REMS

Radically Engineered Modular Systems

Driving Innovation ♦ Delivering Results

Advanced Manufacturing	*Capital Cost Reduction*
Modular Approach	*Start with Small Plants, Smaller Financial Risk, and Better Plant Availability*
Site-Specific Focus from the Beginning	*Lower Cost Path to Better Solutions*
Novel Carbon Reduction	*Greenhouse Gas Emission Reductions without Geological CO_2 Storage*

Gasification Systems and Coal & Coal Biomass to Liquids

NEW PROGRAMS DIRECTION

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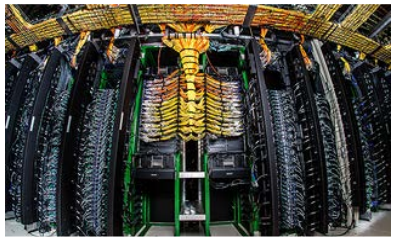
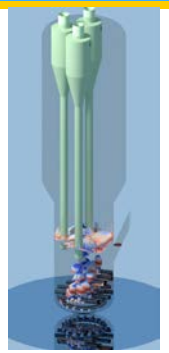
NETL capabilities for the REMS effort

- **Multi-phase simulation and advanced computing on NETL Joule supercomputer.**
- ***<u>Packaged, real-time</u>* fiber optic gas analysis for control and feedstock flexibility.**
- **Specialty alloy and refractory development.**
- **Process design & optimization of integrated systems**





Joule comprises 24,192 cores with a peak performance of 503 TFLOPS. Right: Bubbling pattern in a fluid bed reactor – used to optimize the reactor operation.

Fiber-optic gas analyzer provides multi-component, real-time analysis

NETL gasifier refractory blocks , specialty alloy development, and application to cardiac stent, DOD armor

CCSI
Carbon Capture Simulation Initiative

IDAES
Institute for the Design of Advanced Energy Systems

Four Cornerstones of Coal Conversion Programs' Strategy

1. **R&D Focused on Specific Location** – knowns include: available feed (coal, biomass, etc.); site infrastructure, altitude, weather, workforce sophistication, regulations; and most marketable products
   - Early site and application selection will allow multiple R&D efforts to be focused from early development stages and more coordination of different R&D teams
2. **Radically Engineered Modular Systems (REMS)**
   - Reactor Engineering Design
   - Balance of Plant
   - Continuously improving tool set should allow each following modular system to be more quickly developed and at lower cost
3. **Target Technologies with Sharp GHG Emission Reductions without Geological CO_2 Storage**
   - Future integration with advanced CCS technologies will further reduce GHG emissions to AES goals
4. **Target Smallest-Scale & Lowest Economic Risk Applications First**
   - Stepping stone to larger modular plants aimed at larger markets as techniques improve – learning by doing.

1. Specific Location

- **Focuses R&D Work and Reduces Expenditure of Funds**
  - Reduces the coal types to be analyzed and experimented upon to "one type"
  - Same for biomass
  - Technologies will be focused on making specific products, or multiple products based on the coal type, and location in terms of local needs and/or markets
  - Other opportunities/limitations are known quantities, for example:
    - The amount, quality and variation of sunlight
    - Natural gas availability
    - An unusually high local COE
    - Extreme weather conditions
    - Poor infrastructure
    - High cost/unavailable water
  - Better and easier coordination among teams working on different aspects
- **Better Cost Estimates – site specific information rather than averages**
- **Engaging site owners earlier may allow time for other funding vehicles to help cost share the pilot-plant**

Each Location-Specific REMS Success

- *Builds tool set to reduce cost of next REMS*
- *Builds modular system engineering capability to enable successes in larger markets*

2.a. Radically Engineered Modular Systems

Reactor Engineering Design

Use high performance computing and advanced manufacturing methods to sharply reduce capital costs, even at small scale

- Design and build the optimal reactor shape and size for the feedstock and desired products
- Combine chemical processes into one reactor (process intensification)
- Apply novel chemical reaction controls

Coal/solid fuel reactions	Modeling Tools	Reactor Engineering
Analysis at the particle level • *Evaluate differences in feedstock (structure, composition, size, chemical kinetics)* • *Evaluate novel conversion mechanisms*	***Multiphase flow & kinetics modeling tools*** • *Discover unique reactor geometries through simulation-based optimization* • *Investigate control of flow, feedstock injection, process intensification*	**Reactor concept generation** • Coal behavior analysis • Modeling insights & validation • Rapid prototyping using *advanced manufacturing*

Tool package and methods applicable to any industry that uses chemical reactions in gas-solid reactor: food/ agriculture industries, pharmaceuticals, specialty chemicals, etc.

Use advanced manufacturing to reduce the cost of modular components, and to permit creation of complex reactors able to combine functions

2.b. Radically Engineered Modular Systems

Balance of Plant (BOP)

- Use systems analysis of potential target pilot-plant location and REMS technologies to:
  - Determine the best commercial technologies that apply to the pilot-plant concept
  - Perform a gap analysis to identify highest cost BOP equipment, intensification opportunities, etc.
- Seek R&D proposals to solve most significant BOP issues
  - Tied to REMS inputs and outputs
  - Holistic plant approach, rather than plug and play for distinct new technologies
- R&D BOP progress tightly managed with REMS R&D progress
- Iterative strategy and more information is created on the REMS and BOP technical solutions, and how they impact each other

3. Greenhouse Gas Emissions Reduction without CCS

- **Removal of Carbon: heavy tar or high carbon char**
  - Remove the carbon before it becomes CO2, which requires costly separation and geological storage to remove the carbon from the atmosphere
  - Convert the carbon into high value products that inherently store the carbon in a near-permanent state
    - Carbon Fiber, Graphene, Carbon Foam, etc.
- **Use of Biomass**
  - Biomass co-feed can further reduce GHG emissions
  - Biomass gasification, pyrolysis and coal co-feed all proven to be feasible
  - Smaller plants make higher percentage of biomass use affordable due to shorter transportation travel
- **Use of other GHG emission reduction technique such as hybridization with solar or natural gas conversion**
  - Natural gas in areas with low-cost resource, or hybridization in areas with abundant sunshine, are both examples of how a specific site may have specific attributes to explore
  - Other hybrid possibilities include: DC micro-grids (GHG emissions reduction through increased efficiency), wind, geothermal, nuclear, etc.

4. Target Small Scale & Lowest Economic Risk Applications First

- **Stepping Stone Approach**
  - Tools will be developed as each REMS concept is created, tested and launched
    - Multiphase flow models, advanced manufacturing, reactor engineering, etc.
  - Niche Markets for First REMS Pilot-Plants – must prove viability of modular approach using advanced manufacturing and reactor engineering to reduce capital costs and increase plant availability
  - The use of modular systems will lead to greater availability and lower maintenance costs, but at present is an approach too high in capital costs for larger plants
  - *Smaller, holistic plant successes, using advanced manufacturing and reactor modeling, will:*
    - Reduce the risk of larger-scale applications
    - Make clear specifically what R&D is needed to expand the scale of larger modular plants
- **Co-Production**
  - Smaller more flexible plants must take maximum advantage of coal conversion opportunities
  - Deep dive analysis of coal conversion products will allow most valuable products to be created under optimum conditions, and removed from process, at optimum time
  - ***High carbon co-products will aim for carbon storage in high value products***

Ongoing NETL Activities

- **Survey to:** *"identify unique geographic regions or areas in the United States where factors such as economic forces, resource availability, local pricing, access to markets, and labor availability can enable deployment of new coal conversion technologies"*
- **Two Requests for Information on the verge of being posted**
- **FY2016 NETL ORD Tasks:**
  - Gasification Systems
    - Reacting Multiphase Models for Advanced Gasification Devices
    - REMS Cold Flow Reaction Model Construction
    - REMS Radically Engineered Modular Systems: Reactor Material Design, Construction, and Testing
  - C&CBTL
    - New Materials Design, Discovery, Synthesis, and Characterization for Polygeneration
    - New Reactor and Chemical Process Engineering Approaches for Polygeneration
- **Pre-screening of established R&D technologies for REMS application is being performed**
- **Balance of Plant analysis of existing technologies, advanced manufacturing opportunities and R&D gaps**
- **EDX Account being developed to enable efficient communication and collaboration internal and external to NETL**