PATHWAY TO LOW-CARBON LIGNITE UTILIZATION –

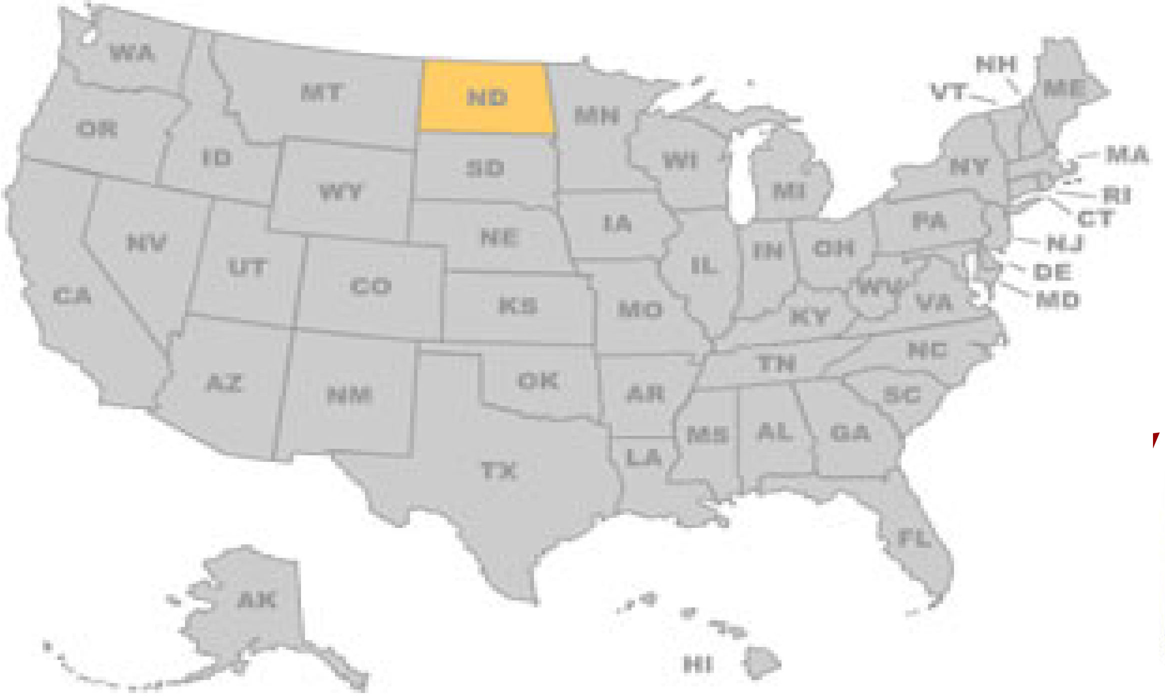
A PARTNERSHIP OF RESOURCE OWNERS/ DEVELOPERS, ENERGY PRODUCERS, STATE AND FEDERAL GOVERNMENT, TECHNOLOGY DEVELOPERS, AND RESEARCH PROVIDERS

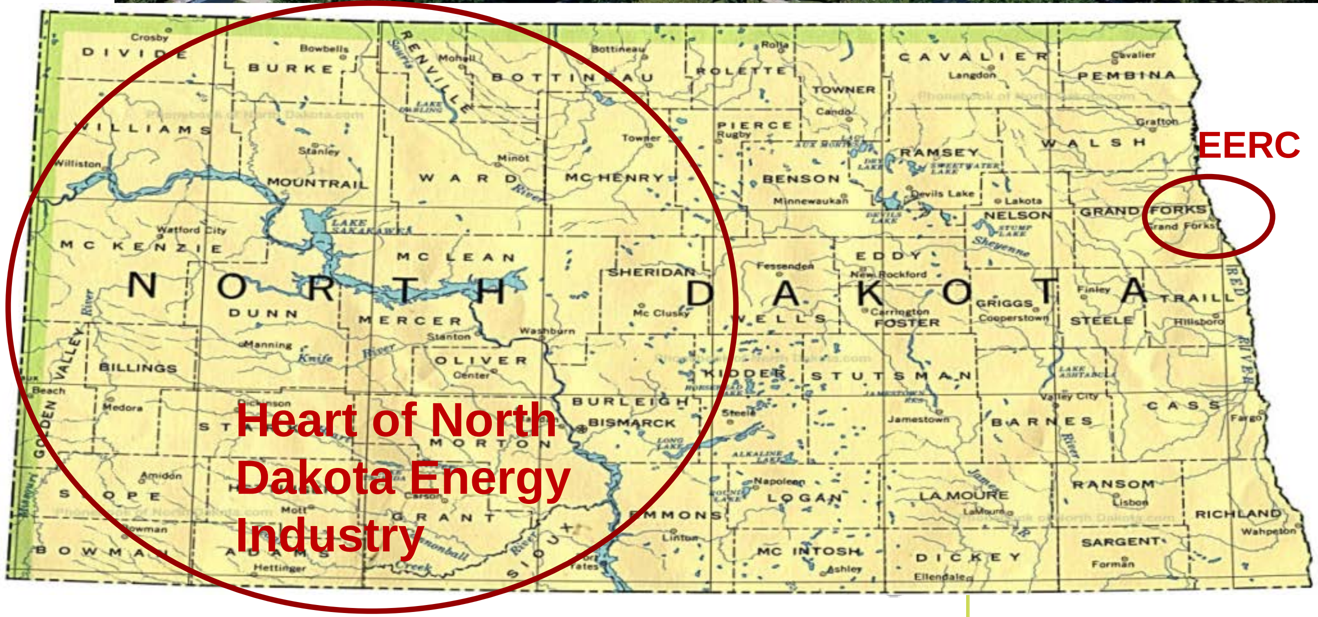
Tom Erickson
CEO

Critical Challenges. Practical Solutions.

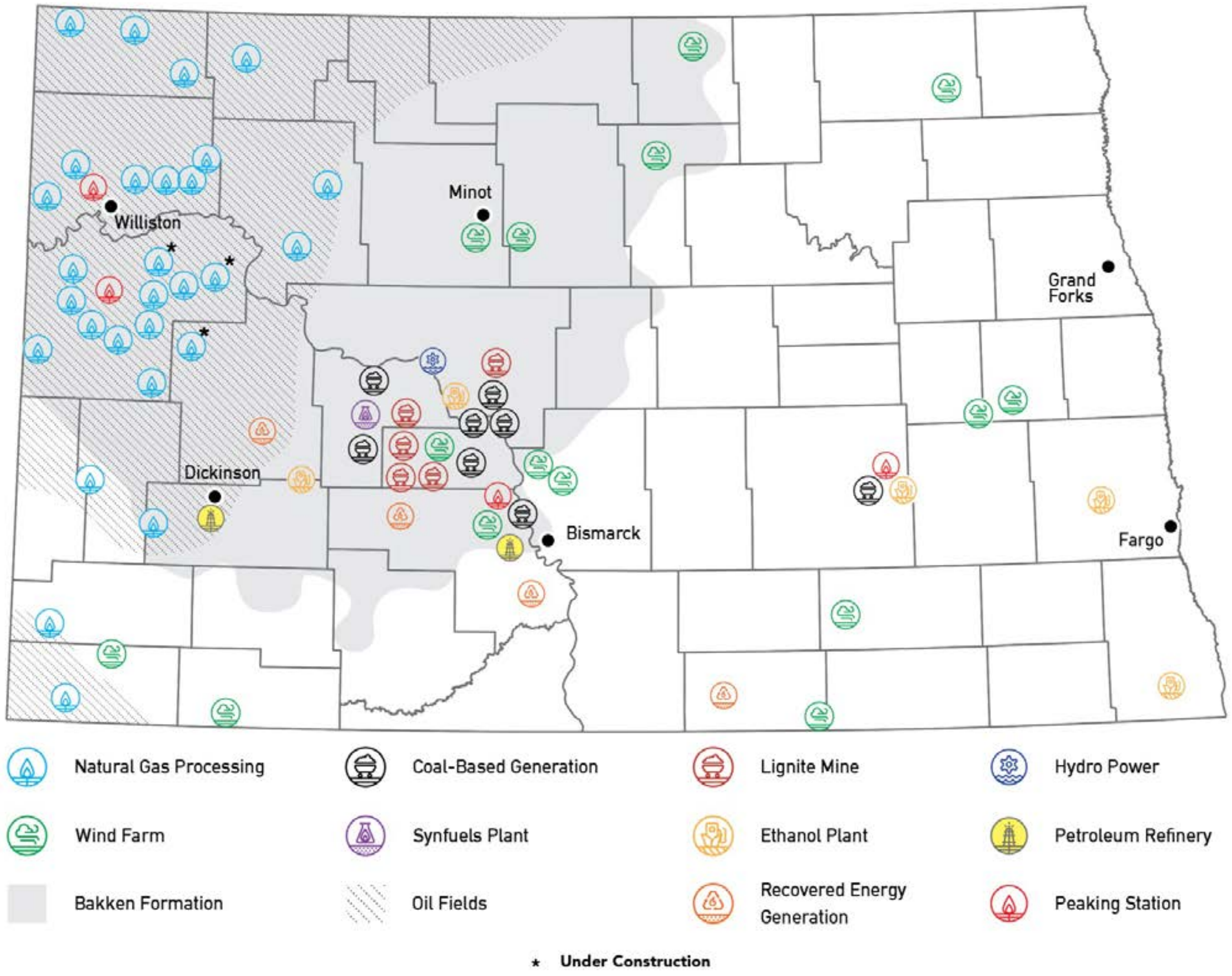
ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

- Branch of the UNIVERSITY OF NORTH DAKOTA focused on energy and environmental solutions for over 1300 clients in 52 countires.





NORTH DAKOTA ENERGY SITES

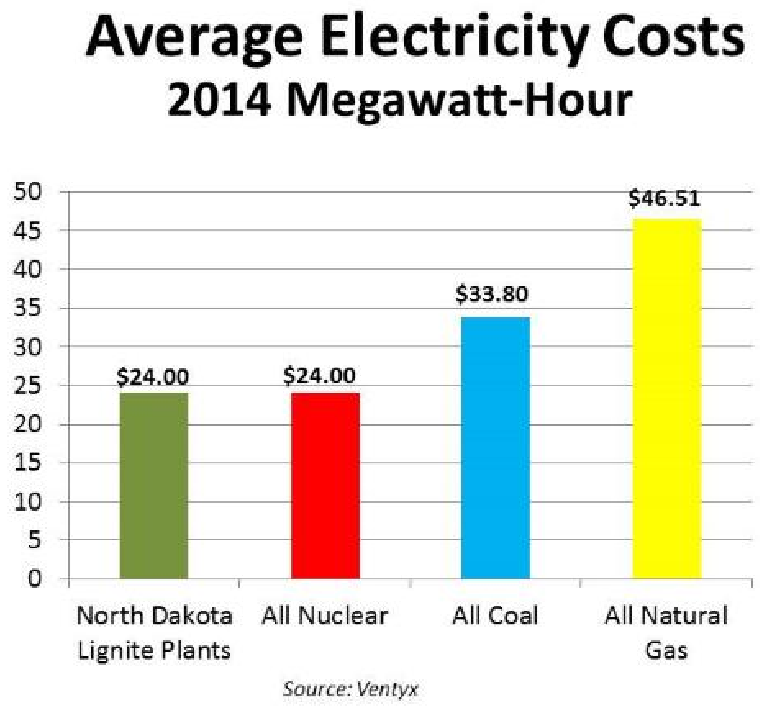


Map from: *Spotlight on North Dakota Energy 2015*.

- Sixth largest energy producer in the United States
- Largest U.S. producer of nine agricultural commodities
- Less than 1% of the U.S. population (approx. 750,000)

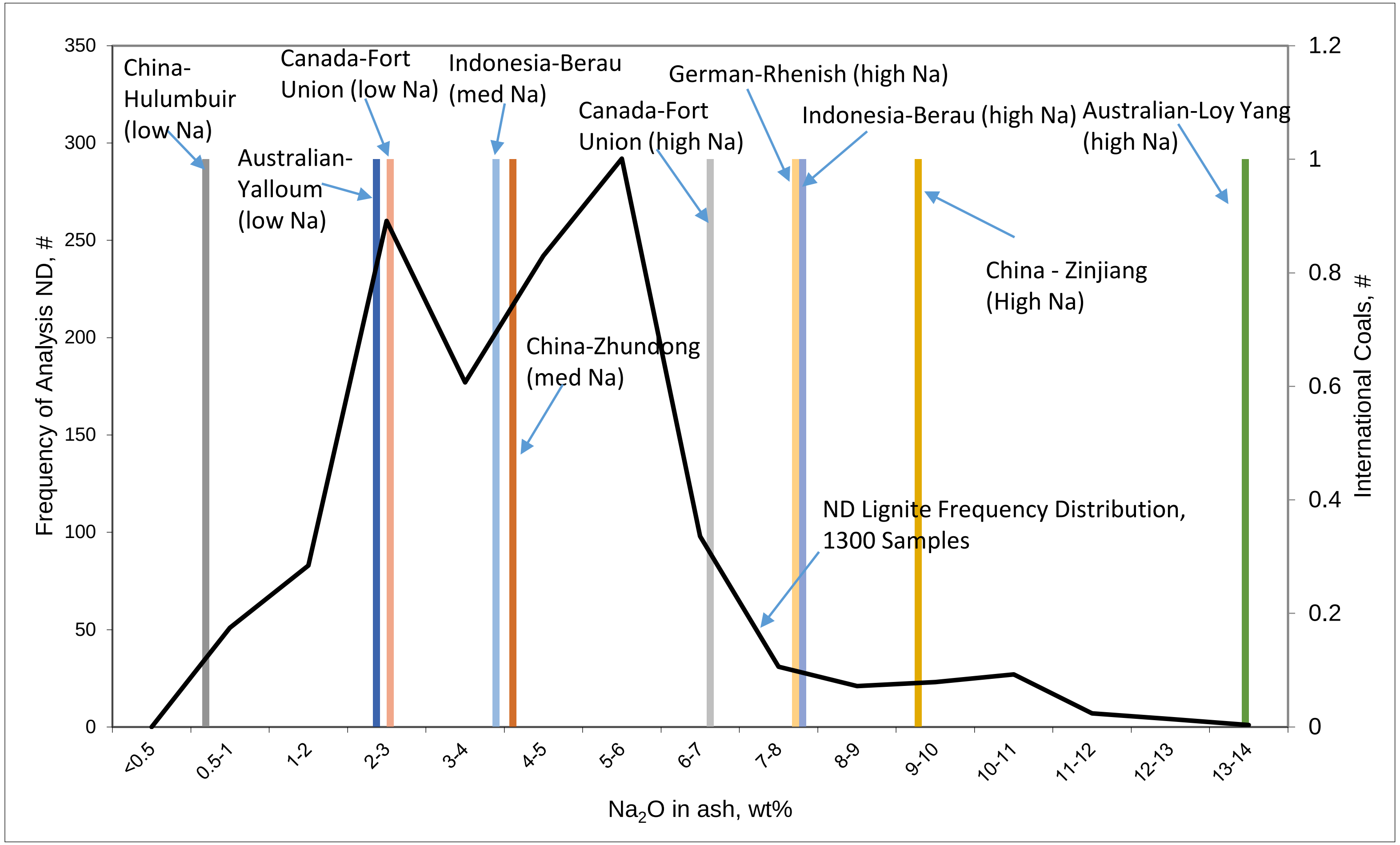
ABOUT NORTH DAKOTA LIGNITE

- Low-rank/brown coal
- High sodium, high moisture
- 800-year supply in North Dakota at current rate of consumption
- Minemouth operations
- High reliability, low costs

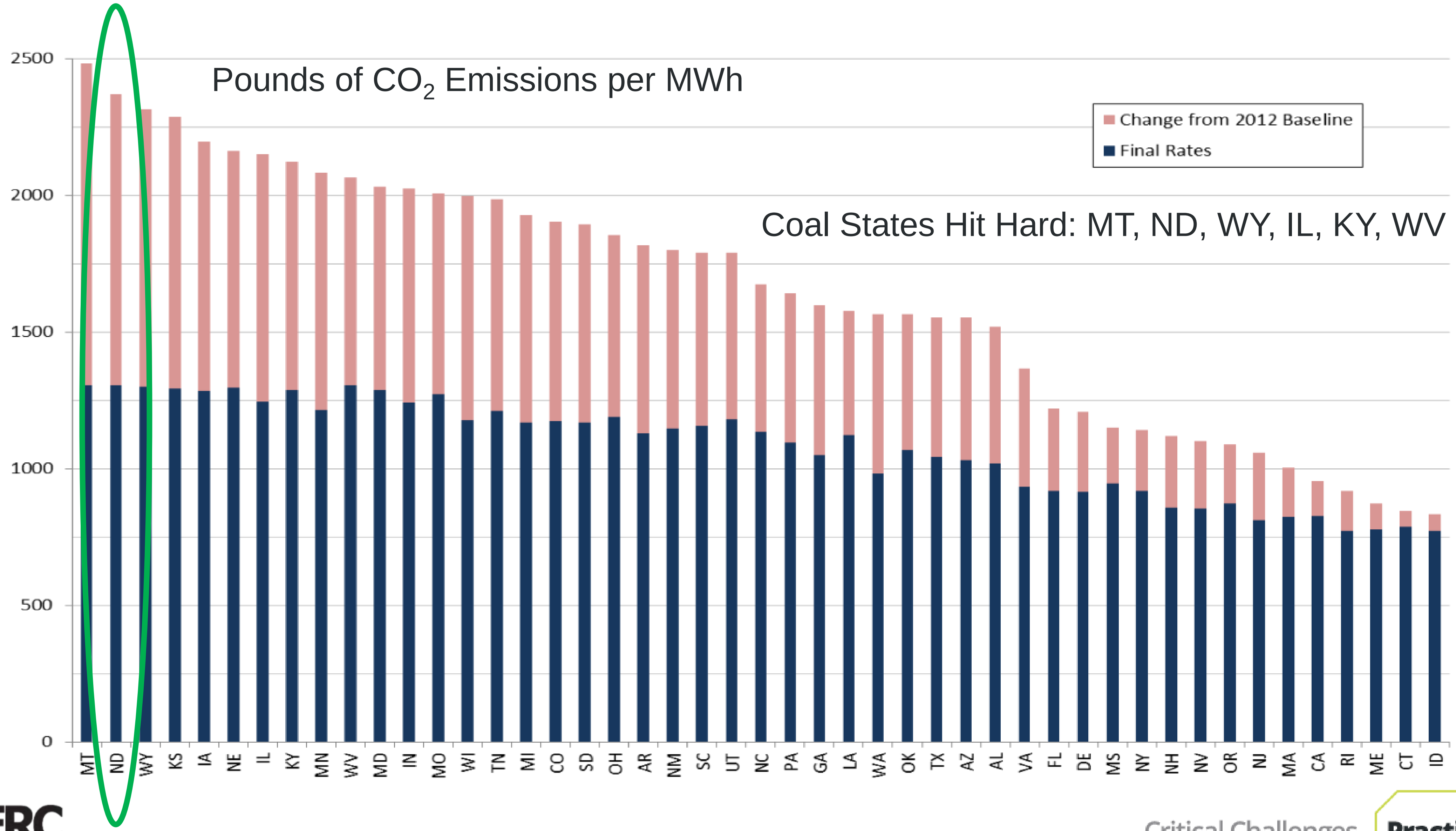


Critical Challenges. Practical Solutions.

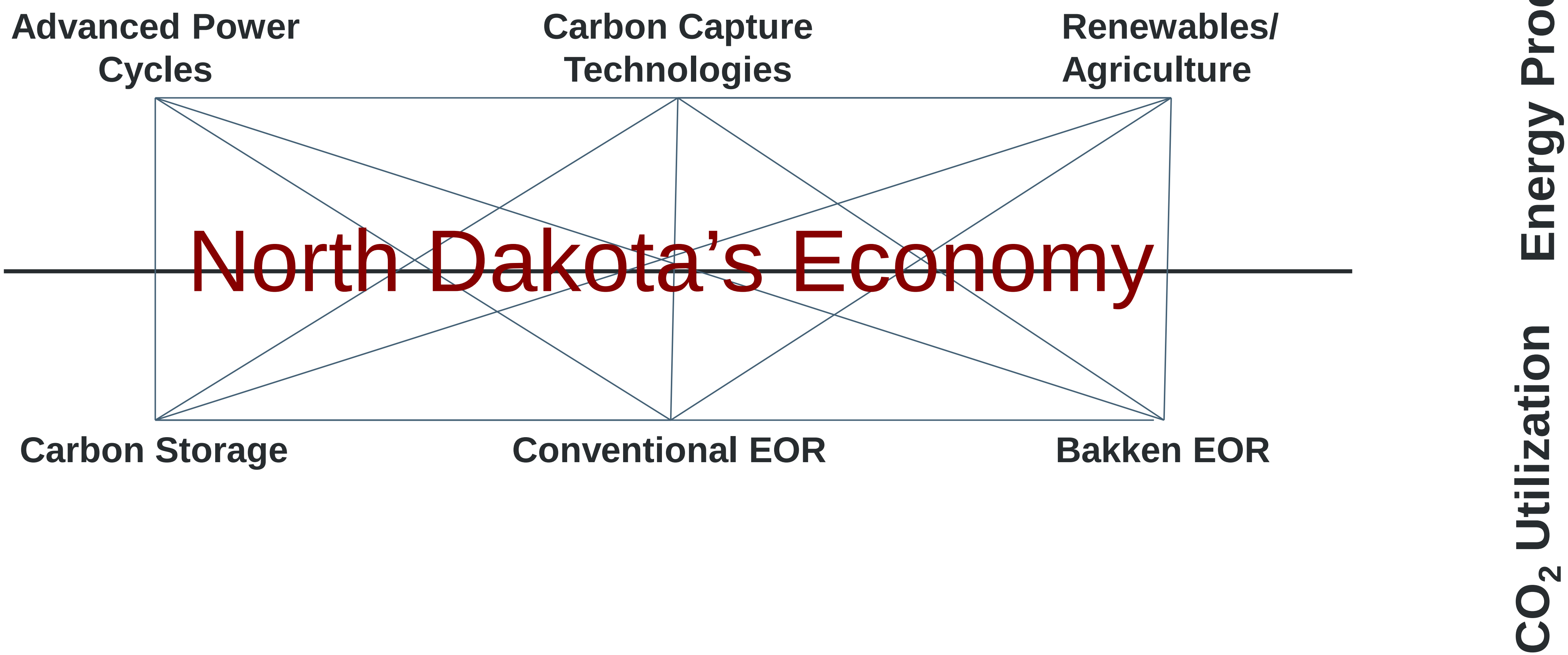
NORTH DAKOTA LIGNITE HAS SIMILAR PROPERTIES TO MANY OTHER COALS FROM AROUND THE WORLD



STATE-SPECIFIC EMISSION RATE TARGETS



LOWERING THE CARBON INTENSITY – STRENGTHENING NORTH DAKOTA'S ECONOMY



LOWERING THE CARBON INTENSITY – STRENGTHENING NORTH DAKOTA'S ECONOMY – FIELD/DEMONSTRATION PROGRAMS

Advanced Power Cycles

- Allam

Renewables/ ...culture

...l CCUS

Carb...

- PCO...

...Studies

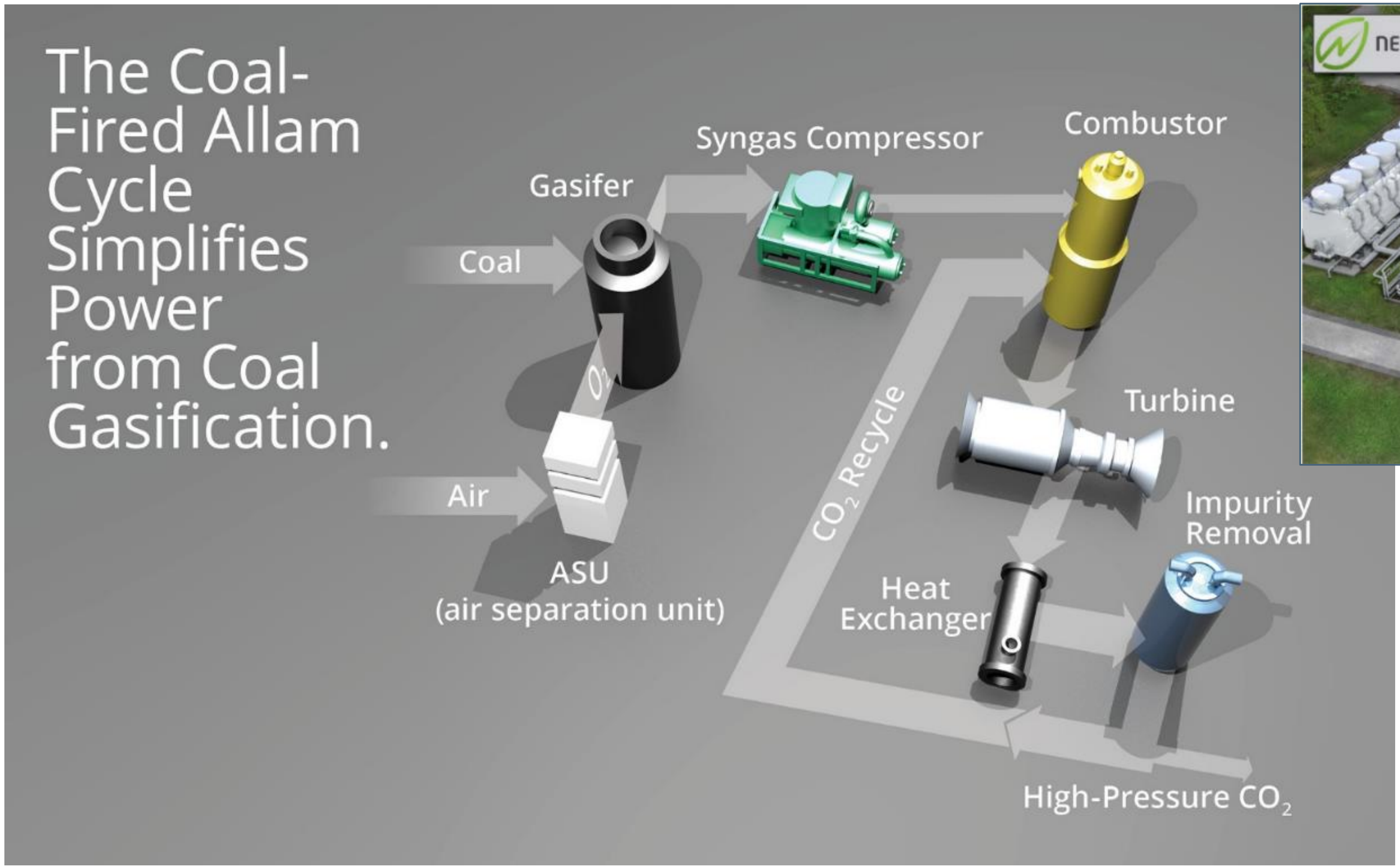
Research

Plains CO_2 Reduction Partnership
Plains Carbon Capture Consortium
Bakken Production Optimization Program
Intelligent Monitoring Program
North Dakota Coal in Advanced Power Systems
Brine Extraction …
Fine Aerosols in Carbon Capture Systems
System Integration Studies

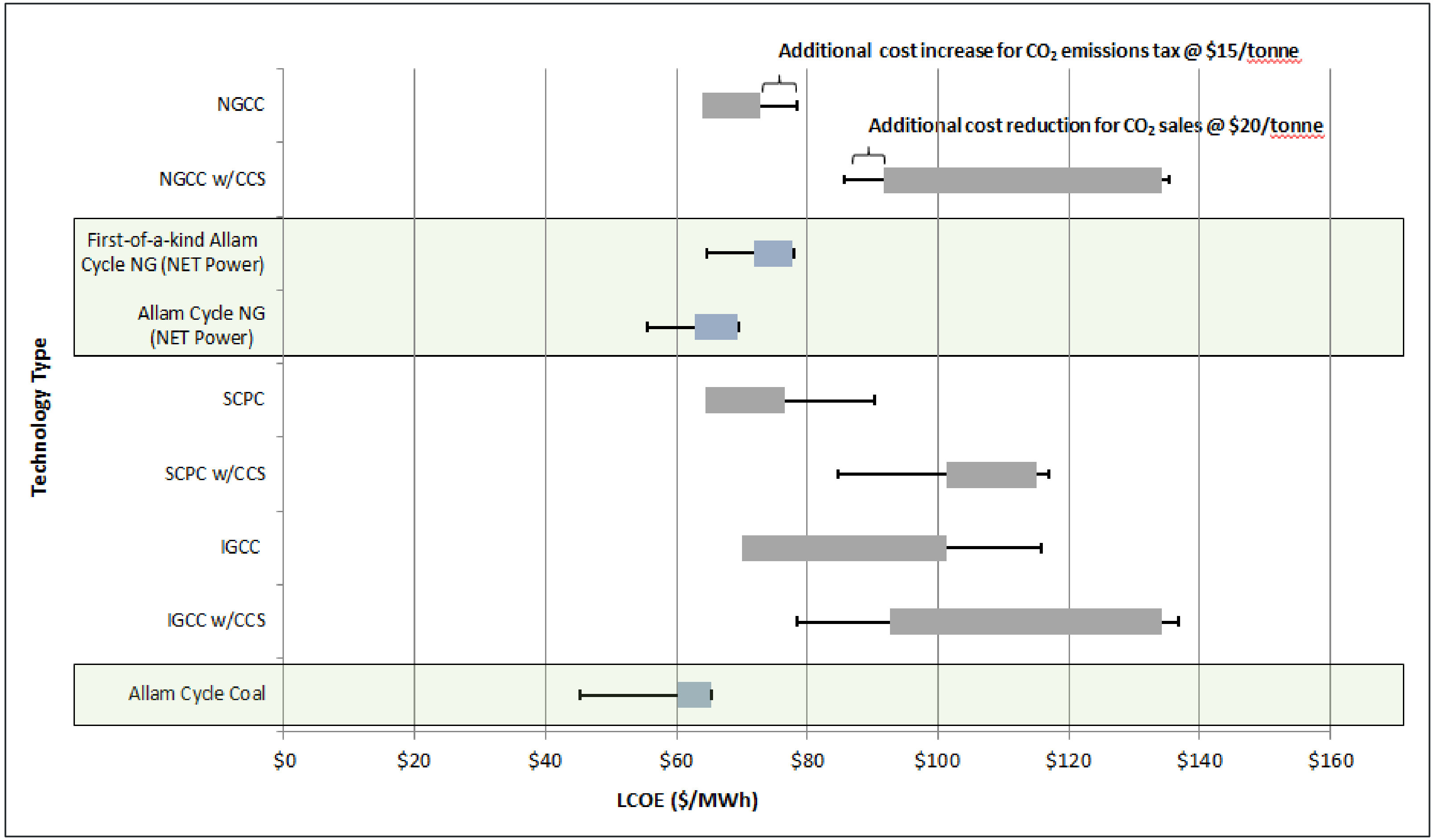
Energy Production

CO_2 Utilization

ADVANCED POWER CYCLES – ALLAM CYCLE



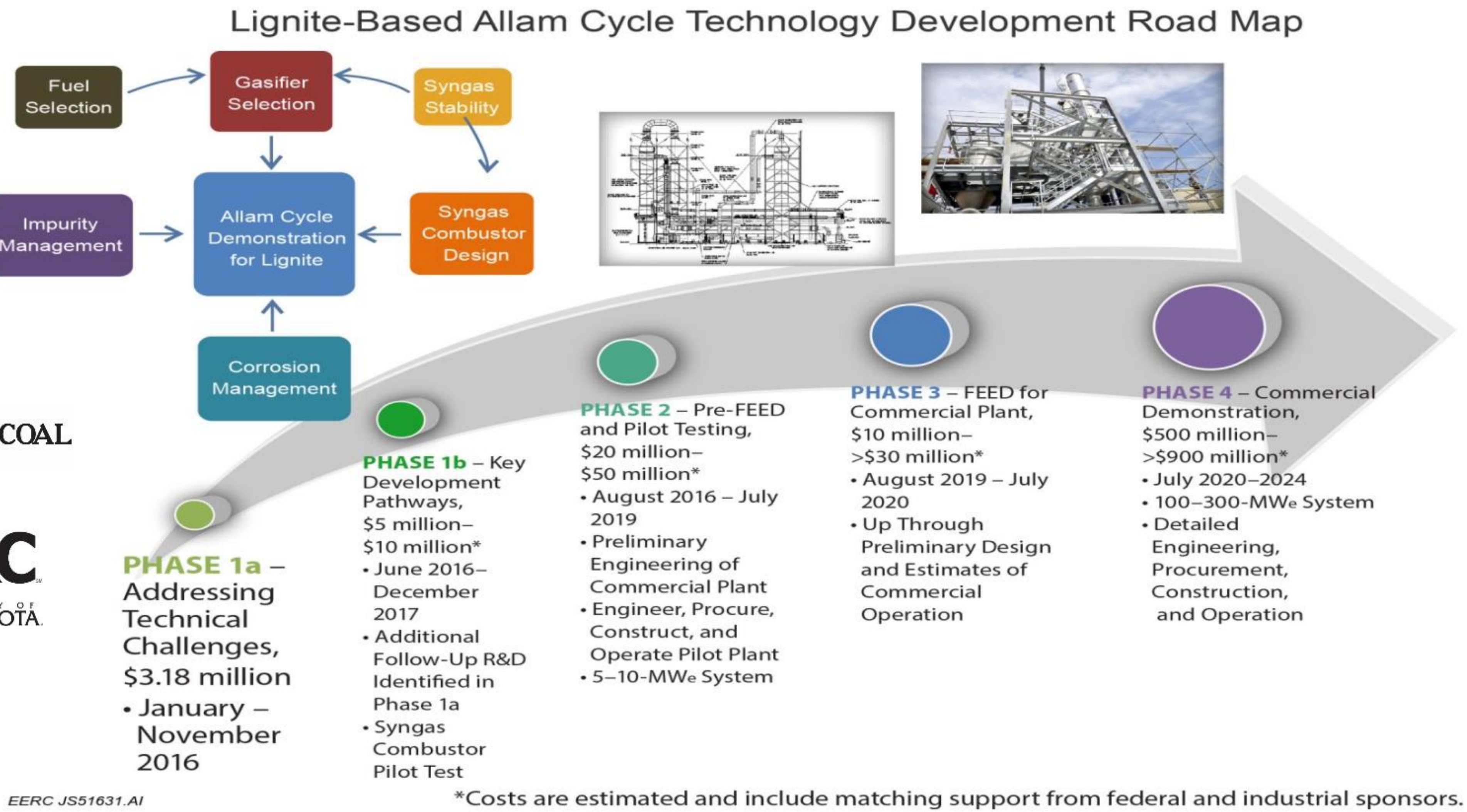
ALLAM CYCLE ACHIEVES CLEAN, LOW-COST ELECTRICITY COMPETITIVE WITH ALL STATE-OF-THE-ART SYSTEMS



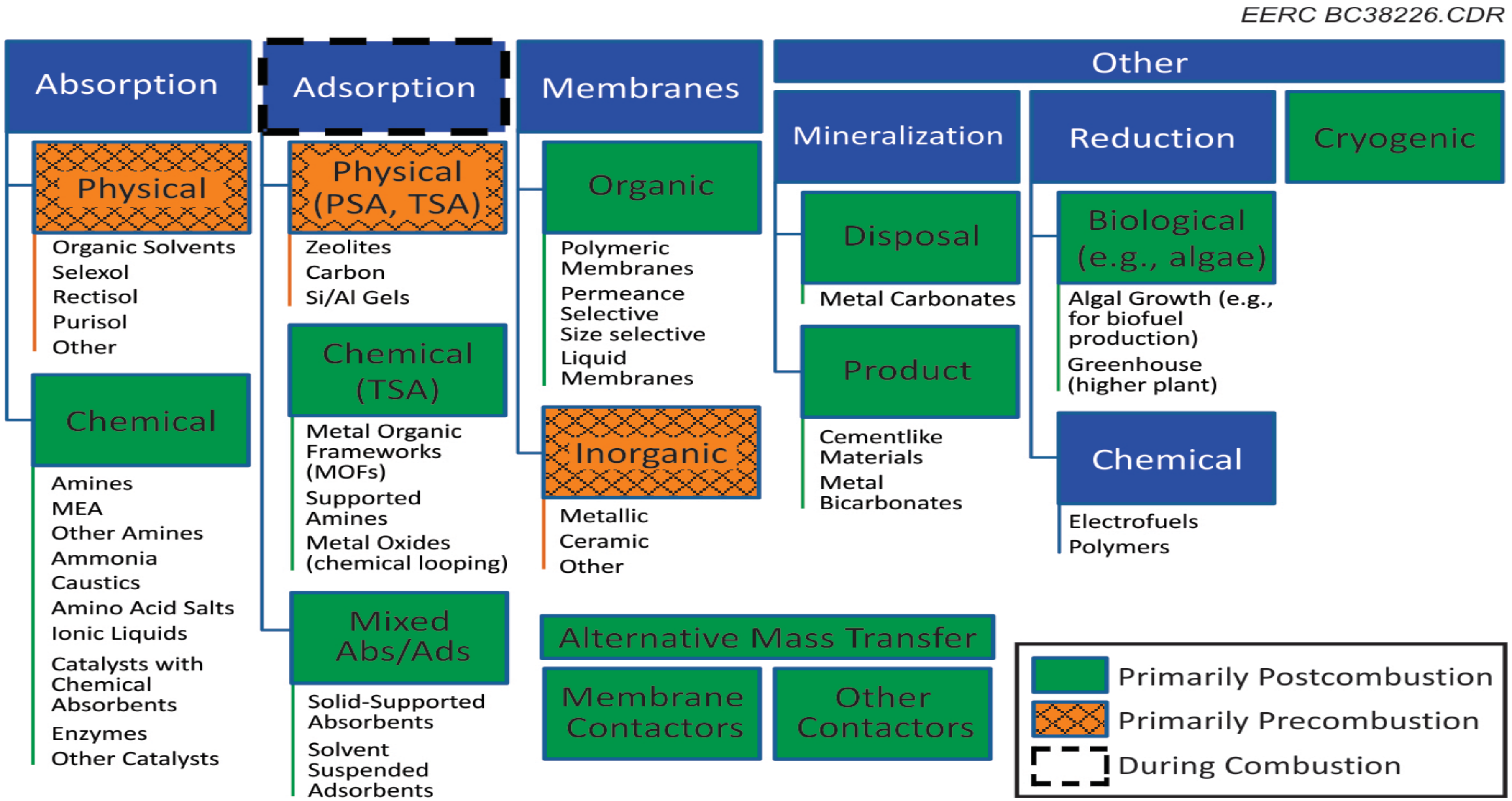
Note:

- LCOE calculated using EPRI methodology.
- Assumes $6.50/MMBtu natural gas and $2.00/MMBtu coal.
- Cost ranges represent data from several sources: EIA (2013), Parsons Brinkerhoff (2013), NETL (2012), Black & Veatch (2012).

PATHWAY TO LOW-CARBON LIGNITE UTILIZATION



CARBON CAPTURE TECHNOLOGY CATEGORIES



Source: Cowan, R.M.; Jensen, M.D.; Pei, P.; Steadman, E.N.; Harju, J.A. Current Status of CO_2 Capture Technology Development and Application; Plains CO_2 Reduction (PCOR) Partnership Phase III Value-Added Report for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-05NT42592; EERC Publication 2011-EERC-03-08; Energy & Environmental Research Center: Grand Forks, North Dakota, Jan 2011.

PARTNERSHIP FOR CO_2 CAPTURE (PCO_2C) PROGRAM

PCO_2C Partners Phases I & II

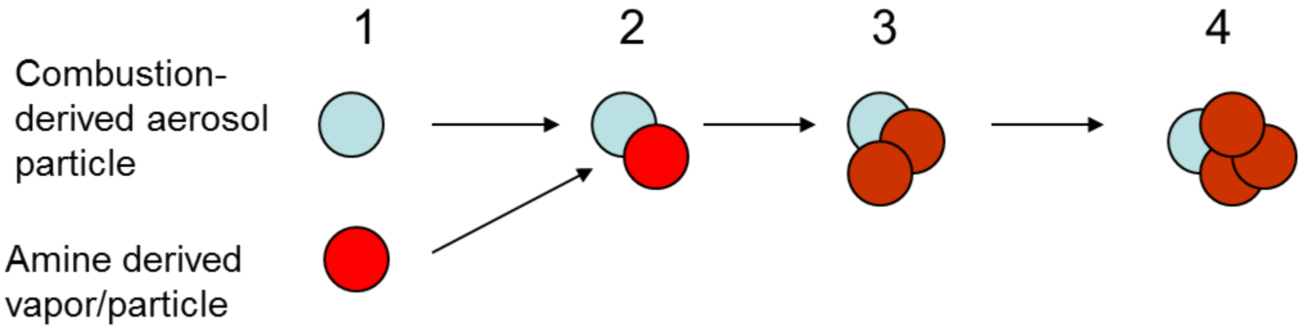
EERC UND North Dakota · NETL · Arthur J. Gallagher & Co. · ATCO Power · Avista · Baker Hughes · Basin Electric Power Cooperative · Black & Veatch · bp · Cansolv · Chevron · ConocoPhillips · Constellation Energy · C-QUEST · eni · GE · Hitachi Inspire the Next · Huntsman · Lignite Energy Council · metso Expect results · Midwest Generation · minnesota power · Nebraska Public Power District · Industrial Commission of North Dakota Lignite Research, Development and Marketing Program · NorthWestern Energy · PacifiCorp · BR Petrobras · Portland General Electric · ppl · PSE Puget Sound Energy · SaskPower · Shell Canada Limited · State of Wyoming Clean Coal Technology Fund · Sulzer · Suncor Energy · TransAlta

PCO_2C Partners Phase III

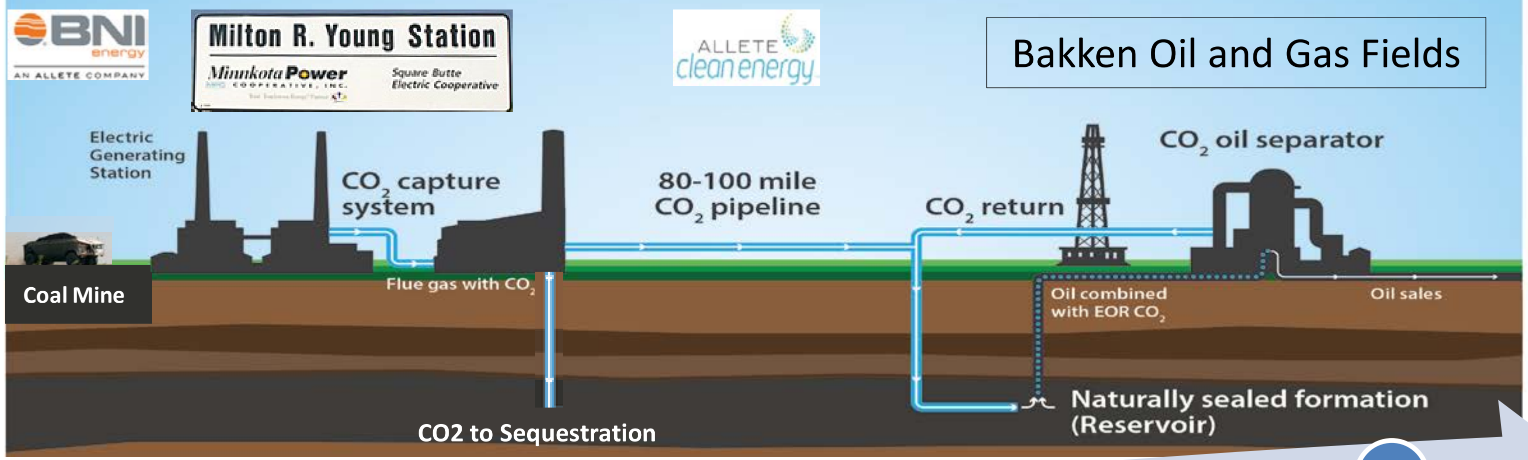
EERC UND North Dakota · NETL · Basin Electric Power Cooperative · CO_2 Solutions · KCRC · MPU · Nebraska Public Power District · Industrial Commission of North Dakota Lignite Research, Development and Marketing Program · ppl · Shell Canada Limited · Tri-Mer Corporation

AEROSOL ISSUES FOR CARBON CAPTURE

- Very small particle derived from fuel impurities (Flagan, 1988)
- Growth of aerosol in the CO_2 capture system – resulting in lost solvent and emissions



Utility Industry Carbon Solutions – Project Tundra



Project Tundra Road Map

Time Line and Cost Estimate	2015–2016	2016–2017	2017–2018	2018–2019	2020–2022
	Key Technology Improvements Addressing the key technical challenges from recent projects to improve efficiency and performance.	**Tundra Design – Gen 2.0 Project** Advance technology: Scale up and broaden design and its application for industry. Federal and state funding and tax credit support.	**CO_2 for EOR and Sequestration** Identify locations and partners; design and test sequestration; permit corridor for CO_2 pipeline and infrastructure for EOR and sequestration.	**Pre-FEED and FEED & Pilot Testing** FEED for full project and agreements for offtake and sequestration. Pilot testing at MR Young Station. Finalize federal and state support.	**Commercial Application** Detailed engineering, procurement, & construction. Operation and affirmation of capture, EOR, and sequestration solutions for industry.
	$1 million	$5 million	$50 million	$100 million	$1.1 billion

August 2016

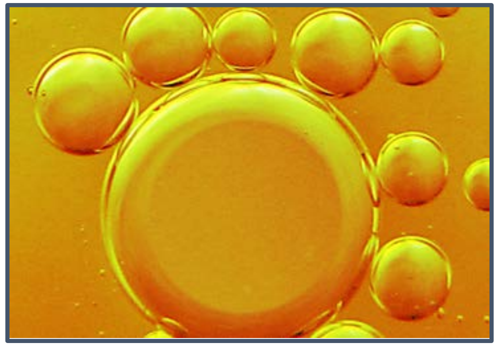
INTEGRATED CCS FOR NORTH DAKOTA ETHANOL PRODUCTION – RED TRAIL ENERGY

- Evolving ethanol markets are opening new opportunities.

- Objectives:
  - Determine technical and economic feasibility for ethanol carbon capture and storage (CCS)
  - Provide a preliminary implementation plan

Red Trail Energy

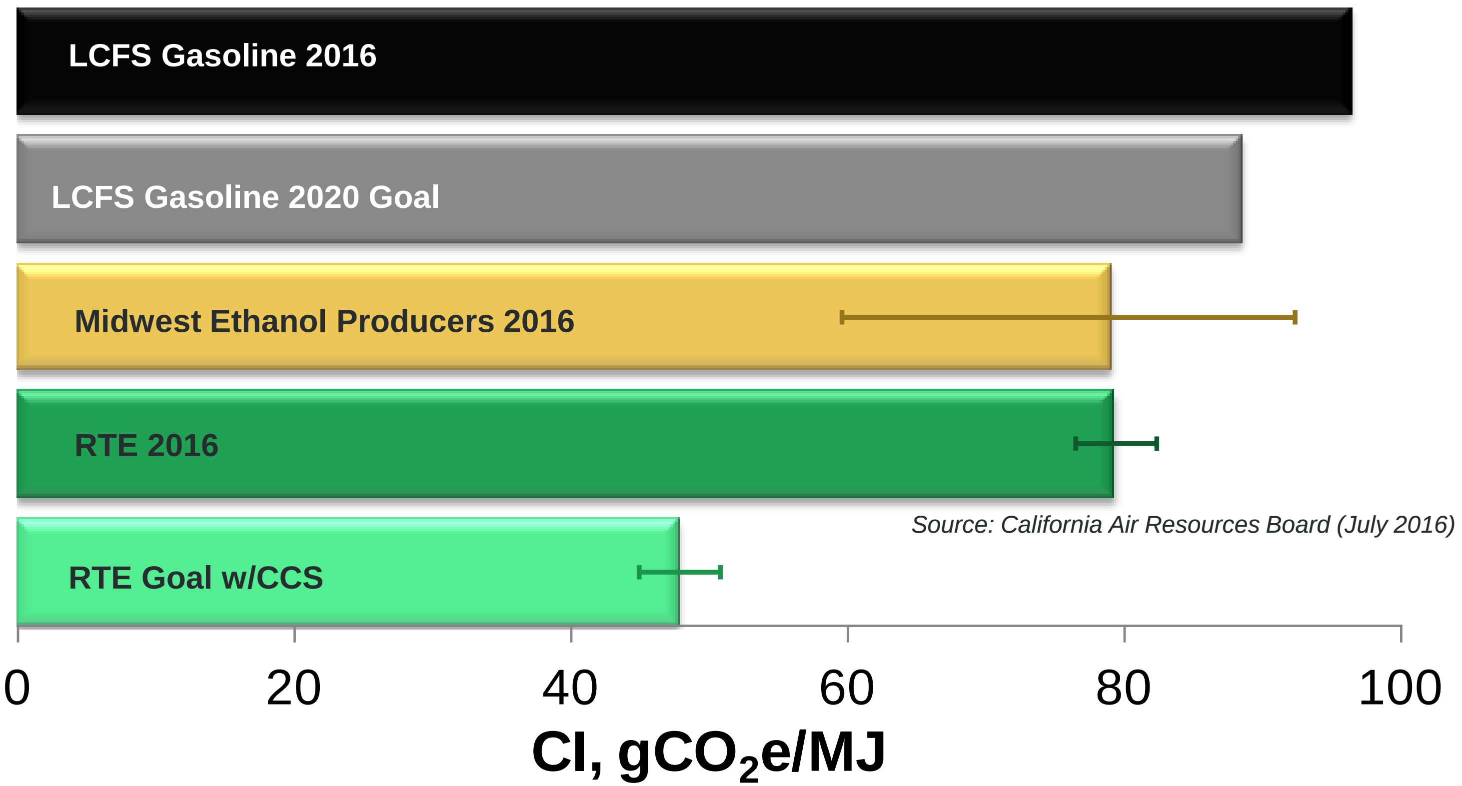
NORTH DAKOTA OIL AND GAS DIVISION



Photographs by OpenSource.com and Ishikawa Ken,

ETHANOL FUTURE WITH CCS

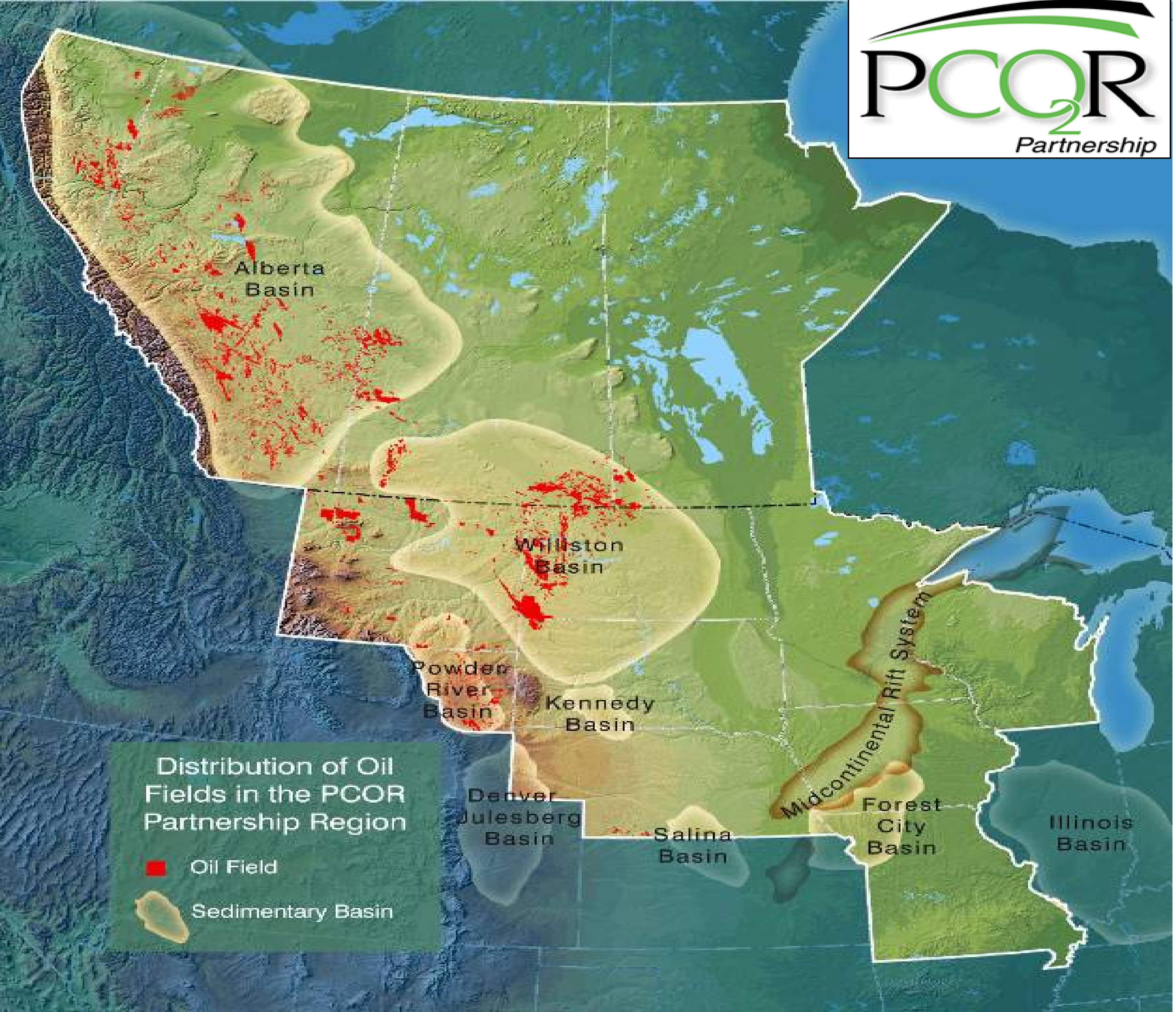
Current and Projected Carbon Intensity (CI) by Fuel Type



REGIONAL CO2 PARTNERSHIPS ACROSS NORTH AMERICA

PCOR PARTNERSHIP

PCOR Partnership 2003 – Present



Oil Fields

6000+ fields evaluated.

Fields in the Williston, Powder River, Denver–Julesberg, and Alberta Basins were evaluated.

Used two methods:
enhanced oil recovery (EOR) and volumetric

- **EOR approach:**
  Evaluated ~160 fields

  Sequestration capacity = 1 billion tons
  Incremental oil >3 billion bbl

- **Volumetric approach:**
  Thousands of fields, total capacity >10 billion tons

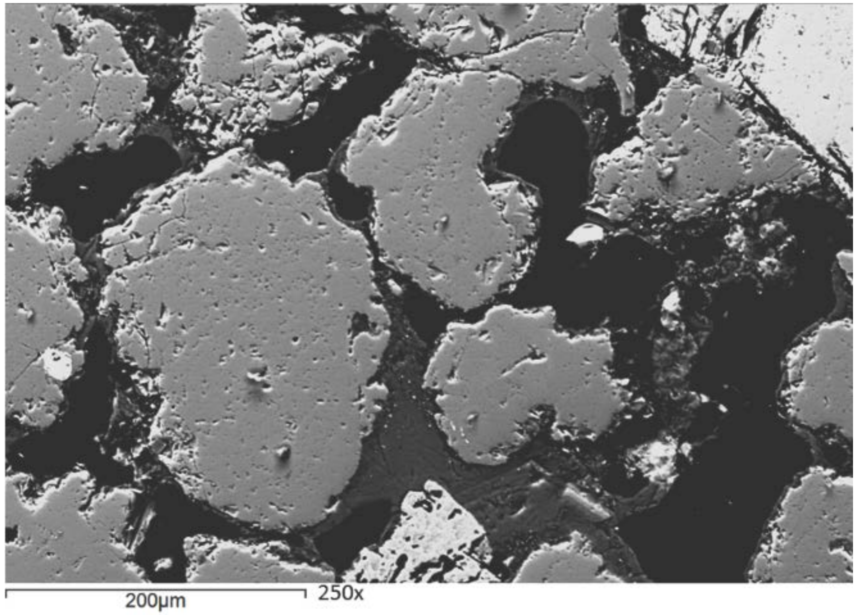

EERC
Energy & Environmental Research Center®
Putting Research into Practice
UNCONVENTIONAL LEADERSHIP FOR AN UNCONVENTIONAL RESOURCE
Bakken Production Optimization Program
• Resource characterization
• Site logistics
• Waste management
• Hydrocarbon utilization
• Water management
• Process optimization and systems analysis
Continental Resources
America's Oil Champion
Marathon Oil
North Dakota oil & gas research program
ConocoPhillips
OASIS PETROLEUM
Nuverra Environmental Solutions
WHITING
HITACHI Inspire the Next
HESS
SM ENERGY
XTO ENERGY
Bakken CO_2 Enhanced Oil Recovery and Storage Project
• Resource maximization
• Innovative reservoir characterization
• Fracture characterization and modeling
NETL
Continental Resources
Marathon Oil
BAKER HUGHES
CMG
KINDER MORGAN
Schlumberger
HESS
XTO ENERGY

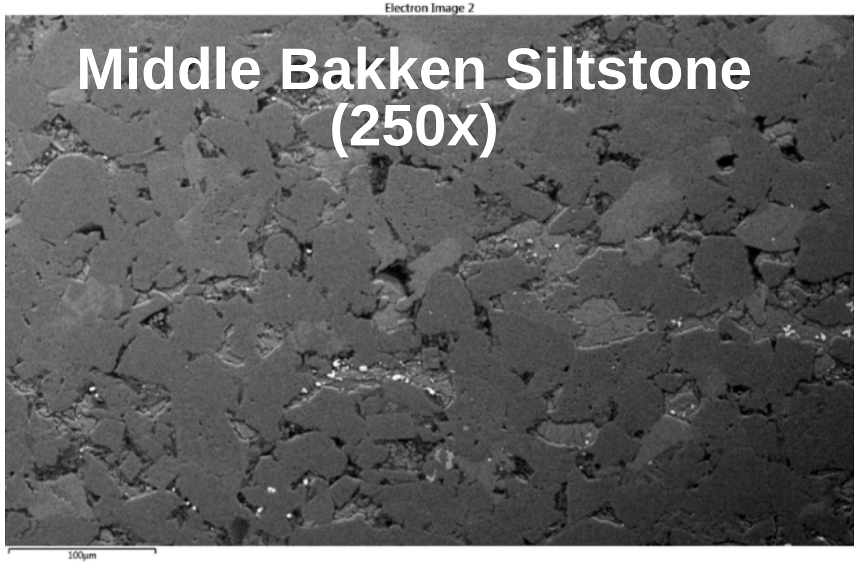
BAKKEN CO_2 DEMAND FOR NORTH DAKOTA – A 30,000-FT VIEW

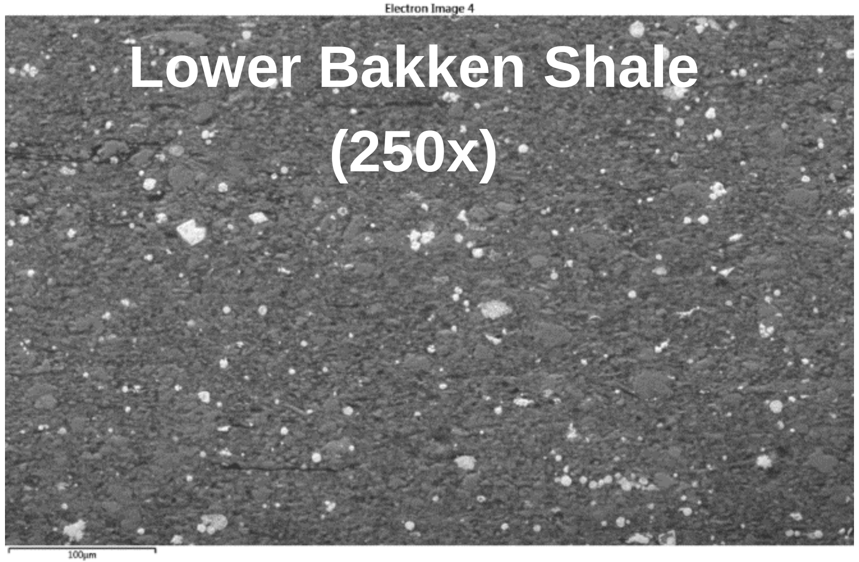
- Based on the following:
  - Traditional evaluation techniques
  - North Dakota Industrial Commission (NDIC) original-oil-in-place (OOIP) estimates
  - 4% incremental recovery
  - Net utilization of 5000 and 8000 ft^3/bbl
- 2–3.2 Bt of CO_2 needed, yielding 4–7 Bbbl of oil.
- North Dakota currently produces ~33 Mtpy of CO_2.
- Bakken growth is creating a projected increase in power demand.

CONVENTIONAL VS. TIGHT OIL RESERVOIR

Muddy Fm Sandstone (Bell Creek)
(250x)







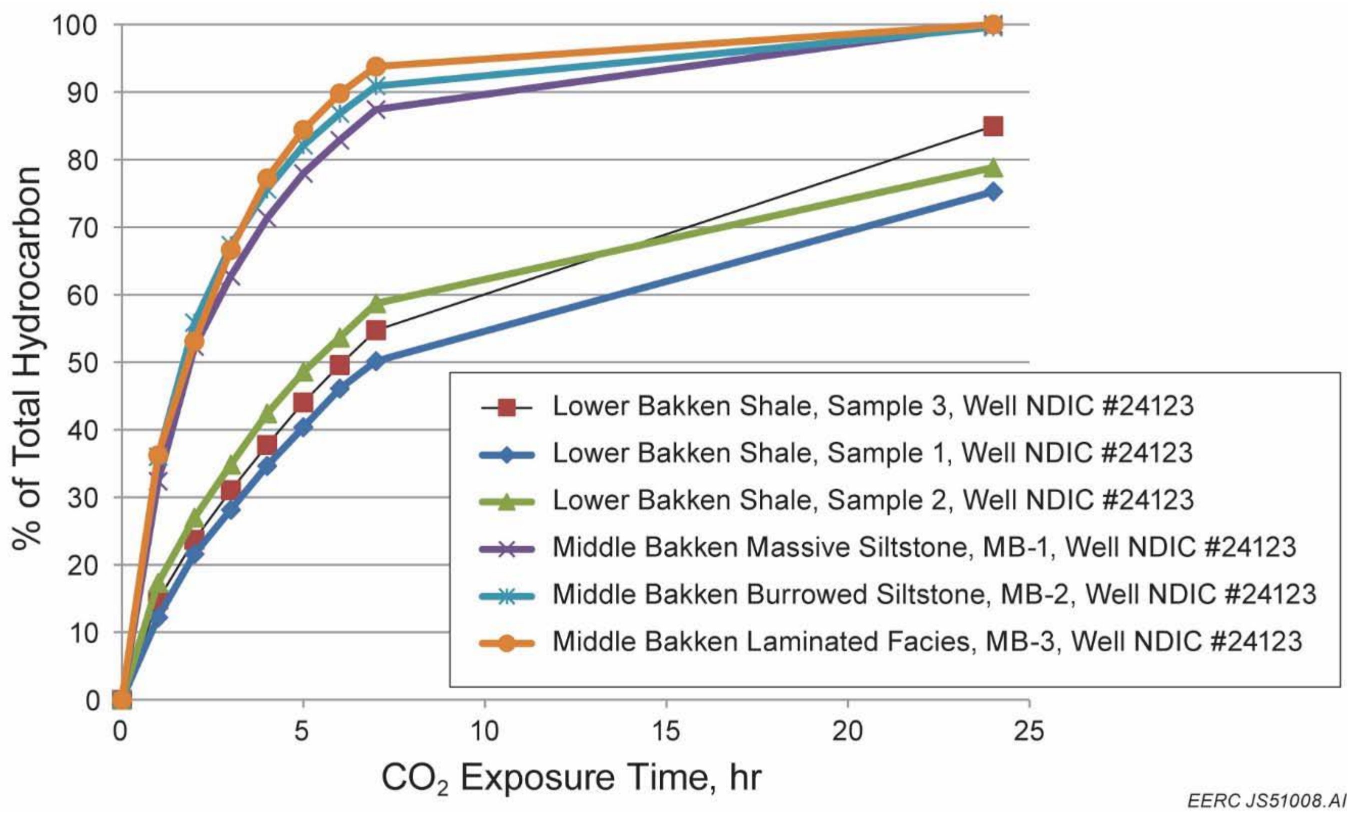
EERC

Practical Solutions.

LAB-SCALE CO_2 PERMEATION AND OIL RECOVERY FROM BAKKEN SHALES AND BAKKEN MIDDLE MEMBER SAMPLES

Oil can be recovered from Middle Bakken rock and Bakken Shales in the lab, but:

- Rates are *highly* dependent on exposed rock surface areas.
- Recoveries are *highly* dependent on long exposure times.



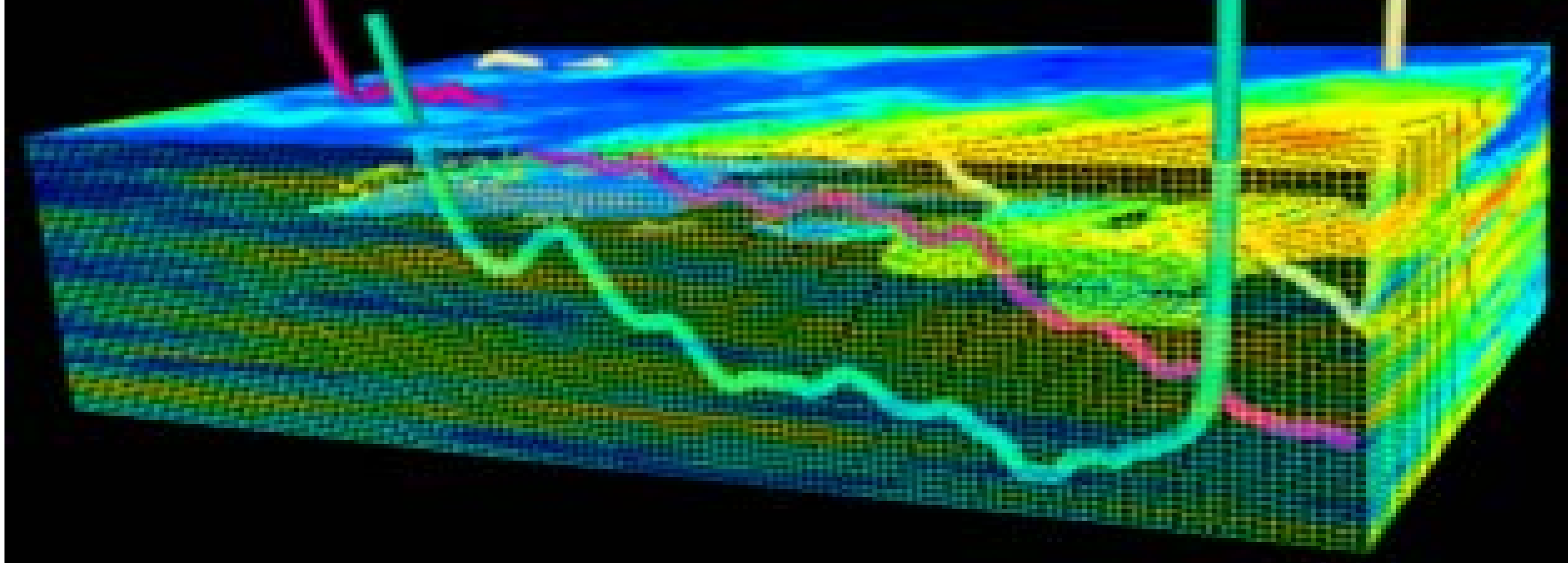
EERC JS51008.AI

DSU SIMULATION RESULTS HIGHLIGHTS

Simulated a variety of injection–production schemes.

Best cases showed significant improvement in total recovery factor (some over 100%).

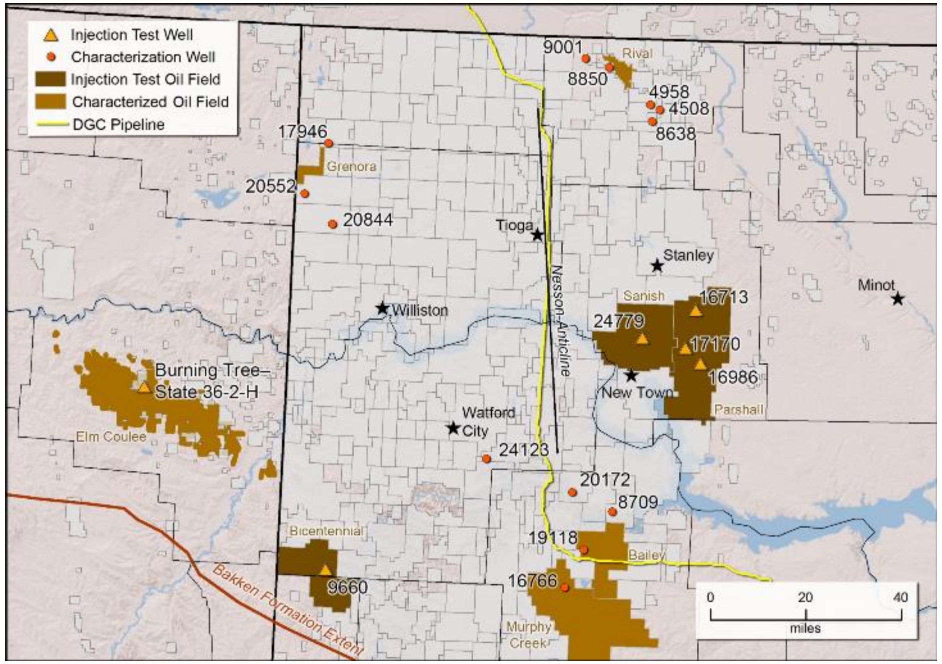
Production response is delayed compared to CO_2 EOR in a conventional reservoir, which is in line with what we see in the lab.



BAKKEN FIELD INJECTION TESTS TO DATE

- Lessons learned
  - Injectivity has been demonstrated.
  - Production responses have been observed, so fluid movement can be influenced.
  - But the improvements that have been predicted by models have NOT been observed.

- Clearly there are gaps between modeling and reality in the field.

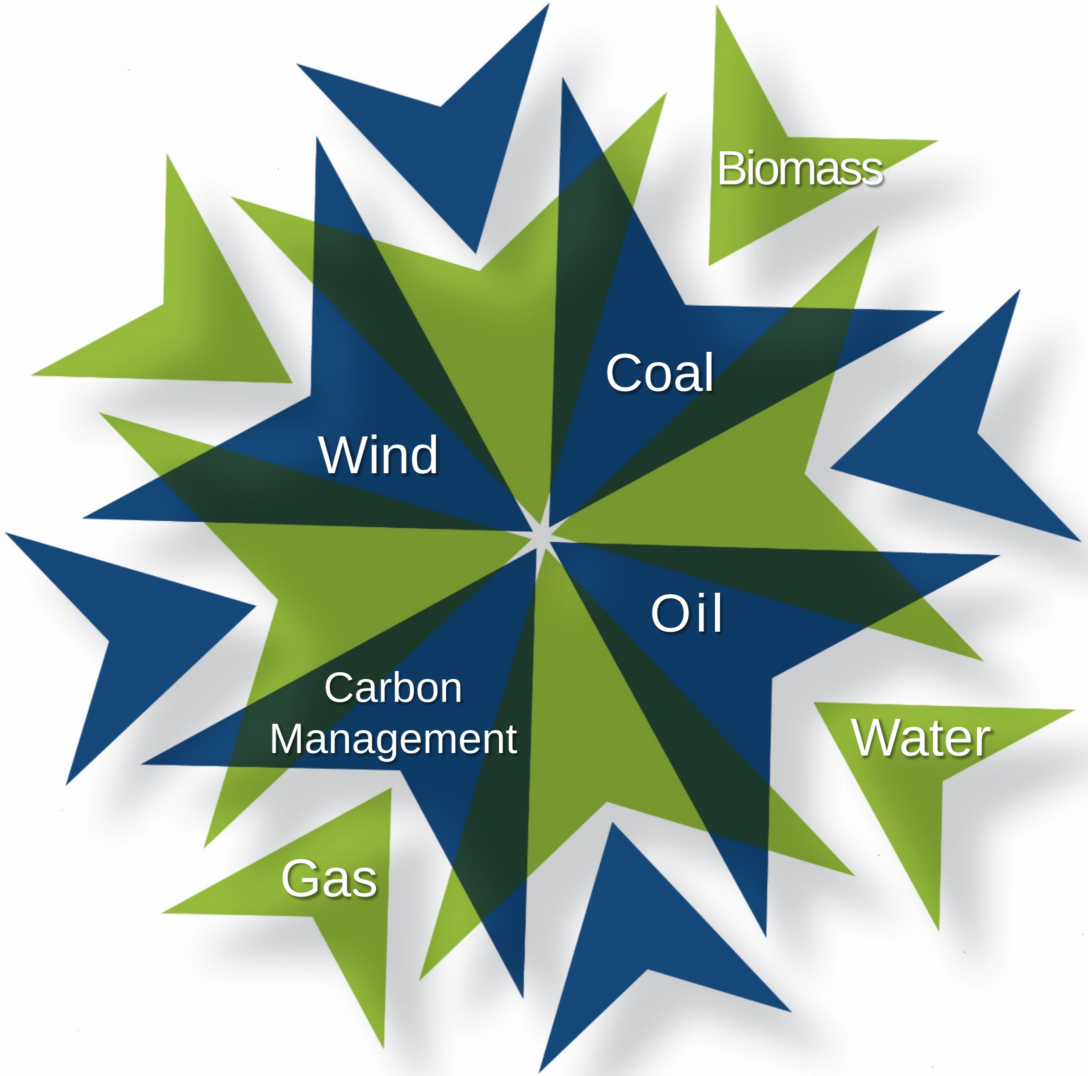


FIELD TEST OF CO_2 INJECTION INTO A BAKKEN RESERVOIR

- An existing vertical well will be used for the injection tests.
- Plan is to inject CO_2 into two distinct, separate zones: the Middle Bakken and the Lower Bakken Shale.
- EERC activities will include:
  - Analyzing reservoir fluids and pressure in different zones for evidence of changes in oil mobility.
  - Providing site-specific modeling support.
  - Designing and implementing an effective monitoring scheme to determine the fate of the injected CO_2 and its impact on the reservoir.

Photo from 2009 EERC CO_2 injection test into a conventional oil well in the Northwest McGregor field, North Dakota.

NORTH DAKOTA'S SOLUTION MUST FOCUS ON WORKING TOGETHER!



THANK YOU!

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