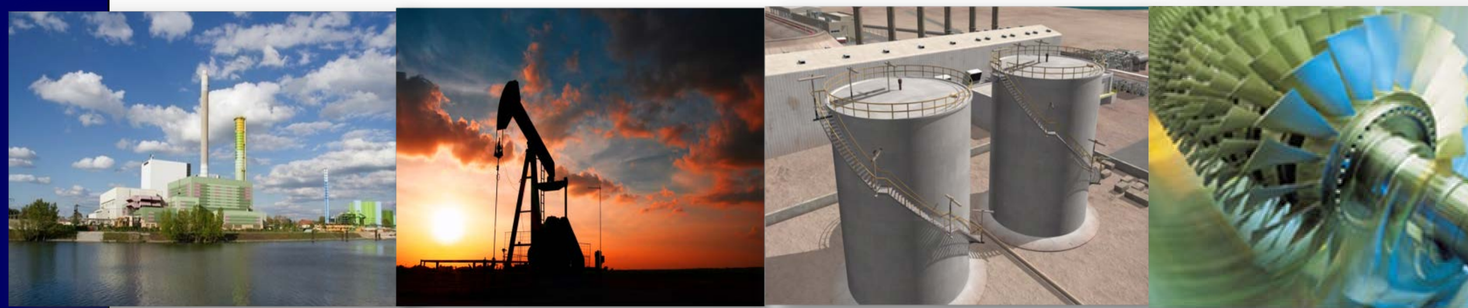
U.S. DEPARTMENT OF ENERGY

Fossil Energy | National Energy Technology Laboratory

Fossil Energy



Advanced Energy Systems Program Overview

Regis Conrad

Division Director Advanced Energy Systems

Office of Coal and Carbon Management

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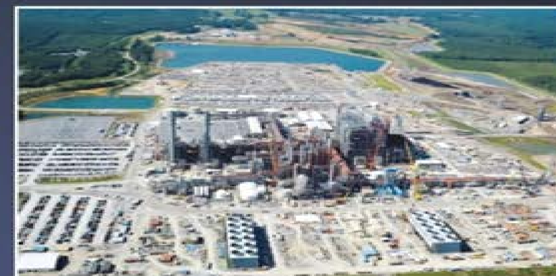
Advanced Energy Systems

OFFICE OF FOSSIL ENERGY

Clean Coal & Carbon Management



VISION

A secure, reliable, and affordable energy future with the environmentally sound use of coal and all fossil fuels

MISSION

Support the research, development, and demonstration of advanced technologies to ensure the availability of clean, affordable energy from coal and fossil fuel resources

GOALS

1. Demonstrate significantly lower-cost CO_2 capture technologies to enable widespread deployment of near-zero emission fossil-based technologies
2. Acceptance by industry, financial institutions, regulators, and the public that CO_2 can be safely injected, monitored, and permanently stored in a variety of geologic formations
3. Conduct high-risk, transformational research and development on coal fossil fuel technologies
4. Drive international collaboration to ensure widespread acceptance and deployment of CCS and advanced coal technologies
5. Provide data and expertise to support policy, legislation, and regulation impacting fossil fuel research

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Advanced Energy Systems

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- **Advanced Energy Systems Program**
    - Gasification and Coal & Coal Biomass to Liquids
    - Solid Oxide Fuel Cells
    - Advanced Turbines
    - Advanced Combustion
    - Supercritical CO_2

Cross-cutting Research Program

- Sensors and Controls
- Extreme Environment Materials
- Computational Modeling
- University Training
- Rare Earth Elements
- Water Management

Objectives:

Move the gasification and coal coal-biomass to liquids programs in a new direction, using all the lessons learned, and apply them to leverage recent technological advances in Advanced Manufacturing by pursuing R&D as the new pathway.

- Retains the foundational objective of the Gasification Systems Program is to **reduce the cost of electricity** from coal with a reduced greenhouse gas footprint.
- Allows the gasification program to remain focused on **leveraging past and ongoing R&D efforts**, as well as looking at **gasification in distinctively different ways**.
- Concepts will help design, and build coal conversion reactors and plants to make them economically attractive, create new coal market opportunities, and significantly reduce the global warming impact of fossil energy use through reduction in size and efficacies.

Modularity Objectives

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Modular systems will enable small, distributed plants to use local, low-cost feedstocks and other local opportunities (such as high solar energy availability) to create products most useful to the local population.

"Usefulness" may be the creation of locally needed products such as electricity, heat, and diesel for off-the-grid communities; destruction of municipal solid waste (MSW) for mid-sized towns and small cities; production of products for sale; or portable small-scale natural gas and oil support systems like flared-methane conversion.

In most situations, it makes sense for modular systems to use their inherent flexibility to take advantage of specific location-based needs, rather than try to create an economical system applicable and suitable for a wide scope of feeds and products.

Modularity Objectives

- Think of Modular Power Plants as being made up of **"building blocks"**
- Each system is pre-constructed and only needs to be connected to other systems.

One downside is size, though small reactors are necessary for easy transportation

Modularity Benefits

R&D to reach maturity. However, there are many challenges including:

- *Advanced Manufacturing:* Currently additive manufacturing is limited in terms of size, and operating conditions limits (pressure, temperature, and particulate/chemical wear) products made through additive manufacturing. To achieve both low capital costs and process optimization, the limits on additive manufacturing need to expand.
  - *Conventional Reactors and Plant Design* – Conventional thinking is limited by manufacturing technologies of the past. Additive manufacturing enables exotic and complex shapes to allow unprecedented manipulation of chemical reactions, and perhaps a disassociation between not only larger size and lower cost, but also long reactor life and high availability – if manufacturing costs are low enough.
  - *Modeling Tools Limits* – The needed modeling tools are at the early development stages. As computing power continues to increase, which has historically been happening at an exponential rate, the power of these tools will increase proportionally, resulting in increasingly accurate predictions of reactor behavior, leading to reduced time and cost for the development of each modular system.
  - *Technologies Designed for Large Plants* – Advanced technologies designed for modular systems need to be developed. Heat management, alternative energy sources (microwaves), biomass co-feeding, and even biological creation of hydrogen are examples of technologies that, while not feasible for large fossil-based plants, could be perfect for modular system use.

GOALS:

5 MWE Oxycombustion Pilot

The program goal is to improve the overall economics for combustion pathways ensuring that their performance and cost potential are substantially better than today's baseline pulverized coal power plant with post-combustion capture.

Develop game changing technologies in the power generation, such as an oxy-fuel combustion power plant, that will have order of magnitude economic, energy savings and environmental impact on the US Power Industry.

Advanced Combustion Program

Objectives:

Pursue advances made in the Advanced Combustion portfolio which to date has focused on;

- Improving Combustion Efficiency
- Pressurized Oxy Combustion technologies
- Chemical Looping technologies
- AUSC for new boilers

Explore new concepts including

- High Pressure, High Temperature Combustion Turbines
- Pulsed Combustion
- Flameless Combustion
- Boiler Integration for sCO2 Power Cycles
- Novel boiler designs and configurations

Strategies:

- Complete FEED studies to evaluate oxy-combustion and Chemical Looping technologies
- Where Required, Technology Development

Future Directions:

- Engagement Industry in completing a 100MWe demonstration plant
- Pilot-Scale Operations

Turbines Program Goals

- Drive Down the Cost of Electricity Production from Coal-Based IGCC Power Generation with CCS

- Develop Technology from Components to Entire Machines that Create Efficiency and Cost Improvements

Turbines Program Objectives

Objectives:

- Improved Efficiencies Associated with Turbine-Based Power Generation
- Reduced Capital Costs

Strategies:

- Improved Technologies Associated with Higher Gas Turbine Firing Temperatures (Combustion, Materials, Aero-Heat Transfer
- New Technologies using Non-Traditional Working Fluids (Indirect and Direct-Fired Supercritical CO_2)

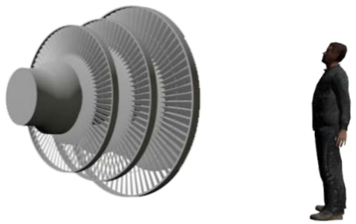
Future Directions:

- Pressure Gain Combustion
- 10 MW Supercritical CO_2 Transformational Electric Power (STEP) Facility

Supercritical CO_2 Program Objectives

Near Term Objectives:

- Construct 10 MWe STEP (Supercritical Transformational Electric Power) pilot scale facility and address technical issues, reduce risk, and mature sCO_2 technology for demonstration.
- Develop next generation materials and technologies and mature through STEP facility



1 meter sCO_2 (300 MWe)
(Brayton Cycle)

Strategies:

- Develop necessary technologies via robust R&D program
- Design program to leverage knowledge and expertise from the national labs, universities and the private sector
- Deployment
  - Promote early deployment of indirect cycle in waste heat recovery, shipboard aux power, military, and other high value applications
  - Demonstrate direct-fire with 50MW demonstration with initial deployment on natural gas with CO_2 storage

Fuel Cell Program Objectives

Objectives:

- Address the technical challenges to commercialization such as gas seals, interconnects, advanced materials development, materials characterization, anode contaminants, internal reformation, and failure analysis.

- RD&D to focus on components that support the fuel cell system such as controls and sensors, heat exchangers, blowers, and power conditioning to ensure system reliability, long-term operation, and are cost effective.

Strategies:

➢ Develop specific targets to meet the goals, such as:
  - System Performance Degradation: 0.2%/1,000 hours
  - System Cost: $900/kWe (Nth-of-a-Kind)

➢ Focus on developing innovative stack designs in the 5-10kWe scale.

Future Directions:

- FY2017: FOA 400 kWe Power Prototype System Field Test
- FY2020: FOA 1 MWe-class Power System at customer site

Objectives

Development of sensors focuses on measurements to be made in high temperature, high pressure, and/or corrosive environments of a power system or underground injection system. Focused on distributed intelligence for decision making and optimization of plants.

Objectives:

Transform computationally intensive models into reduced order, fast, user-enabled models for the purposes of study, development, and validation. These tools will be used to optimize data handling and exploit information technology in the design of advanced energy systems with carbon capture.

Goal:

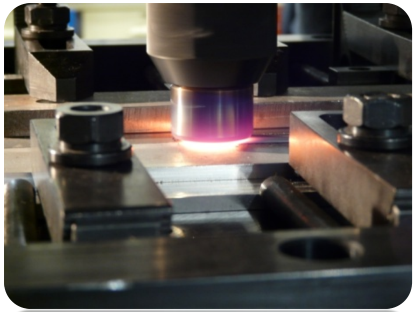
Develop modeling methodology tools and manufacturing processes that can provide a scientific understanding of high-performance materials compatible with the hostile environments associated with advanced Fossil Energy (FE) power generation technologies.

Objective:

Materials R&D focused on structural and functional materials that will lower the cost and improve the performance of fossil-based power-generation systems.

The Problem & the Vision for Materials Development

- **The Problem: New high temperature structural alloy development and commercialization is time consuming and expensive: >10 years and multi-million $ for a single alloy**

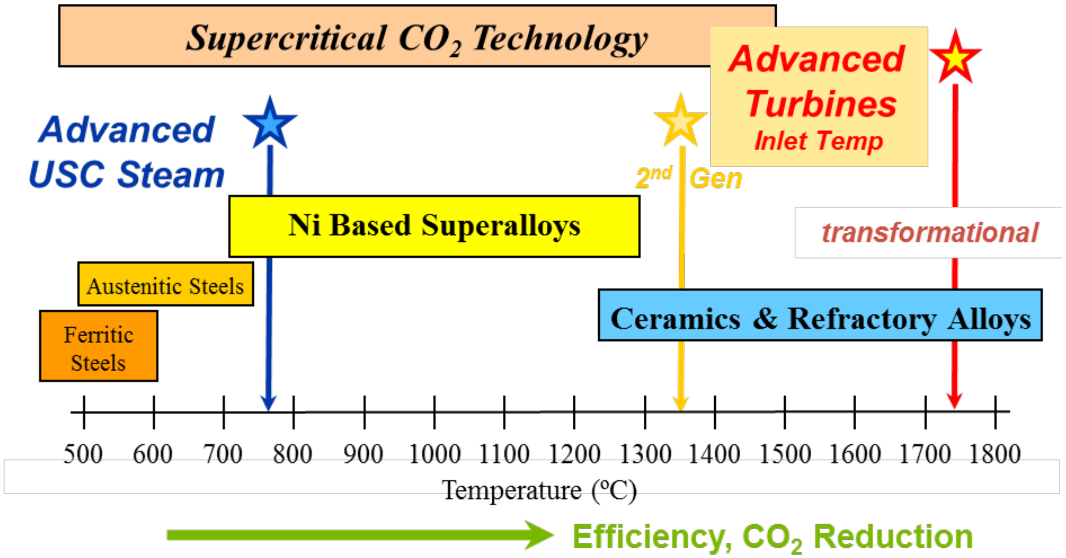


  - Many technical requirements for success
  - Mechanical testing is expensive
  - Long term mechanical properties are sensitive to small
  - variations in composition.
  - Long life requirements currently requires long duration creep tests to be sure that alloy has required strength
    - There are no demonstrated early experimental indicators of long term creep behavior
  - Current state of the art of computational materials design and experimental methods does not yet address long term life

- **The Vision: Reduce the cycle time, cost and failure rate of advanced FE materials development by at least a factor of 2X by use of integrated High Performance Computational (HPC) materials design and long term predictive behavior tools coupled with smarter, more efficient experimental techniques and use of data analytics to leverage existing data and knowledge to its maximum possible extent.**

Extreme Environment Materials Program

- **Advanced FE systems**
  - Extreme environments
  - Long service life (>100,000 h)
  - Large components
- **Opportunity**
  - New Phase Stable Alloys
  - Manufacturing of Alloys, Materials Systems & Components
  - Build upon DOE-FE successes with Integrated Computational Materials Engineering (ICME) environments



R&D needs

- **Develop multi-scale computational models to link atomic scale phenomena with microstructural evolution, manufacturing and materials performance.**
- **Targeted Validation Experiments**
  - Improved accelerated test methodologies for long service life properties.
  - Experimental test-beds for simulated service environments.
    - e.g., environmental-mechanical test chambers
    - Real-time insitu characterization for fundamental mechanisms identification

Desired Outcome

- **Validated Simulation Based Engineering to accelerate the design, development and deployment of materials for extreme service environments.**

Water Management Program

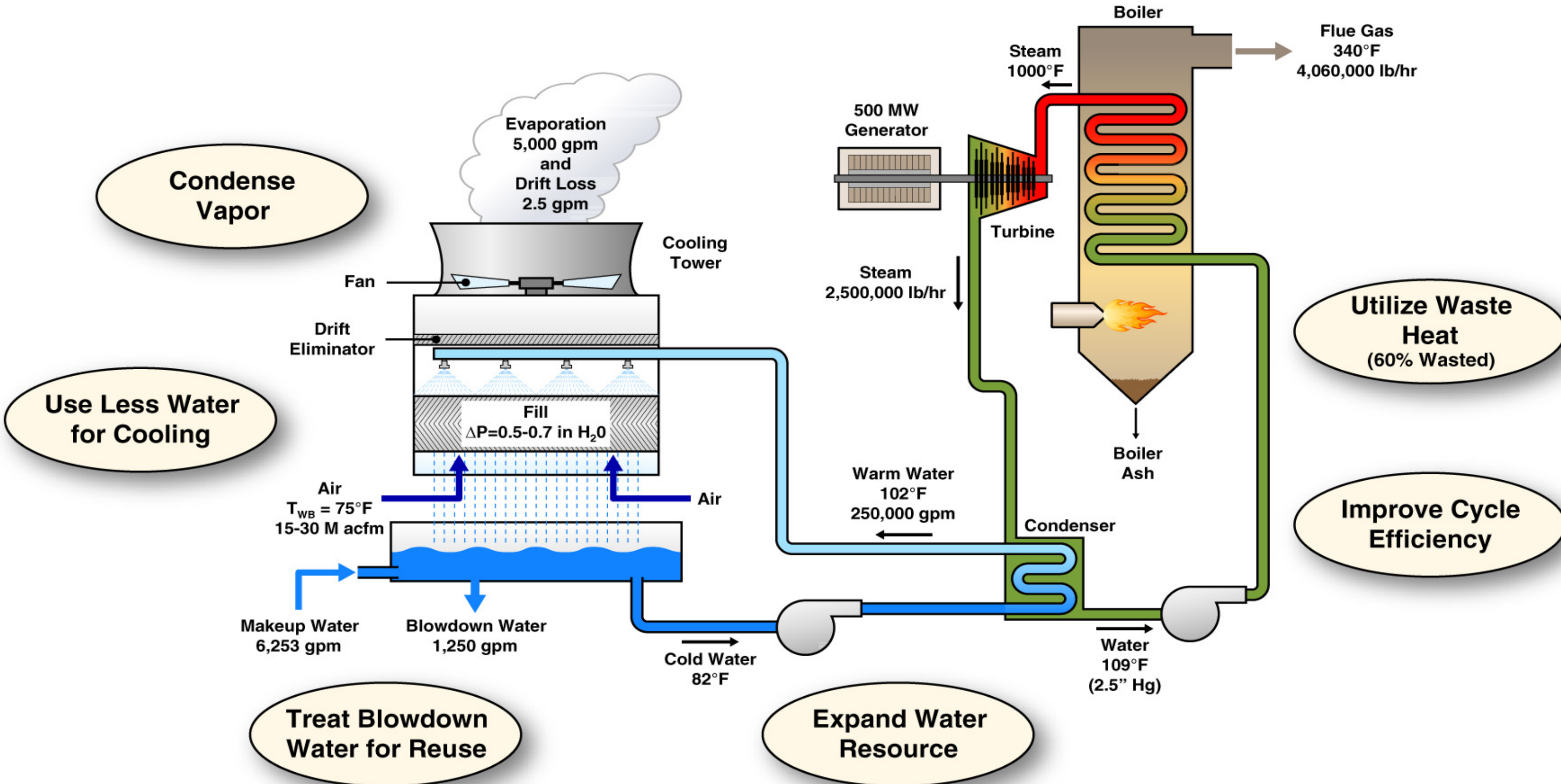
Goals:

- Water Management R&D supports sustainability and improved water efficiency focusing on treatment and use of non-traditional water, water-efficient cooling, and data modeling and analysis activities.

Objectives:

- Field test technologies and processes for treating water produced by injection of carbon dioxide in deep saline aquifers and explore water-limited cooling and innovative multi-stage filtration technologies. Data modeling and Analysis will gather existing water availability data and compile for regional analysis.

Water Research Opportunities



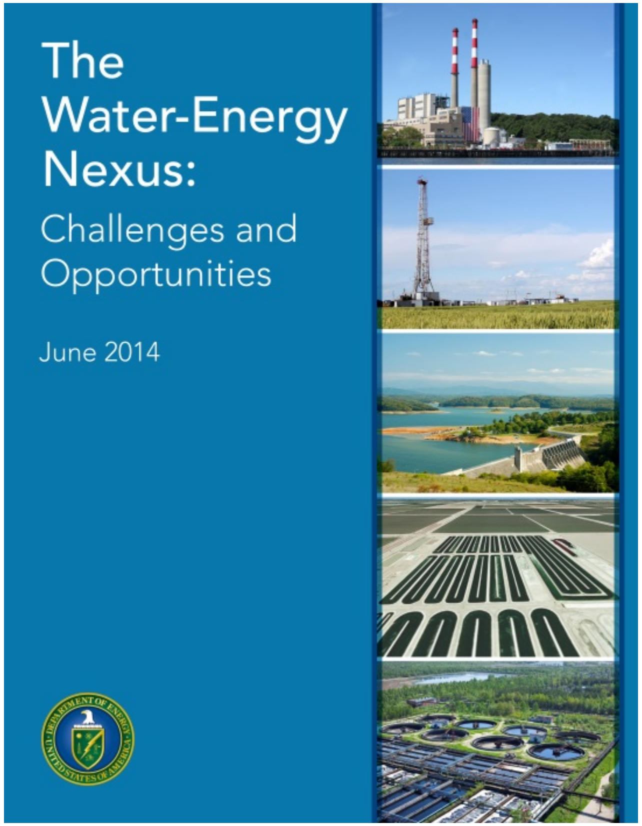
<u>Innovation Priorities</u>: Advancing cooling technologies, and applying novel water treatment and waste heat concepts to improve efficiency and reduce water use

Water Research Opportunities

- **Advanced / Novel Heat Transfer and Cooling Systems**
  - *Wet, Dry, Hybrid*
  - *Incremental & Step Change Improvements*
  - *Advanced Manufacturing of Recuperators for Combustion Turbines*
- **Water Treatment and Reuse**
  - *Economic Pathways for Zero Liquid Discharge*
  - *Treatment of high TDS Waters (promote greater Water Reuse)*
  - *Majority of NETL R&D Currently Focused in this Area*
- **Process Efficiency and Heat Utilization:**
  - *Pathways for produce more power per unit of water withdrawn, consumed, and treated*
  - *Utilization of Low-Grade Heat*
  - *Bottoming Cycles*
- **Data, Modeling and Analysis**
  - *Tools to enable regional and plant level decision making*
  - *Develop a National Water Atlas*
- **Breakthrough or Out of the Box**
  - *Low / No water FE based Systems, Distributed Generation, Grid Upgrades*

Energy-Water Nexus: DOE's Role

- DOE has strong expertise in technology, modeling, analysis, and data and can contribute to understanding the issues and pursuing solutions across the entire nexus.
- Our work has broad and deep implications
  - User-driven analytic tools for national decision-making supporting energy resilience with initial focus on the water-energy nexus
  - Solutions through technology RDD&D, policy analysis, and stakeholder engagement
- We can approach the diffuse water area strongly from the energy side
  - Focus on our technical strengths and mission
  - Leverage strategic interagency connections

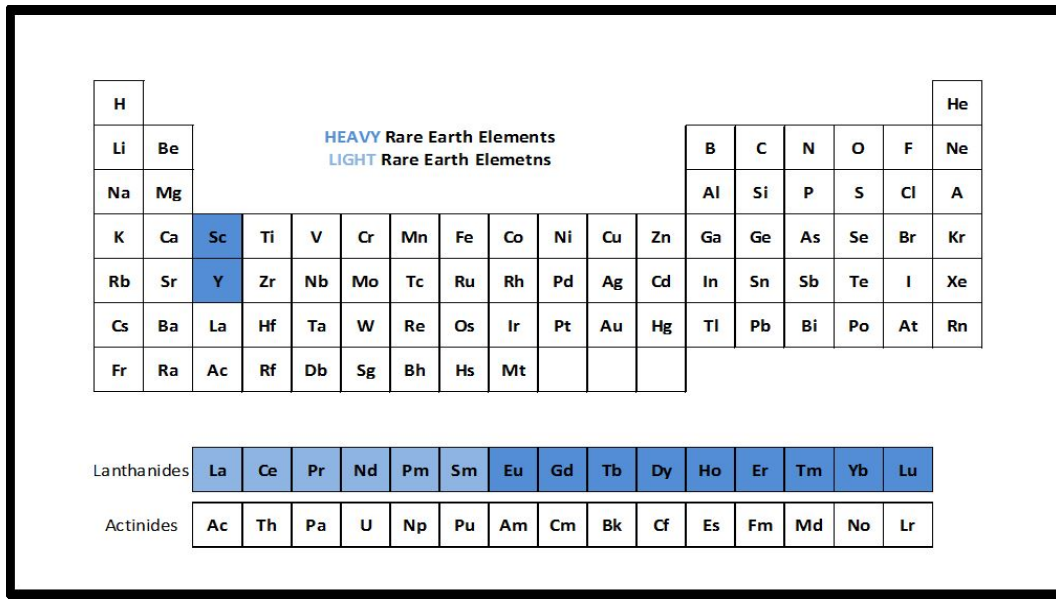


Download the full report at:
energy.gov/water-energy-tech-team

Rare Earth Elements Program Goals

- Establishment of the Economic Production of Rare Earth Elements from Coal and Coal Byproducts

- Establishment of Economic Rare Earth Production Opportunities in U.S. Coal Fields



Periodic Table of Depicting Heavy and Light REEs

Rare Earths Elements Program Objectives

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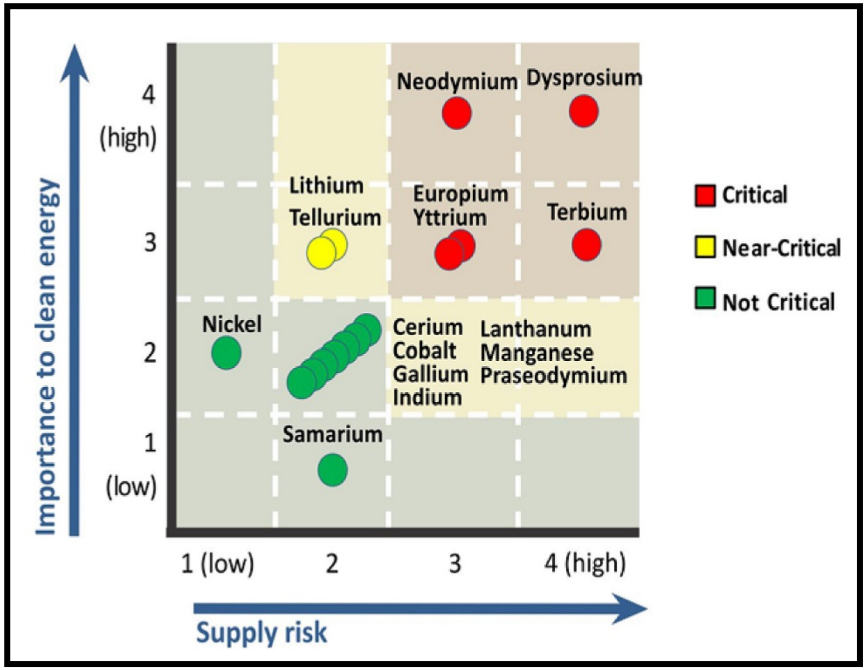
Objectives:

- Identify Highest Rare Earth Content Materials in the U.S. Coal Value Chain
- Ore-Specific Plant Designs for these Materials
- Financial Projections for Rare Earth Production from these Materials
- Economic U.S. Rare Earth Production Opportunities



Strategies:

- Engagement of U.S. Technical Resources, Including Industry and Academia
- Where Required, Technology Development

Future Directions:

- Expanded Search for High Rare Earth Assays
- Pilot-Scale Operations

Thank You