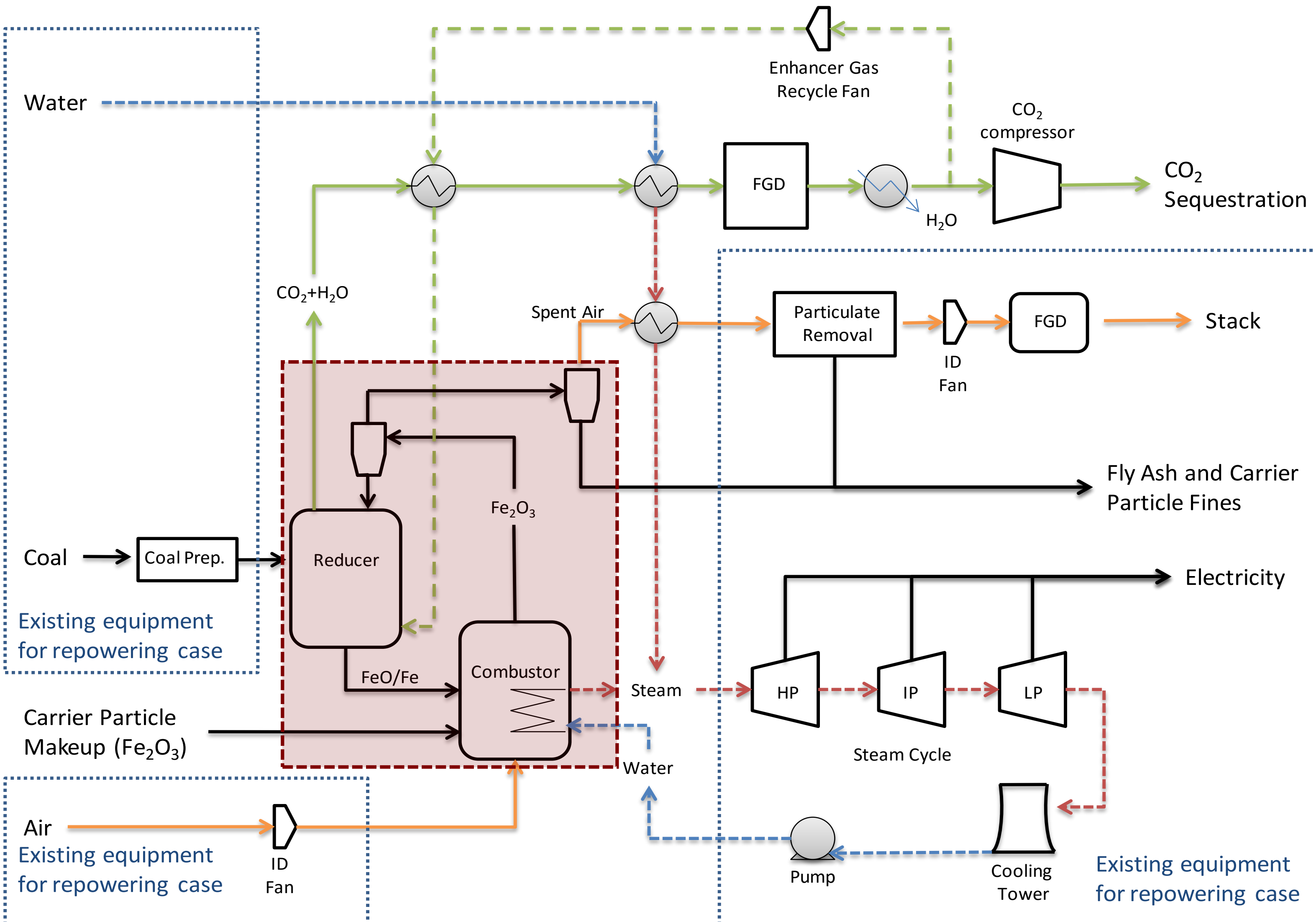
Overall: Coal + Air → CO_2 + H_2O + Spent Air

Advantages

- Indirect Oxidation of the Fuel – separate the Air and the Fuel
- No CO_2 separation cost – prevent dilution of CO_2 with N_2 in Air
- Fuel Flexibility – concept can be applied to any carbonaceous fuel
- Improved Efficiency
- No NO_x formation
- Capable of exceeding DOE's target of <35% increase in COE with 90% carbon capture

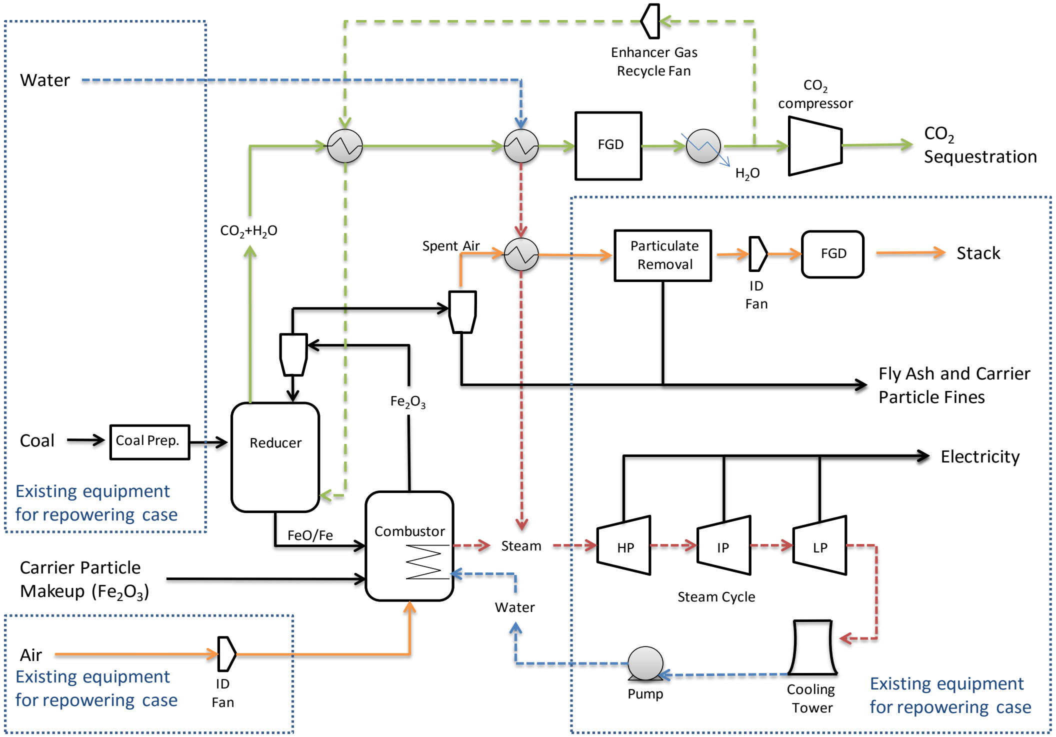
Fan, L.-S., Zeng, L., Luo, S. *AIChE Journal*. 2015.

Coal-Direct Chemical Looping Process

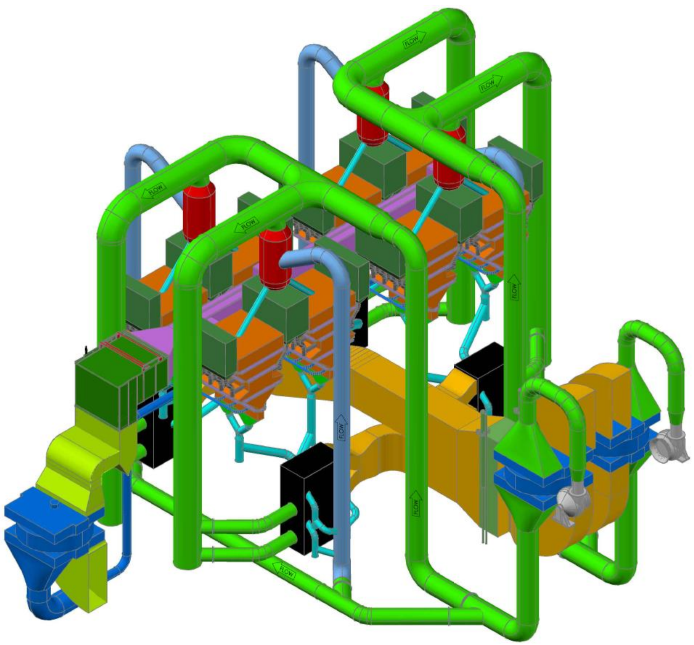


Thomas, T., L.-S. Fan, P. Gupta, and L. G. Velazquez-Vargas, "Combustion Looping Using Composite Oxygen Carriers" U.S. Patent No. 7,767,191 (2010, priority date 2003)

550 MW_e CDCL Commercial Plant



550 MW_e CDCL Plant



	Base Plant	MEA Plant	CDCL Plant
Coal Feed, kg/h	185,759	256,652	205,358
CO_2 Capture Efficiency, %	0	90	96.5
Net Power Output, MW_e	550	550	550
Net Plant HHV Efficiency, %	39.3	28.5	35.6
Cost of Electricity, $/MWh	80.96	132.56	102.67
Increase in Cost of Electricity, %	-	63.7	**26.8**

OSU Process: Unique Advantages

- **Oxygen Carrier**
- **Reactor**

Oxygen Carrier Selection: Periodic Table

Cost Range ($/kg)

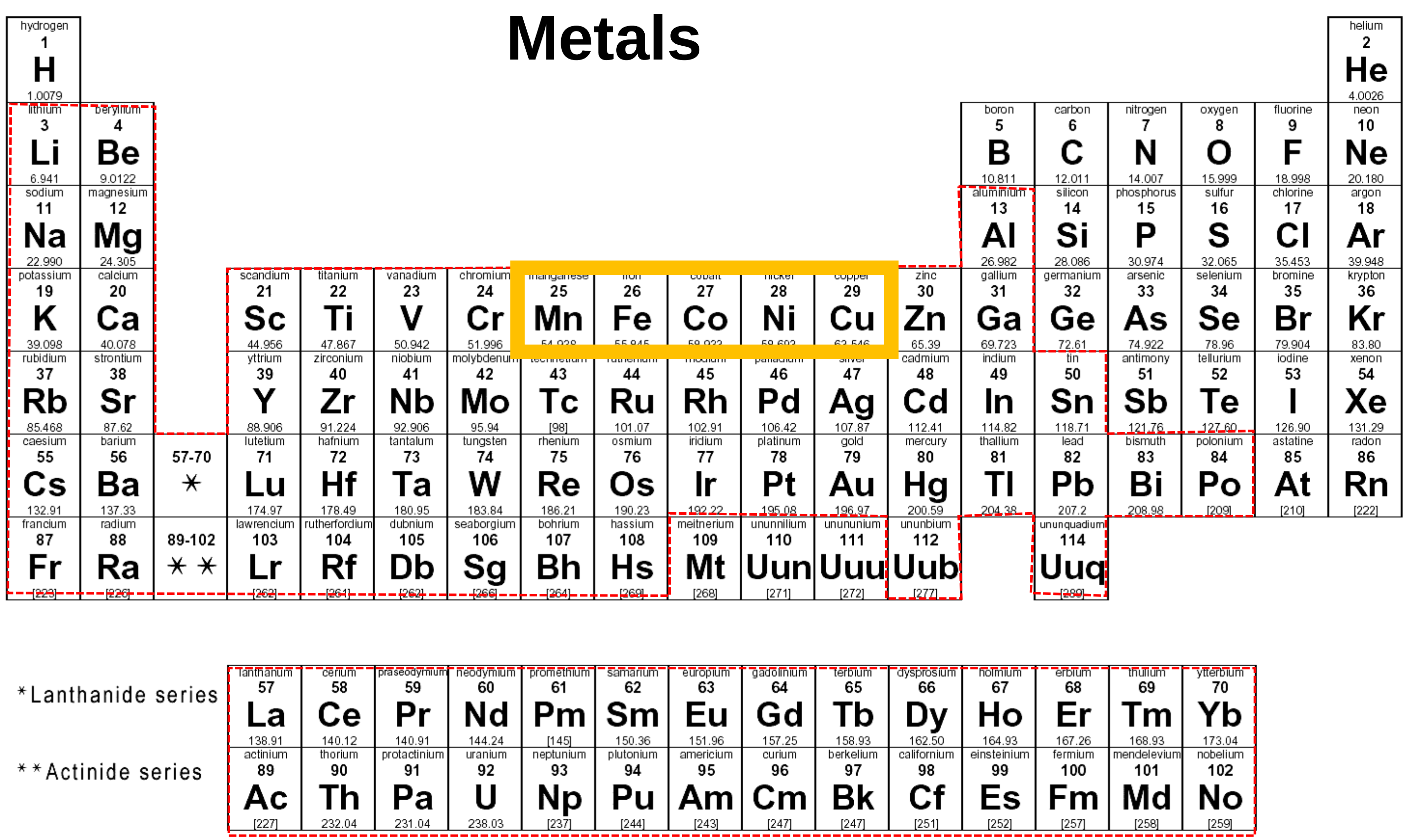
< $1/kg
Fe, K, Ca, Ti, Al, Ba, Na, Sr

$1/kg to $10/kg
Mn, Mg, Cu, Zn, Ce, Cd, Pb, Zr, Cr, La, Rb

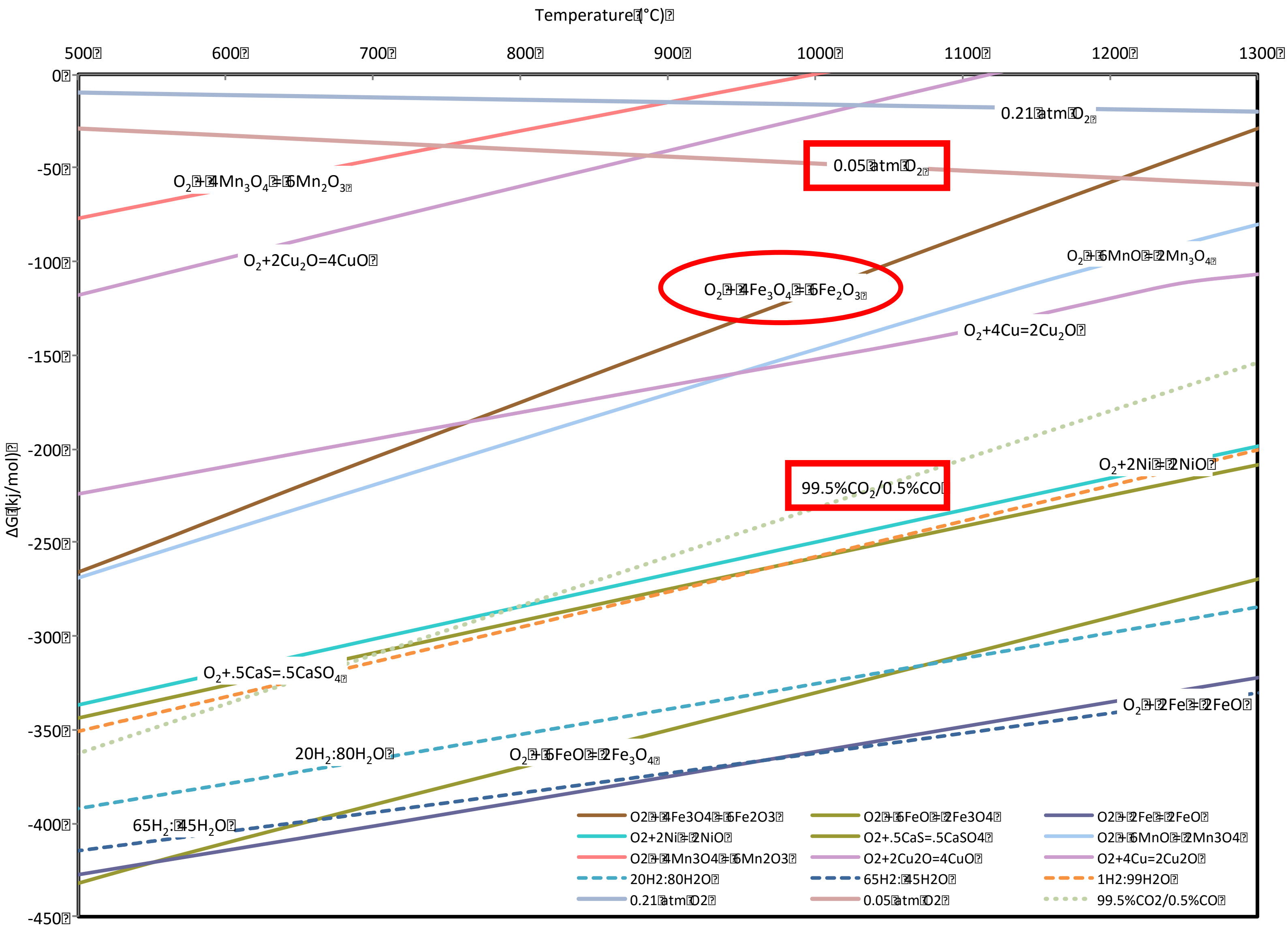
$10/kg to $100/kg
Bi, Co, Hg, Sn, Ni, W, V, Li, Y, Nd, Gd

$100/kg to $1000/kg
Ga, In, Ag, Pr, Eu, Er

> $1000/kg
Tl, Dy, Ir, Lu, Ho, Tm, Yt, Ru, Au, Pt, Pd, Rh, Ra, Po, Cs, Sc

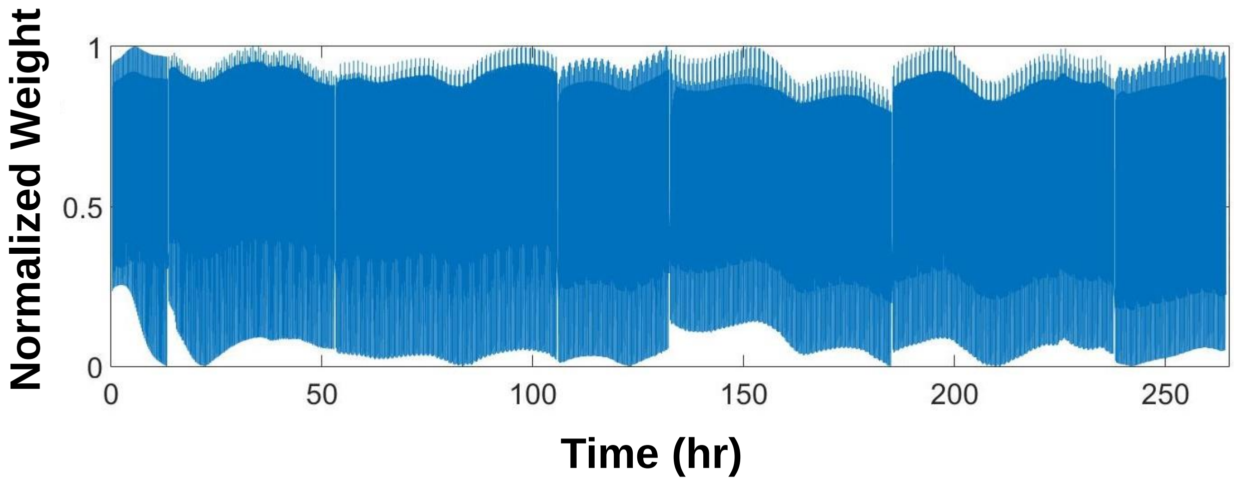


Oxygen Carrier Selection: Ellingham Diagram

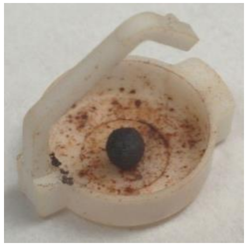


Oxygen Carrier: Recyclability of Pure and Composite Metal Oxides

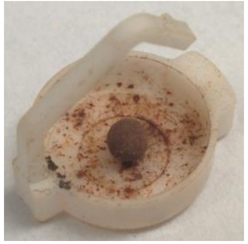
Cyclic Redox of Composite Fe_2O_3



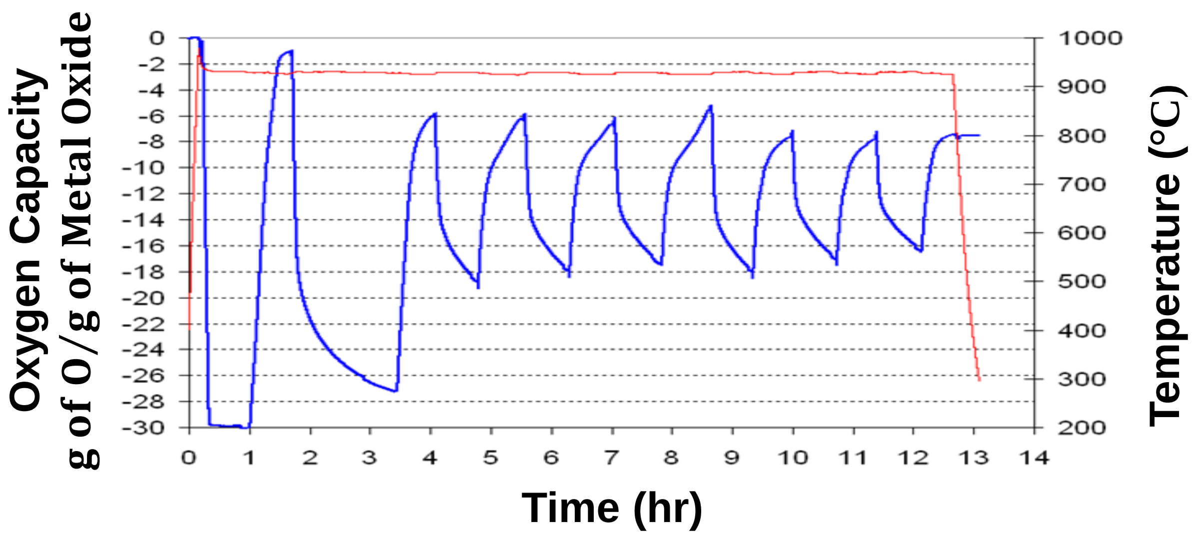
before



after



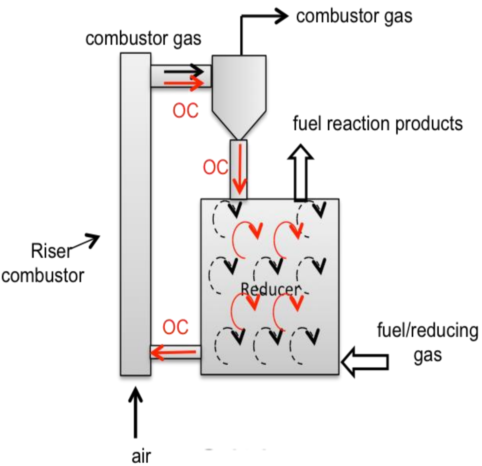
Cyclic Redox of Pure Fe_2O_3

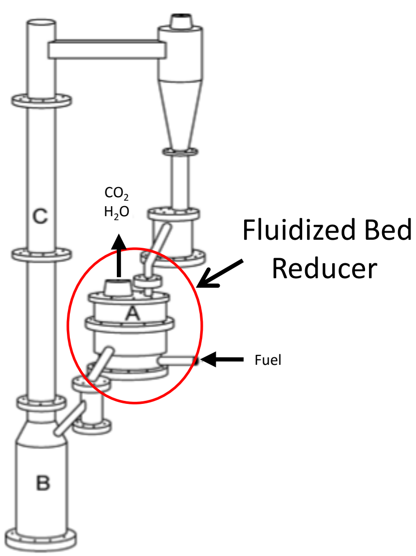


Fan, L.-S. Chemical Looping Systems for Fossil Energy Conversions. Wiley, 2010.
Li, F., Kim, H.R., Sridhar, D., Wang, F., Zeng, L., Fan, L.-S. *Energy & Fuels*. 2009.

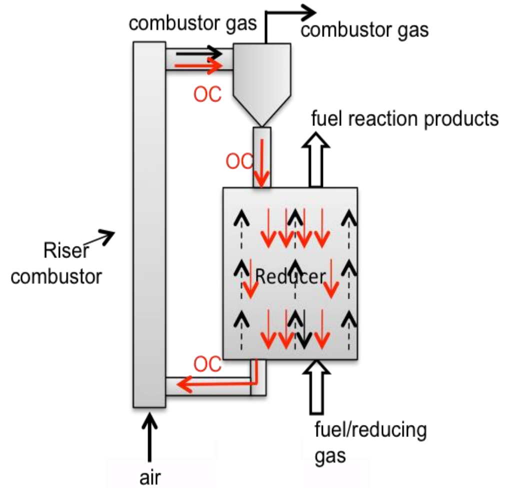
Reactor: Modes of Operation

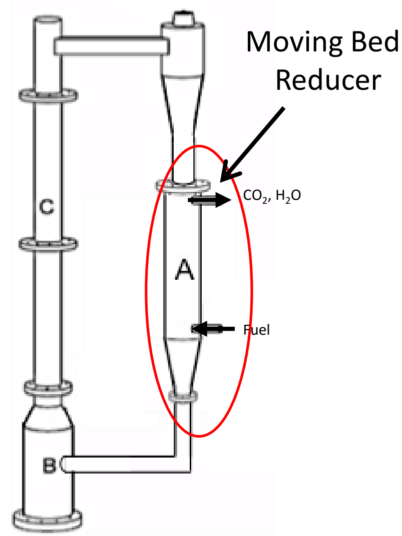
Mode 1- reducer: fluidized bed or co-current gas-solid (OC) flows





Mode 2 - reducer: gas-solid (OC) counter-current dense phase/moving bed flows





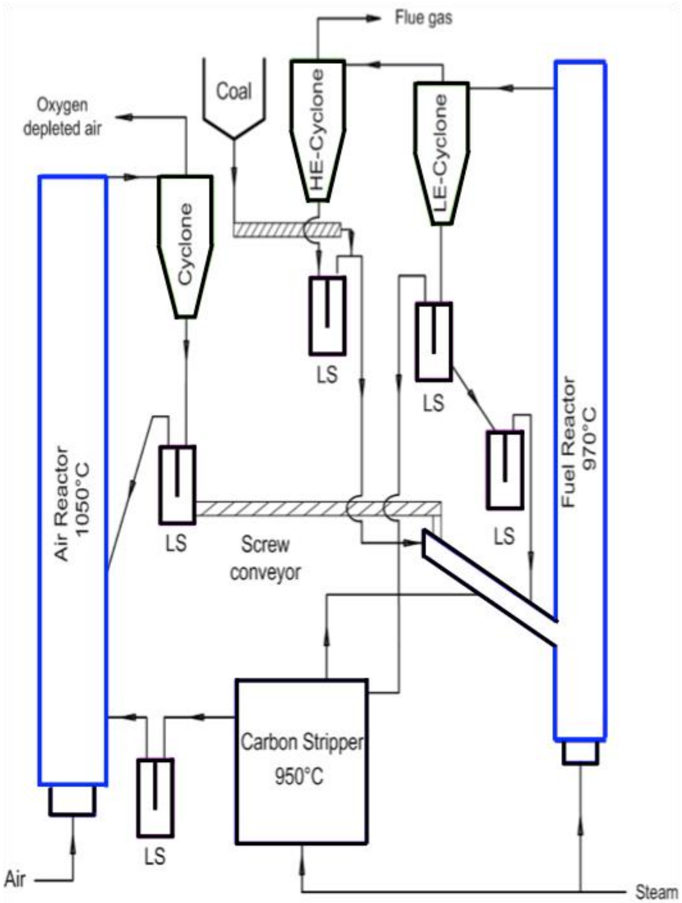
Reducer	Mode 1	Mode 2
Operation Regime	Bubbling, turbulent, fast fluidized, or spouted bed	Moving packed, or multistage fluidized bed
Gas Solid Contacting Pattern	Mixed/Cocurrent	Countercurrent
Controllability on Fuel and OC Conversions	Poor, due to back mixing and gas channeling	High
Maximum Iron oxide Conversion	11.1% (to Fe_3O_4)	>50% (to Fe & FeO)
Solids circulation rate	High	Low
Ash Separation Technique	Separate Step	In-Situ
Subsequent Hydrogen Production	No	Yes
Particle size, μm	100-600	1000-3000
Reducer gas velocity*, m/s	<0.4	>1.0
Reactor size for the same fuel processing capacity	Large	Small
Hydrodynamics effects on scaling up	Large	Small

*Reducer gas velocity calculated at 900 °C, 1 atm

Thomas, T. J., Fan, L.-S., Gupta, P., Velazquez-Vargas, L.G. U.S. Patent 7,767,191.

Reactor: Chemical Looping Reactor Comparison

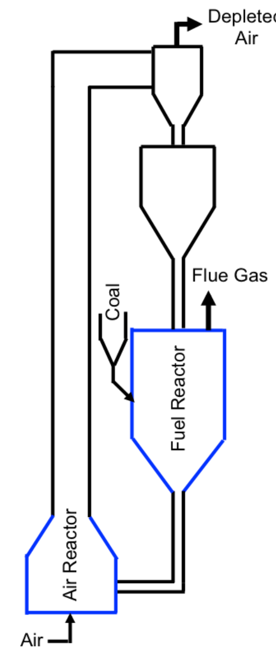
Alstom – Darmstadt MeO_x[1]



Total Reactor Volume: 3.80 m³

- Mechanical solid conveying
- Carbon stripper required
- Multiple components – difficult to integrate

OSU

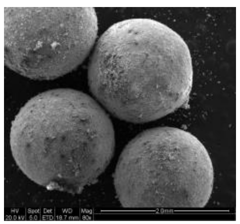


Total Reactor Volume: 0.93 m³

- No internal mechanical moving parts
- Packed moving bed design increases oxygen carrier conversion, reducing solid flow rate
- In-situ ash separation
- Scalable reactor design
- Simple design – no loop seals/carbon strippers

Abdulally, I. et al. Clearwater Clean Coal & Fuel Conference 2012 43–54.

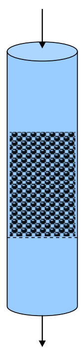
Evolution of OSU Chemical Looping Technology



Particle Synthesis

1993

TGA Tests

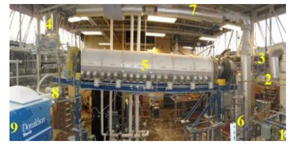


Fixed Bed Tests

1998

Bench Scale Tests

2001



CCR Process

SCL Process

STS Process

Sub-Pilot CDCL Process Tests

2007

Pilot Scale Demonstration

2010 to date

Fan, L.-S., Zeng, L., Luo, S. *AIChE Journal*. 2015.

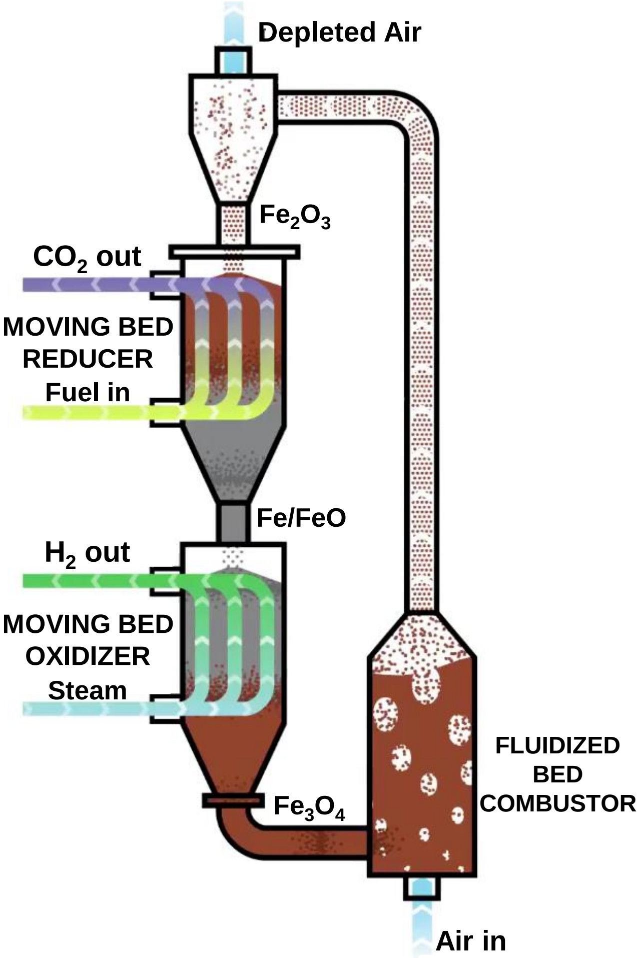
25 kW$_{th}$ Sub-Pilot Demonstration

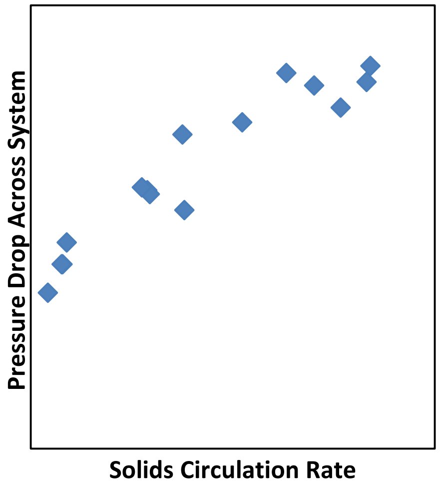
Fuel Feedstock	Type
Syngas	CO/H_2
Coal volatile	CH_4
Coal char	Lignite
	Metallurgical Coke
	Petroleum Coke
Coal	Sub-Bituminous
	Bituminous
	Anthracite
	Lignite
Biomass	Wood pellets

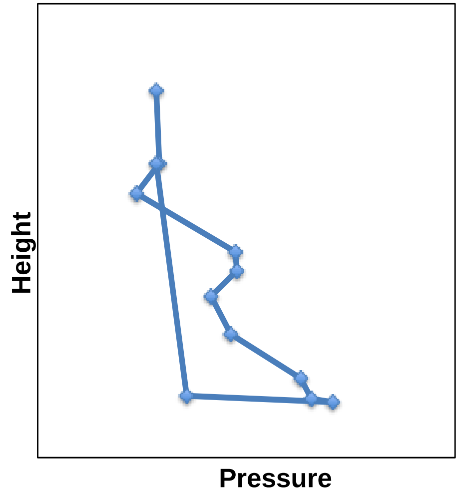
- Combined >1,000 hours of operational experience
- Successful conversions achieved with all feedstocks tested

OSU Chemical Looping Pilot Plant Operation

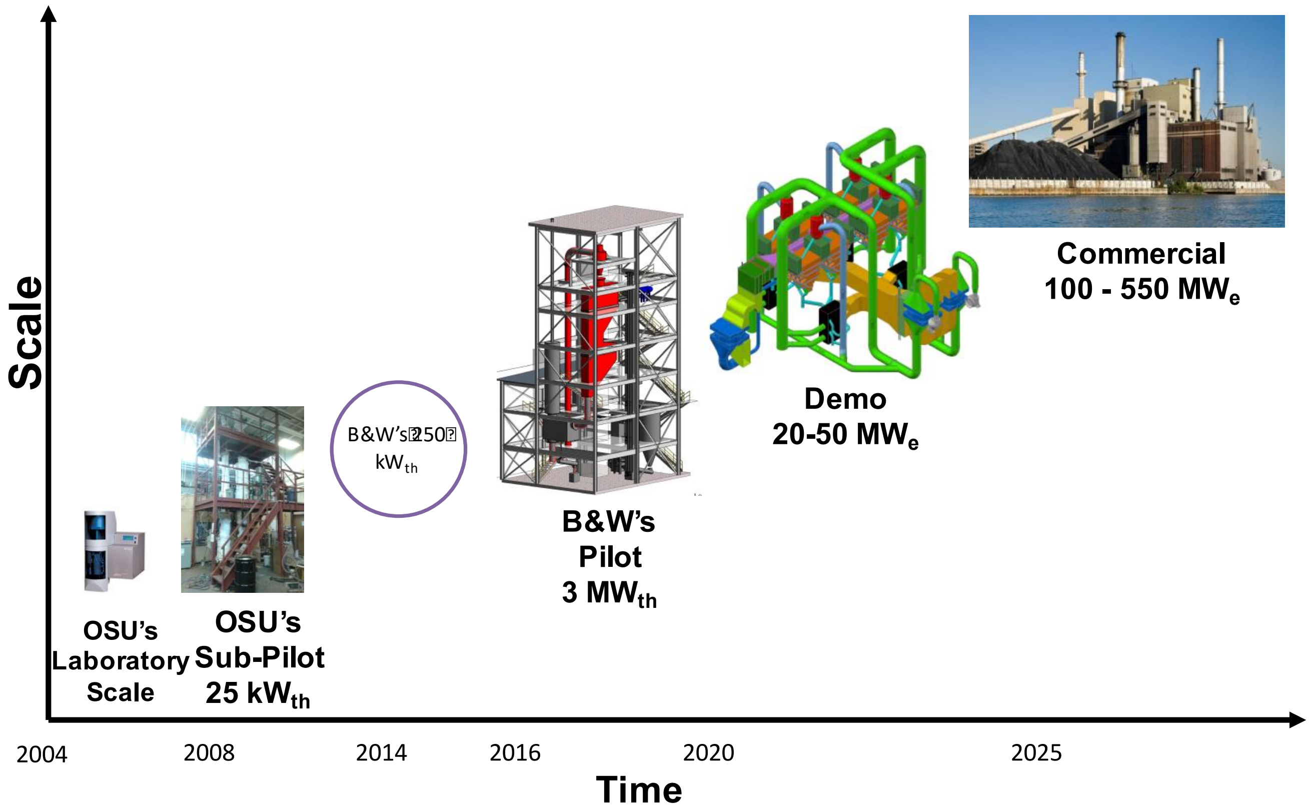
250 kW_{th} - 3 MW_{th} High-Pressure Pilot Unit	1:1 Pilot Unit Cold Model







Where Do We Go From Here



- CDCL process can achieve 96% carbon capture (84 lb/MWh)
- OSU chemical looping technology platform is a promising tool to continue to use fossil fuels, globally
- Pilot scale demonstration in operation
- Private investment required for large scale demonstration testing

Industrial Collaborators

- Shell Global Solutions
- * WorleyParsons Group
- American Electric Power
- The Linde Group
- CONSOL Energy Inc.
- * Babcock & Wilcox Power Generation Group
- * Particulate Solid Research, Inc.
- First Energy Corporation
- Clariant Corporation
- IWI Incorporated
- Duke Energy Corporation
- Littleford Day Inc.
- Dayton Power and Light Inc.
- FLSmidth Group
- Carmeuse Lime & Stone Group
- Minerals Technologies Inc.

Sponsors

- U.S. Department of Energy (NETL and ARPA-E)
- National Science Foundation
- Ohio Development Services Agency
- The Ohio State University

Test Site Host

- National Carbon Capture Center

Questions

Andrew Tong
Email: tong.48@osu.edu
Phone: 614-292-8255

L.-S. Fan
Email: fan.1@osu.edu
Phone: 614-688-3262

NARUC

February 15, 2016

EPA'S POWER PLAN

Paul Bailey
Senior Vice President
American Coalition for Clean Coal Electricity

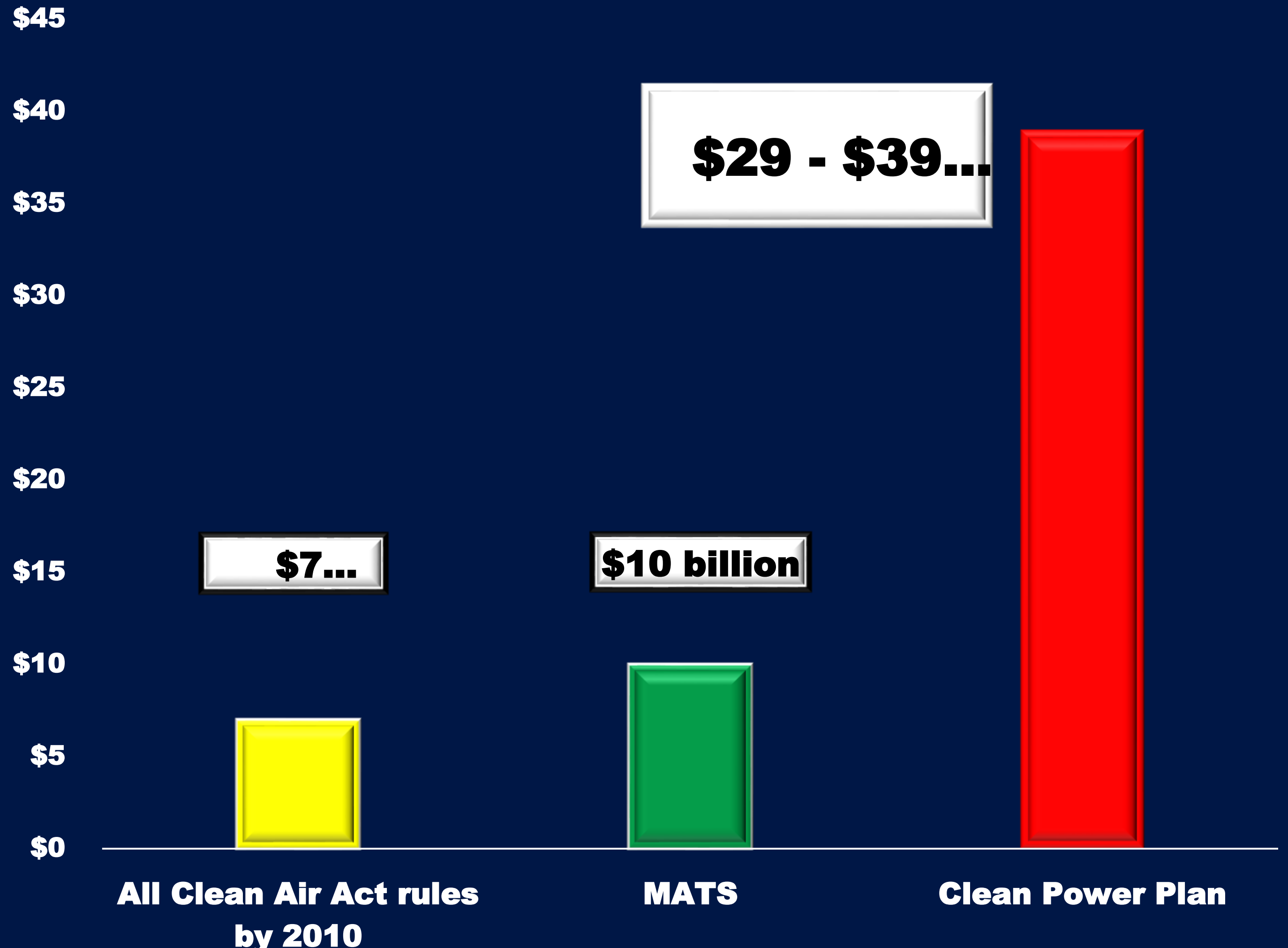
FATE OF THE POWER PLAN

SCOTUS stays Power Plan	February 9, 2016
D.C. Circuit decision	September 2016
Elections	November 8, 2016
New POTUS and Congress	January 2017
SCOTUS decision	June 2017 / 2018

SCOTUS STAY OF POWER PLAN

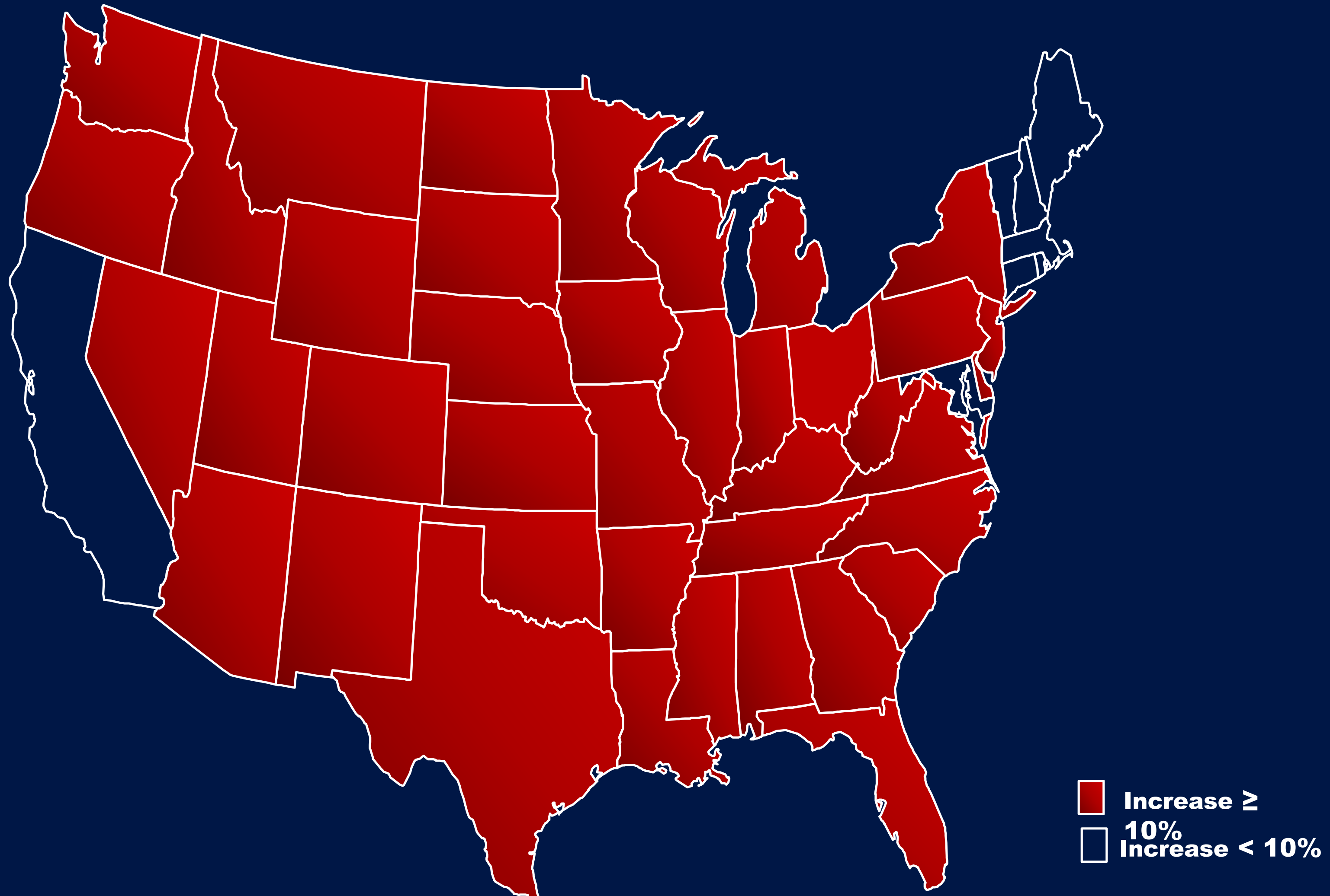
- Stay based on “fair prospect” that SCOTUS would overturn Power Plan, as well as two other criteria
- Five of nine justices supported the stay
- Stay remains in effect until SCOTUS makes final decision

Together, all of EPA's clean air rules for power plants cost less than $7 billion in 2010. MATS was projected to cost $10 billion per year. The Power Plan could cost as much as $39 billion per year.



Annual cost of all Clean Air Act rules for the electric power sector promulgated by 2010 from U.S. EPA, *The Benefits and Costs of the Clean Air Act from 1990 to 2020* (2011), Table 3-2. Electric utility direct annual compliance costs were $6.6 billion (2006$) in 2010; this is equivalent to $7.1 billion in 2010$. MATS annual cost from U.S. EPA, *Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards*, December 2011 ($9.6 billion cost in 2006$ is equivalent to $10 billion in 2010$.) Projected cost of Clean Power Plan from NERA analysis (2015$).

Electricity prices for 40 states could increase by 10% or more because of the Power Plan



EPA'S POWER PLAN WILL HAVE NO EFFECT ON CLIMATE CHANGE

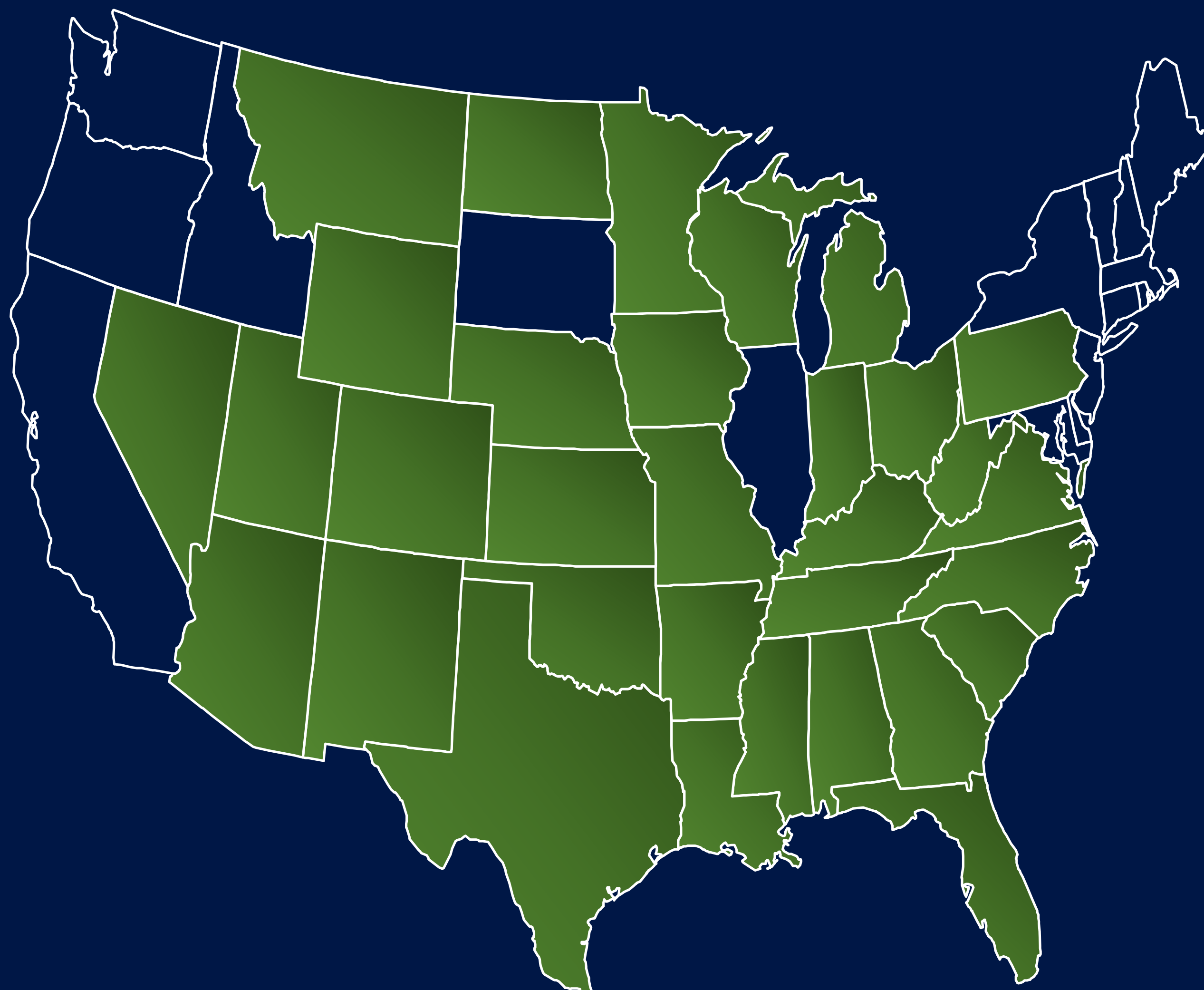
CO_2 concentrations will be reduced by 0.2%

Global average temperature rise will be reduced by 0.013°C (1/80th of a degree)

Sea level rise will be reduced by 0.2 millimeter (the thickness of two sheets of paper)

ACCCE, *"Climate Effects" of EPA's Final Clean Power Plan*, August 2015; Lomborg, Bjorn, "Impact of Current Climate Proposal," *Global Policy* (2015) doi: 10.1111/1758-5899.12295.

FAMILY ENERGY COSTS FOR 32 STATES



FAMILY ENERGY COSTS

Data on 32 states with 60% of all U.S. households.

Electricity is one of the largest energy expenditures for families.

Income of low- and middle-income families is small.

Energy costs are proportionally greater for families with lower incomes.

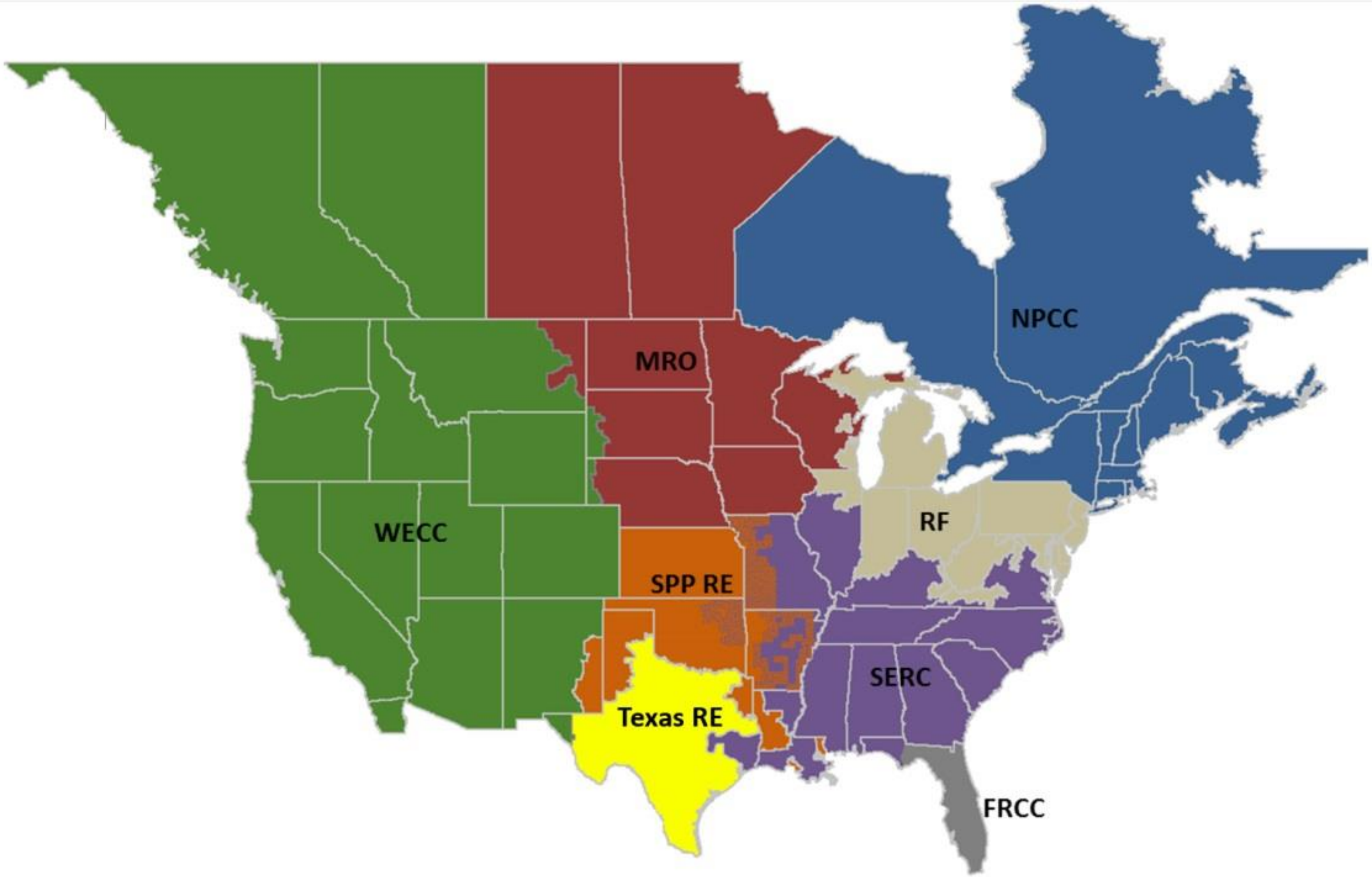
The myth of lower electricity bills under the Power Plan.

How Will NERC and the Regional Entities Help States Develop CPP Compliance Plans?

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Moderator:

Commissioner Asim Haque, Ohio


NPCC
MRO
RF
WECC
SPP RE
SERC
Texas RE
FRCC

Panelists

Gerry Cauley, President and CEO, NERC

Mike Kormos, Ex VP and COO, PJM

Scott Henry, President and CEO, SERC

Clair Moeller, Ex VP, MISO

Jim Robb, CEO, WECC