Additional Value Opportunities for Lignite

BCIA Carbon to Products Seminar

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Lignite Energy Council

Topics of Presentation

- Lignite Energy Council
- Background of the North Dakota Lignite Research Program
- Research Portfolio and Opportunities in North Dakota
- Additional Value Opportunities for Lignite Use

Lignite Energy Council (LEC)

- Lignite Energy Council
  - Trade association focused on lignite coal opportunities
  - Over 250 members including all major users and miners of lignite in northern half of the United States and Canada
  - Key activity is R&D related to "new" technology options for clean and efficient use of lignite under the Lignite Research Program of the North Dakota Industrial Commission

Work collaboratively with the Renewable Energy Council and the Oil & Gas Research Program

  - *Optimum use of regional resources for clean, efficient, low-cost reliable power while reducing the carbon footprint*
  - *Supply energy to regional residents and industry, while strengthening the economy through creation of jobs and affordable electricity.*

Research & Development Priorities for the LEC

- Support continued options to enhance performance of the existing fleet
- Invest in transformational research (Next generation of lignite conversion systems that integrate CO_2 capture)
- Focus on Carbon Capture Utilization & Storage (CCUS)
- Leverage international R&D breakthroughs
- Renewed Focus
  - Additional value propositions for lignite
  - Polygeneration opportunities

Historical Successes

- Thriving with high-sodium coal

Optimized operations and cleanability

- Addressing Hg and trace elements

Costs reduced by more than 20X

- Spiritwood – industrial complex
- Dryfining – coal upgrading
- Lignite mining, use, and reclamation advances through data, instrumentation & controls

To highlight a few

- Meeting regulations for primary pollutants

Addressing potential future NOx challenges

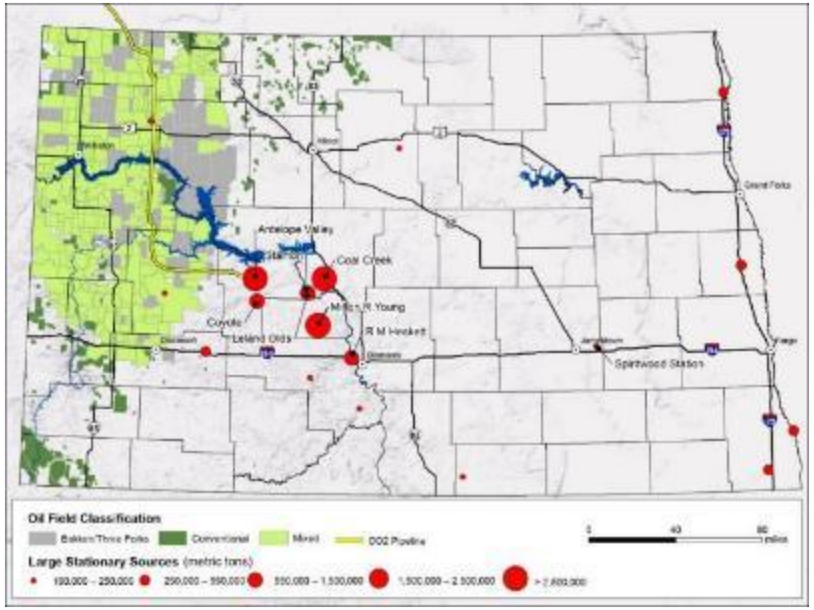
- Support of only US coal-to-synfuels plant

DGC adding urea to product suite

Basin Electric Antelope Valley Station and DGC Synfuels Plant
www.dakotagas.com

Much of the Recent Focus Has Been on Carbon Management - North Dakota is Ideally Suited

- North Dakota has an ideal situation for CO_2 management
  - CO_2 emission sources are in close proximity to CO_2 storage targets
  - Between 23 and 78 Gt of storage available within the state between saline formations and oil reservoirs



Bakken CO_2 Demand in North Dakota – A 30,000-ft View (EERC)

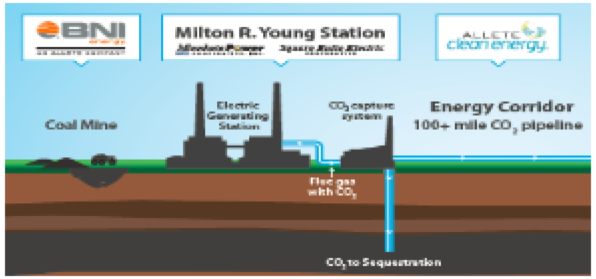
- Based on the following:
  - Traditional evaluation techniques
  - North Dakota Industrial Commission OOIP (original oil in place) estimates
  - 4% incremental recovery
  - Net utilization of 5000 and 8000 ft^3/bbl
- 2 to 3.2 billion tons of CO_2 needed
- Could represent 50 to 100 years of North Dakota's current CO_2 emissions from coal-fired power!

EERC

North Dakota Carbon Solutions Needs

Existing Plant Solutions

Project Tundra



CO_2 Utilization and Storage Solutions

PCOR and CarbonSAFE

EOR Partners

New/Replacement Solutions

Allam Cycle

Additional Value Opportunities for Lignite

- Current Commercial Uses
- Technology Developments

Coal Gasification for Fuels, Chemicals and Hydrogen

Lignite

Syngas
CO_2
Heat

Direct or Indirect Liquefaction

Liquid Fuels and Additives
Gasoline
Jet Fuel
Diesel

EOR

Nitrogen Fertilizers

Chemicals

Electricity

Great Plains Synfuels Plant

Figure from Basin Electric Power Cooperative Web Site – www.basinelectric.com/Energy_Resources/Gas/index.html

Current Commercial Example

- Producing natural gas (over 54 billion standard cubic feet/year) from coal since 1984.
- Produces a number of by-products, including CO_2 (40 billion standard cubic feet/year) that is piped to Saskatchewan and sold for EOR.
- New system would take advantage of technology advancements and separate out hydrogen product.

Coproduction

Over time the Great Plains Synfuels Plant added to the revenue stream by adding to a growing list of coproducts.

In addition to SNG products include:

- Ammonia Sulfate
- Anhydrous Ammonia
- Krypton and Xenon
- Liquid Nitrogen
- Dephenolized Crysilic Acid
- Naphtha
- Phenol
- Tar Oil
- Urea and Diesel Exhaust Fluid (DEF)
- Carbon Dioxide

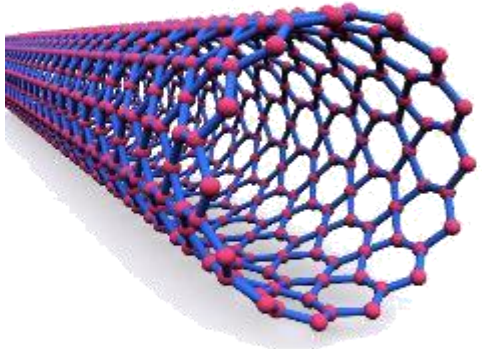
Over half of the annual revenue for the last two years reported has been from coproducts

Fertilizer

- Approximately 1 ton of ammonia (NH_3) can be produced from 1.5 tons of coal
  - Hydrogen from coal gasification, combined with nitrogen produces ammonia
  - Further processing of ammonia with coal-derived CO_2 produces urea fertilizer for easier handling and storage
- Developmental electrochemical processes may provide low-pressure, smaller scale alternative to traditional thermo-catalytic approaches

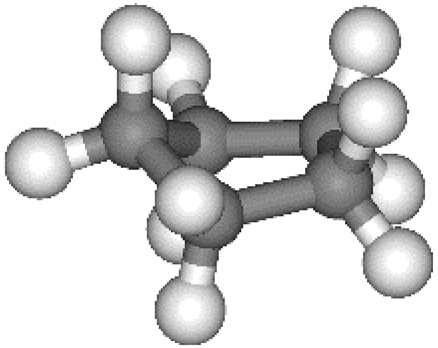
Carbon-based Products

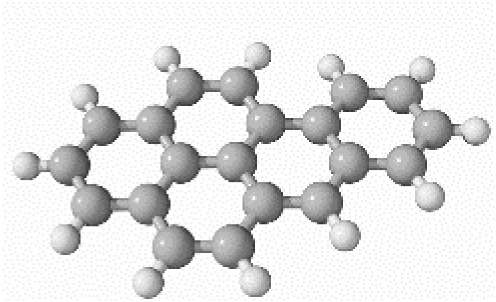
- Activated Carbon
  - Facility in final design stages in Valley City, North Dakota
- Carbon Black
  - Semi-continuous pilot unit at the EERC, proof-of-concept complete
- Carbon Fiber
  - Coal-derived pitch has unique properties
  - High value product with growing market
- Carbon Nanotubes and graphite
  - High value product with growing markets

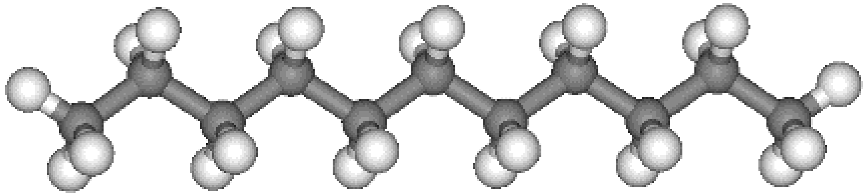


Hydrocarbon Production from Direct Coal Liquefaction

- Produces aromatic and cyclic hydrocarbons
  - complimentary paraffin hydrocarbons produced through gasification and gas-to-liquid processes
- One ton of coal can produce 100-120 gallons of hydrocarbon liquid
- High carbon conversion efficiency to fuel
- Technology development needed to optimize continuous operation and reduce capital expense

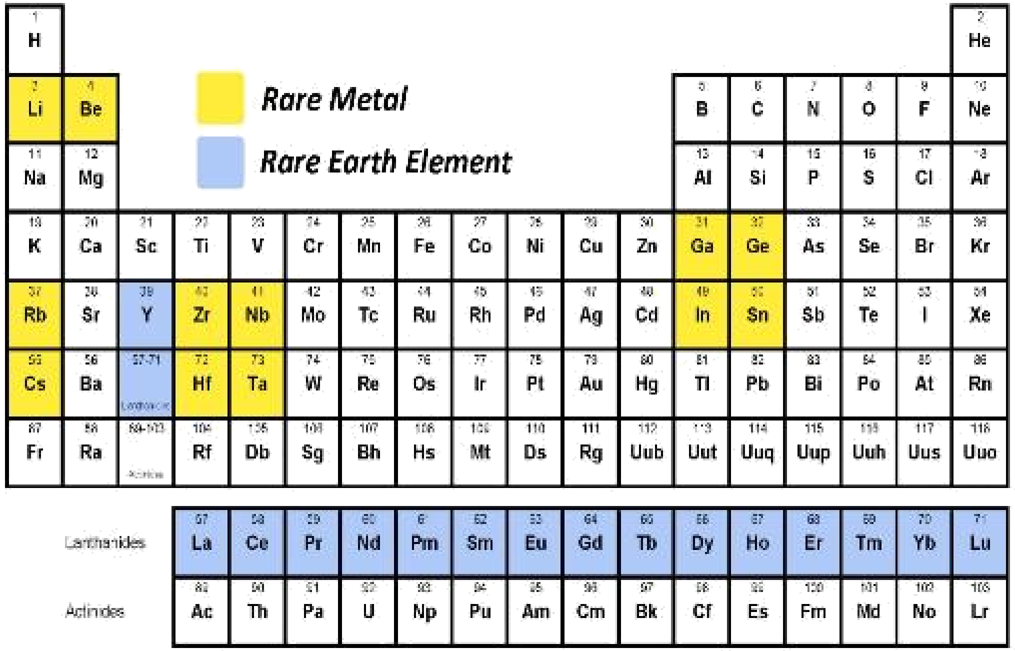






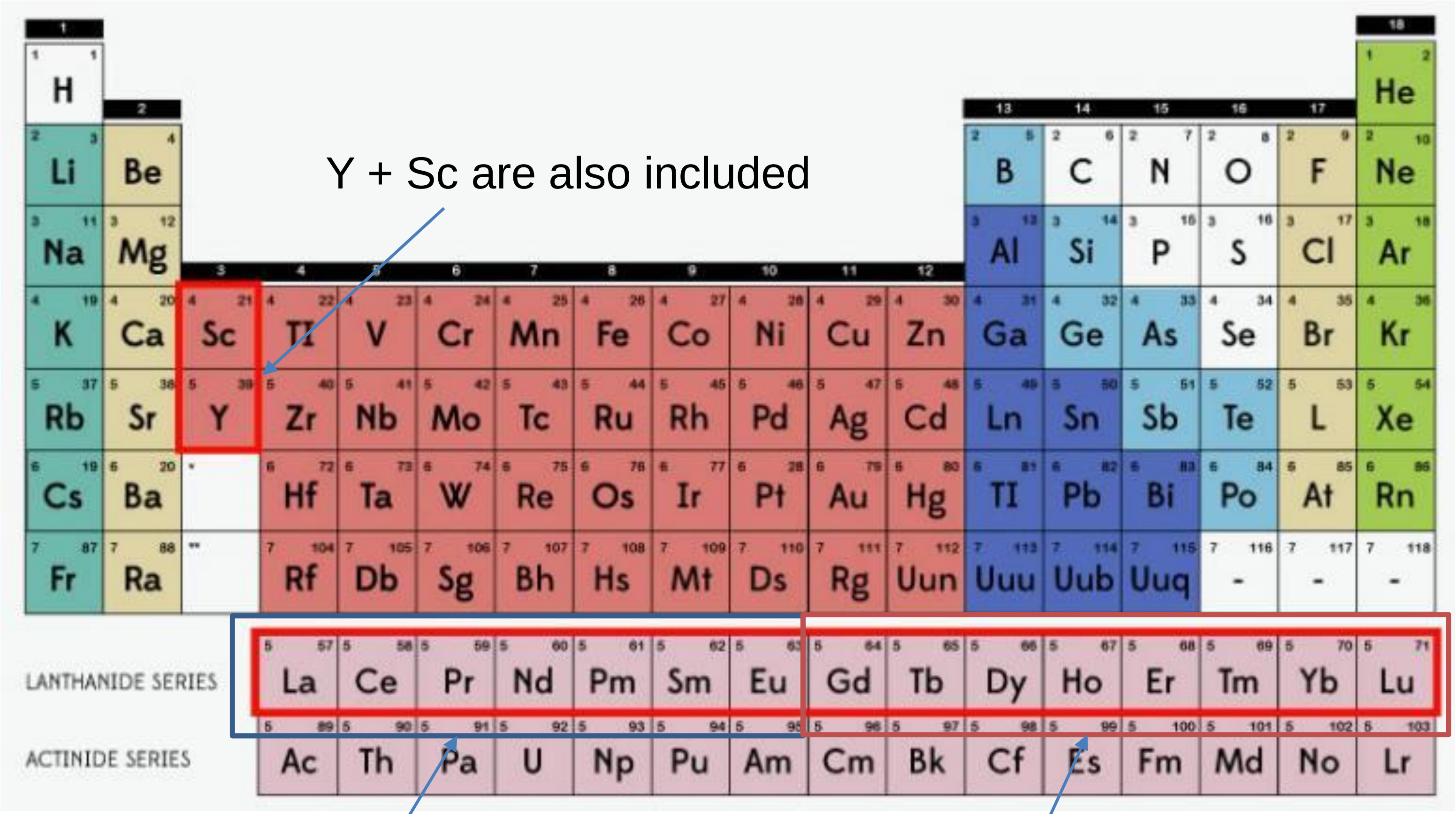
High Value Material Extraction

- Pioneering work by the North Dakota Geologic Survey has led to several funded projects investigating recovery of high value materials from coal and byproducts:
  - Characterization study of coal and byproducts across North America
  - Rare earth element extraction from ND lignite
  - Rare earth element extraction from coal combustion byproducts
- Technology development is needed to optimize and improve economics of processes that extract and concentrate rare earth elements and other high value minerals.



Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feed Stocks

Y + Sc are also included



Light Rare Earth Elements

Heavy Rare Earth Elements

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Why are REEs Important?

- Unique properties makes them very useful in numerous applications
- Often termed "Chemical Vitamins" → low usage, high impact
- Essential materials for many high-value and critical applications
  - ✓ Magnets, batteries, electronics, computers, auto vehicles, renewable energy, military defense…**and many many others**
  - ✓ REEs make possible $7 Trillion in value-added products globally
  - ✓ Unique properties prevent replacement by other materials

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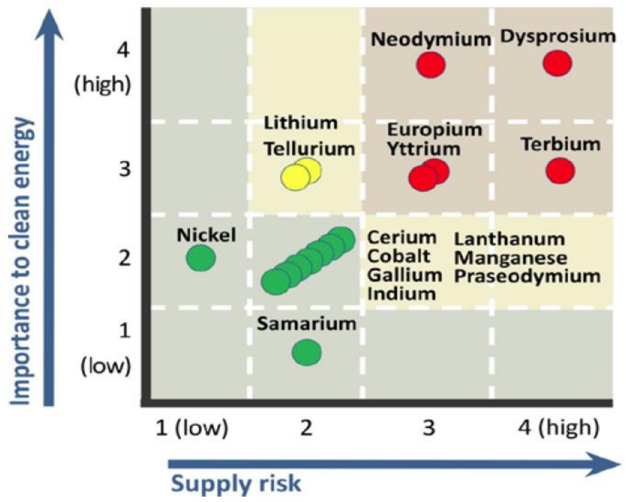
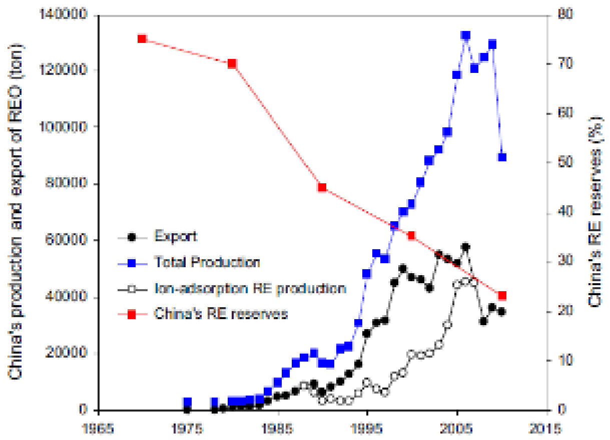
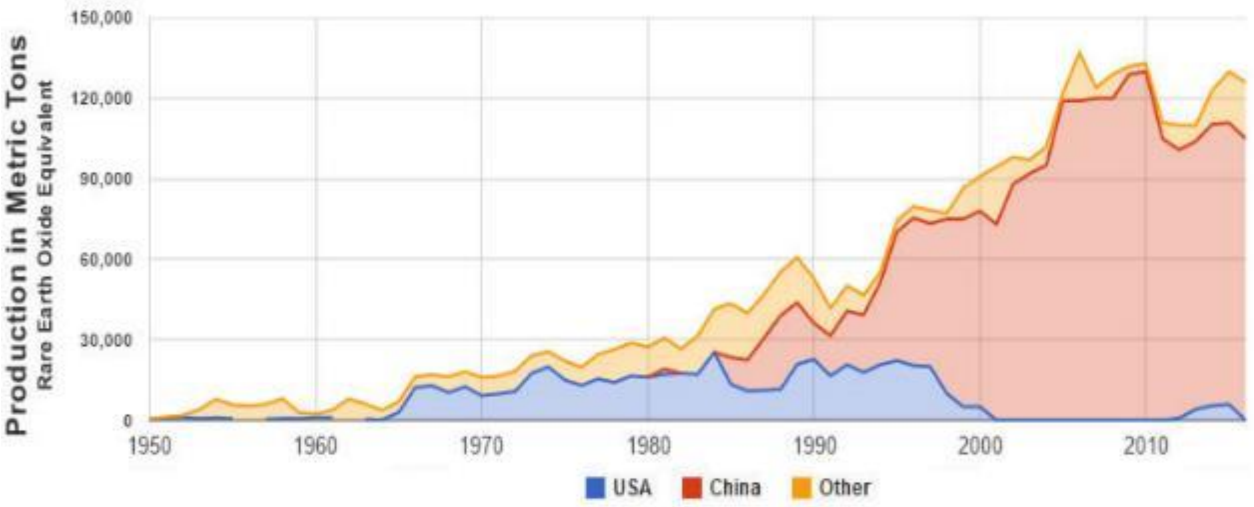
Why Research REEs from Coal?

- Several REEs identified as 'critical' – mostly the less common HREE
- China dominates global market - 83% of production in 2016
- **U.S. 100% import reliant**
- Chinese production rich in the HREE; U.S. deposits deficient
- Chinese reserves dwindling (HREE-rich ion adsorbed clays)
  - **Current deposit for ~100% supply of HREE gone by 2025**
  - Growth market sectors are dependent on HREEs – wind turbines, HEVs and many others







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REE Extraction/Concentration Testing - Process Summary and Key Benefits

- REEs easily removed from the raw ND lignite coals due to weak organic bonding
- REE extraction performance summary – direct extraction from unprocessed ND lignite
  1. **>2.0wt%** REE concentration @ 36wt% REE recovery
  2. 1.36wt% REE concentration @ 68wt% REE recovery
  3. 0.8wt% REE concentration @ 86wt% REE recovery
- Much simpler extraction process than fly ash or mineral-bound REEs
- No physical beneficiation required – process similar to Chinese ion-adsorbed clays
  1. Solvent-based extraction of REEs from coarsely ground raw coal
  2. Hydrometallurgy techniques to concentrate REEs in the leachate
- Mild leaching process – no high temperatures or pressures; no concentrated acids/bases
- **Selective** REE extraction – only strips the organically associated REEs, leaving the mineral forms and organic matter behind – does not require digestion of entire ore/mineral
- Coal beneficiation process – reduces ash content and preserves organic content/structure; ~100% removal of 'problem' elements such as sodium
- Industrially proven processing methods – fast time to market and low scale-up risks

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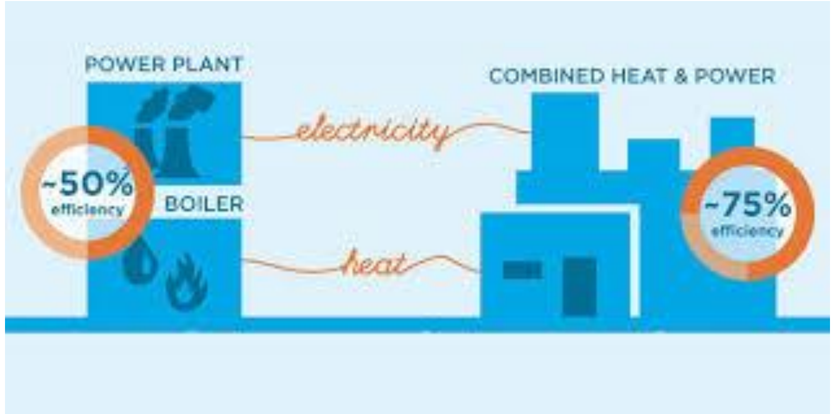
Leonardite

Leonardite is an oxidized form of lignite, rich in humic acid.

- Existing agricultural uses
  - soil conditioner to improve moisture retention and reduce toxins
  - Animal feed additive, source of trace minerals
- Growing market in oil field fluids
  - Leonardite is used as an additive in water-based drilling fluids
- Global humic acid market was $325.6MM in 2014 (Leonardite Production, LLC)

Waste Heat and Combined Heat and Power

- Enormous potential for waste heat use
  - Seven ND power plants = 7500 MWth
  - Space heating for 3.2 million homes
- Low cost natural gas challenges economics of low-grade waste heat utilization
- The US Department of Energy is working on new technology and approaches to improve efficiency of waste heat use
- Combination of CO_2 and waste heat could enhance greenhouse agriculture



- Combined heat and power (CHP) achieves higher energy efficiency than electricity production alone.
- Spiritwood and Coal Creek Stations in ND provide electricity to the electrical grid and steam to co-located agricultural industries
- Some commercial plants use steam for oil refining, natural gas processing, water desalination, or pharmaceutical production.

Resource Recovery from a Coal Fired Power Plant to Enhance Agricultural Production in Open Field and Greenhouse Facilities

Plant Integration:

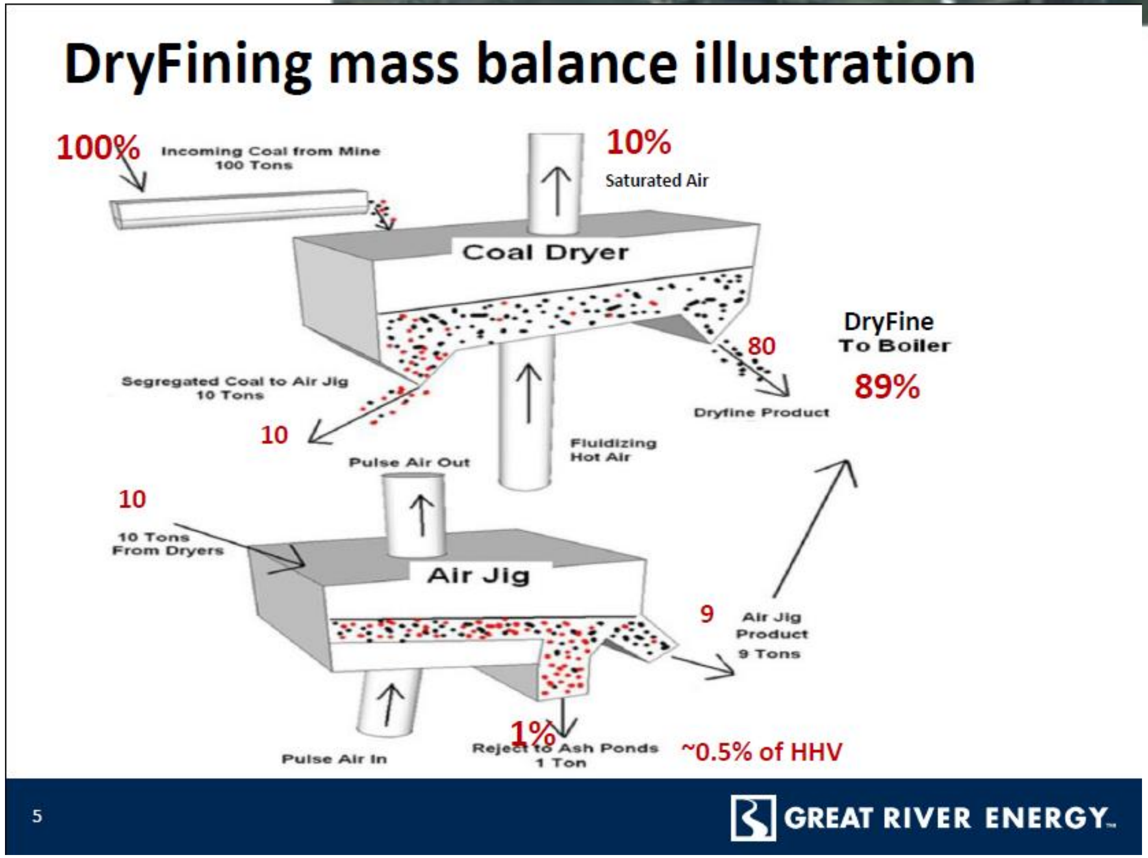
- Waste heat used for greenhouse heating demands
- CO_2 & Flue gas used to enhance plant growth
- Plant water / condensate can supplement irrigation

Updates:

- First planting cycle complete (data analysis ongoing)
- Low and intermediate concentrations of CO_2 improved plant growth and highest level was antagonistic
- Second planting cycle to include varied levels of CO_2

Coal Beneficiation with Waste Heat

- Benefits:
  - Reduced coal consumption
  - System efficiency improvement
  - Reduced emissions
    - SO_2
    - NO_x
    - Hg
    - CO_2
  - Opportunity to utilize plant waste heat



Advanced Reclamation Strategies for North Dakota coal mine lands

Questions??