About the Webinar

We hope you will leave the webinar with knowledge about:

- Better understanding of the research being conducted at NETL in Advanced Manufacturing and Rare Earth Metals and how successes in research may impact the region and the nation
- How to engage and interact with NETL
- What is the Regional Workforce Initiative and how can you engage with the RWFI

Webinar Agenda

NETL RWFI: Working with NETL

I. Welcome Message and background from the NETL Regional Workforce Initiative Team
   - Welcome to NETL!
   - What are the research thrusts at NETL?
   - What is the NETL RWFI?

II. Energy 101- Advanced Materials and Manufacturing
   - What is advanced manufacturing?
   - What type of research is being conducted at NETL about advanced manufacturing/ composites and advanced materials
   - What type of skills are necessary for the advanced manufacturing worker?
   - What's the potential economic impact of success?

III. Energy 101- Rare Earth Metals
   - What are Rare Earth Metals and why are they important?
   - What are the research challenges?
   - What is the potential economic impact of success?

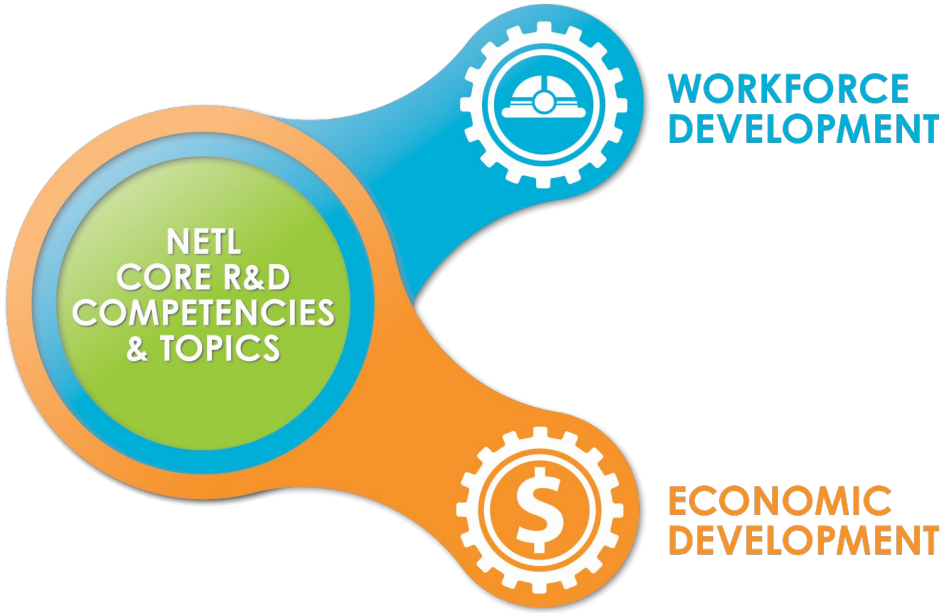
IV. Conclusion- How to stay connected to NETL and the Regional Workforce Initiative

NETL Regional Workforce Initiative (NETL RWFI)

NETL Regional Workforce Initiative Mission

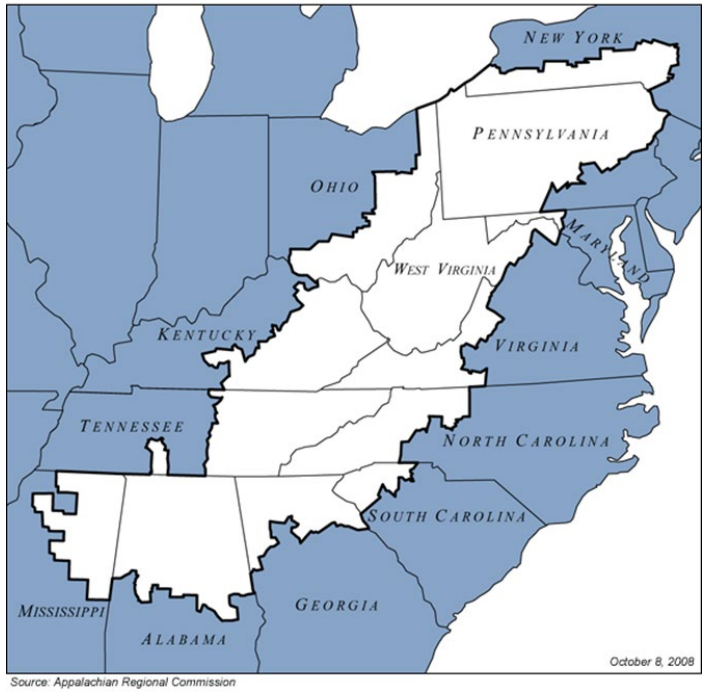
A Platform For:

- Communication and collaboration with regional/national stakeholders and partners, DOE and other federal agency partners
- Connecting public investment in energy and advanced manufacturing NETL R&D to national and regional economic development, education, and jobs
- Discussing energy and manufacturing regional and national workforce skills gaps generally and specifically to NETL's core R&D



How We Engage:

- Monthly E-Note Email Bulletin
- On Campus Engagements
- Webinars and Webcasts
- NETL RWFI Website
- Participation and representation at regional and national energy and manufacturing workforce meetings and groups



Source: Appalachian Regional Commission

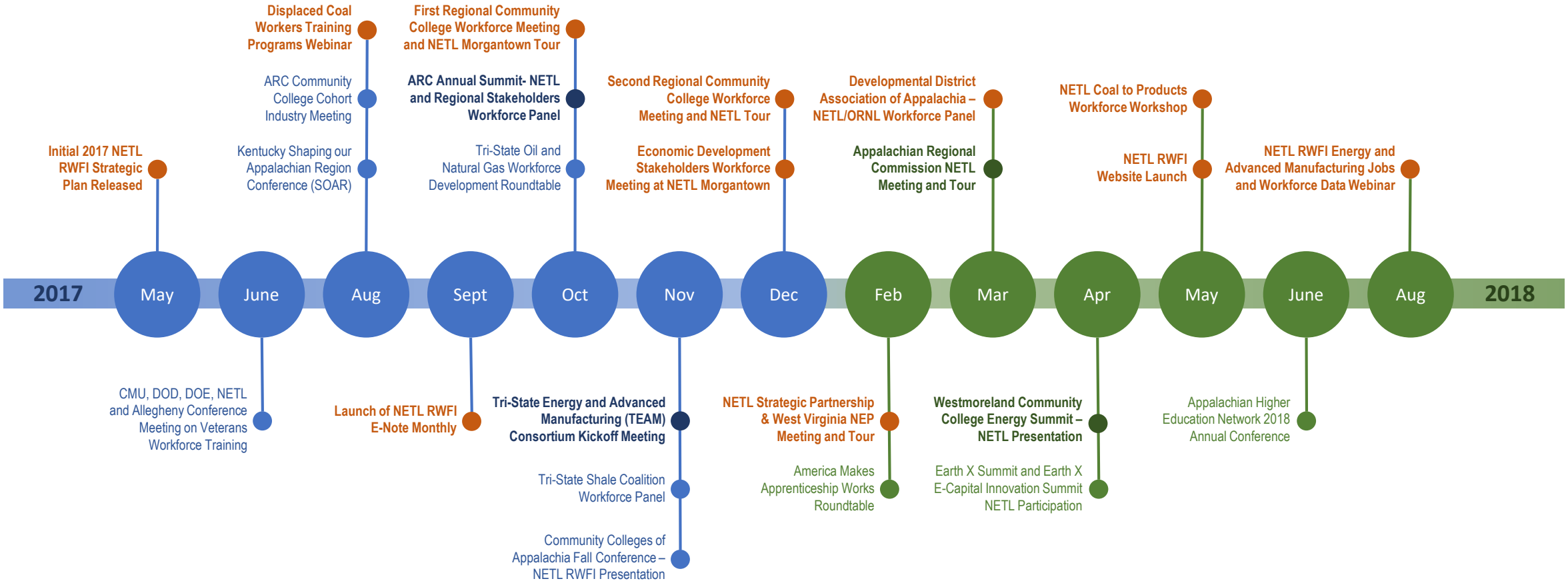
Responsive to Administration Priorities

RWFI aligns to the Administration's efforts to connect R&D investment to economic growth, job growth, and development of a skilled technical workforce.

- OMB Memorandum to Agency Heads on FY 2020 Administration Research Development Budget Priorities
- EO-Establishing the President's Council for the American Worker
- EO-Establishing Apprenticeships in America
- EO-Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure

RWFI Outreach, Meetings, Webinars, and Workshops

Consistent, meaningful, outcome driven, engagement

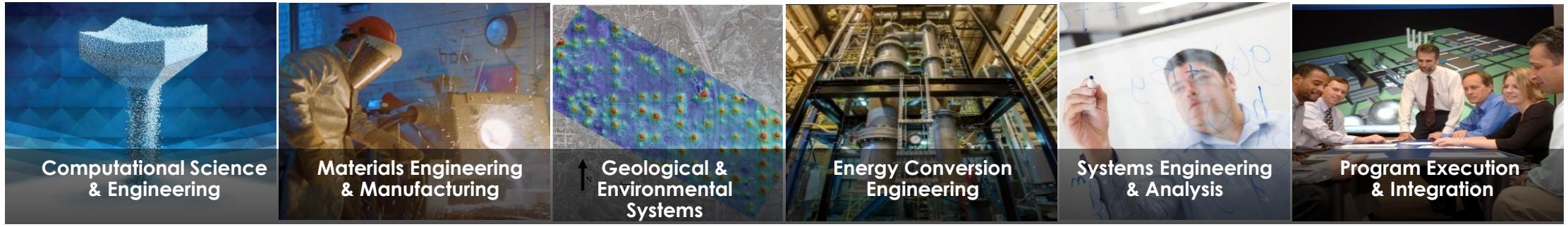


RWFI Opportunities for FY 2019

- Continued outreach to regional stakeholders, such as the Appalachian Regional Commission (ARC)
- Planning for RWFI webinars on:
  - Economic Development
  - Energy Technology 101 (March 28th 2019)
  - US Energy and Employment Report PA/OH/WV Data
- Potential on-campus events:
  - The future of work in the national and regional fossil energy sector
  - Energy and advanced manufacturing industry workforce roundtable
  - Innovation and Entrepreneurship in Energy and Advanced Manufacturing

Core Competencies & Technology Thrusts

NATIONAL ENERGY TECHNOLOGY LABORATORY



COAL

Carbon Storage | Carbon Capture | Sensors & Controls | Advanced Materials | Advanced Computing | Advanced Energy Systems | Water Management | Rare Earth Elements

OIL & GAS

Enhanced Resource Production | Environmentally Prudent Development | Methane Hydrates | Offshore | Natural Gas Infrastructure | Unconventional

Support to Other DOE Offices

Energy Efficiency & Renewable Energy (EERE)

Vehicles | Solid State Lighting | Geothermal

Office of Electricity (OE)

Microgrid | Energy Storage

Cybersecurity, Energy Security, and Emergency Response (CESER)

Energy Security & Restoration | Cybersecurity

Contact Information

For More Information, Contact Anthony Armaly

anthony.armaly@netl.doe.gov

+1-412-386-6040

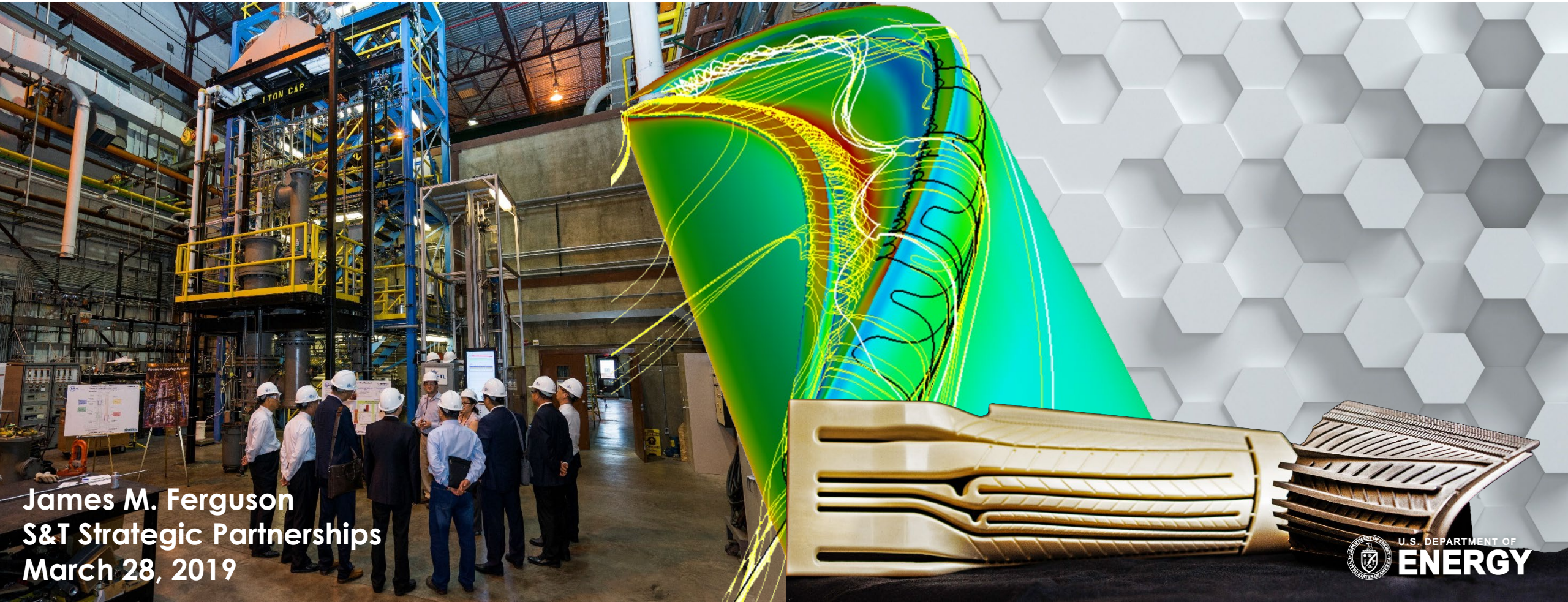
www.netl.doe.gov

NETL Advanced Manufacturing Overview:

For NETL Regional Workforce Initiative
Energy 101 Webinar

NATIONAL ENERGY TECHNOLOGY LABORATORY

Solutions for Today | Options for Tomorrow



James M. Ferguson
S&T Strategic Partnerships
March 28, 2019

U.S. DEPARTMENT OF ENERGY

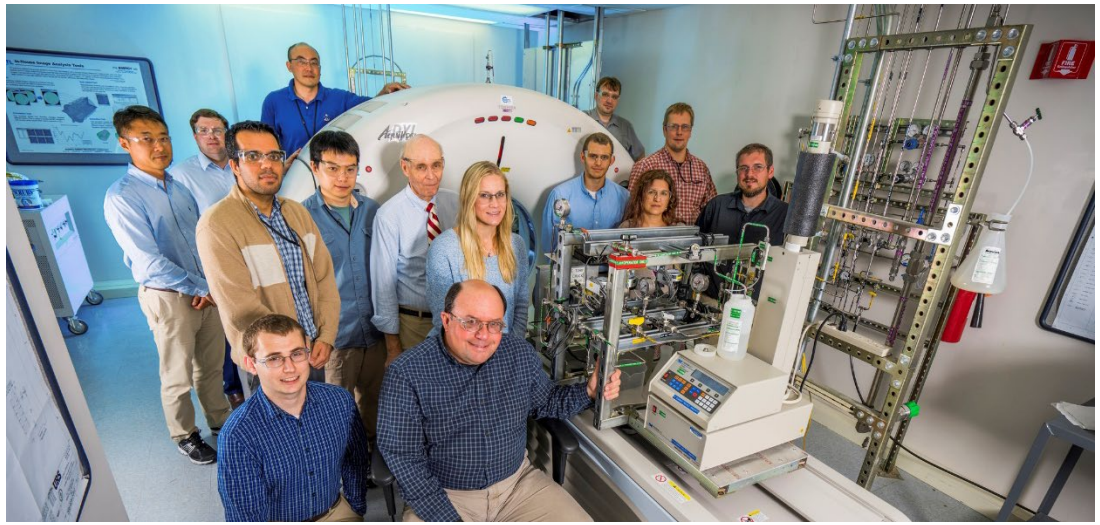
NETL Advanced Manufacturing Activities

- **Research: Extramural and Intramural**
  - Up to ~ 20-30 Financial Assistance Awards
  - Up to ~ 5-10 R&IC Field Work Proposals (FWPs)
  - Up to ~ 3-5 R&IC Small Business Innovation Research (SBIR) Awards
- **Memberships:**
  - America Makes (Active)
  - RAPID Manufacturing Institute (Pending)
  - Advanced Robotics for Manufacturing (ARM) Institute (Pending)
- **Collaborations:**
  - MOU with Oak Ridge National Lab (signed March 2018)
  - NextManufacturing Consortium at Carnegie Mellon University
  - Other Government/Industry/Academia

Advantages of Advanced Manufacturing

Advanced Manufacturing (AM) definition: Use of innovative technologies, improved processes, and management methods to improve the manufacturing of products.

- Reduced transportation costs
- Overall improved performance
- Fewer materials wasted (reduced inventories)
- Extreme performance requirements of turbines requires AM solutions
- Demonstrated history creating AM technologies and high value gas turbine parts
- NETL has experienced project managers to execute the subject program
- Technical assistance to thousands of industrial plants
- Reduced climate and environmental impact
- Improved national energy security and competitiveness throughout the supply chain



GOAL

Within 5 years, NETL becomes a leader and major force in the development of fossil-based AM technology improvements (e.g., cost reduction, efficiency, reliability, time to market, environmental footprint) across the fossil energy value chain.

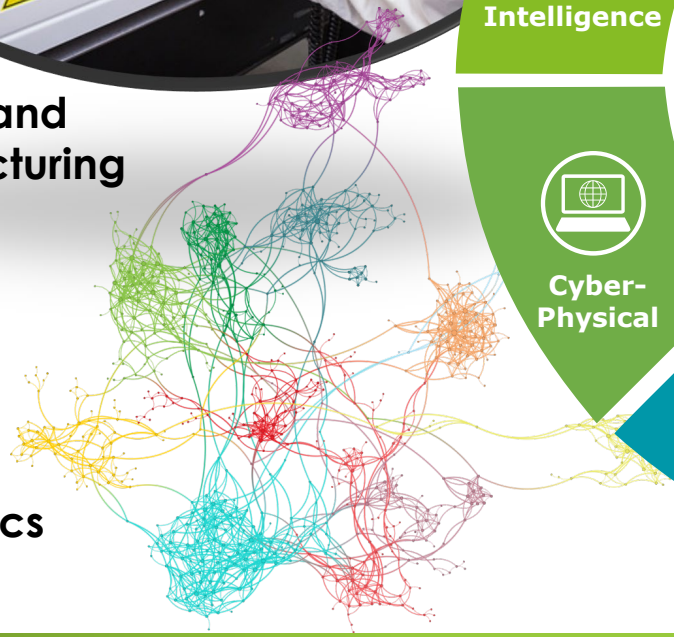
Energy and Advanced Manufacturing

A 21st century energy transition, a new era of energy innovation, and energy market expansion present a golden opportunity to boost U.S. employment

Fossil-focus in Advanced Manufacturing

NATIONAL ENERGY TECHNOLOGY LABORATORY

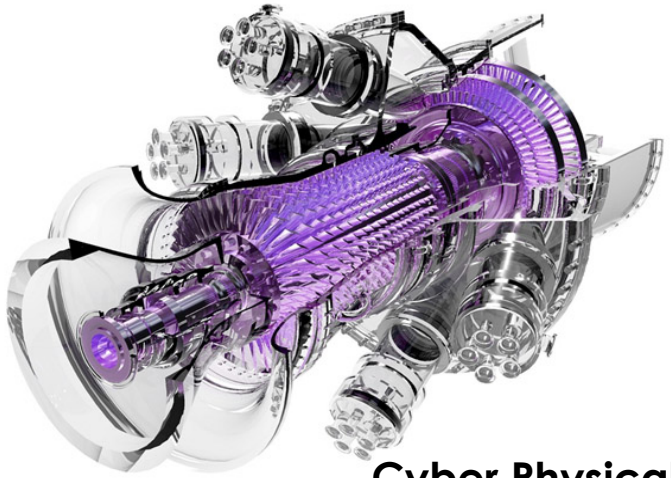
Processing and Nano-Manufacturing



Data Analytics "Big Data"

Intersection of fossil energy and advanced manufacturing

- Nano-Manufacturing
- Big Data
- Process Intensification (RAPID)
- Additive Manufacturing (America Makes)
- Robotics (ARM)
- Machine Learning
- Cyber-Physical
- Artificial Intelligence



Cyber Physical Modeling

Additive Manufacturing

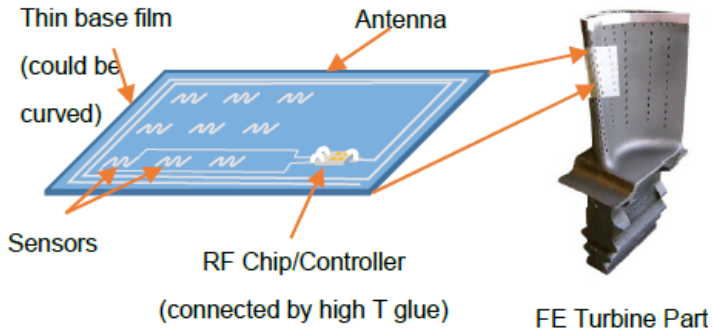
NETL Strengths: Advanced Manufacturing in Fossil Energy

Compelling Applications

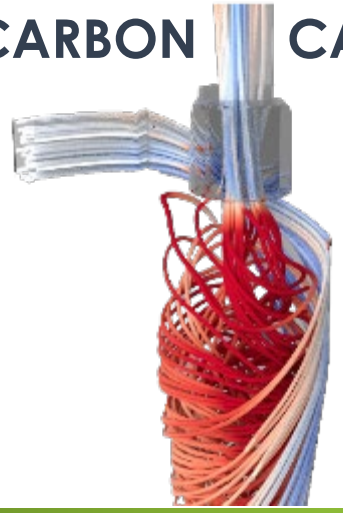
STRUCTURAL MATERIALS

GAS TURBINES

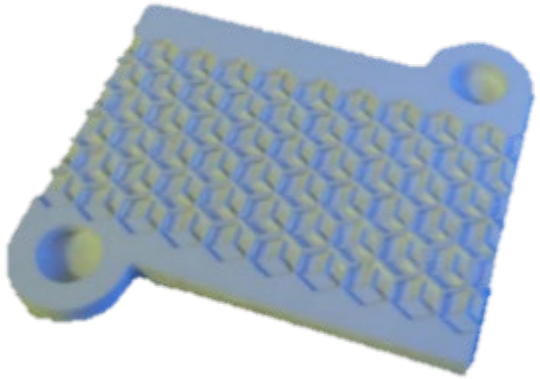
SENSORS & CONTROLS



CARBON CAPTURE



HEAT EXCHANGERS



SOLID OXIDE FUEL CELLS

Materials Engineering & Manufacturing

NATIONAL ENERGY TECHNOLOGY LABORATORY

Functional and Structural materials solutions to enable efficient and effective power cycles and resource recovery

Materials:

- Soft materials
- Engineered nano-materials
- Advanced alloys
- Composites & ceramics

Current Thrusts:

- Heat resistant & corrosion resistant alloys
- Magnetic alloys
- Environmental barrier coatings & materials
- Sensors for process monitoring & system integrity
- Carbon products from coal
- Rare earth elements from coal & coal by-products
- CO_2 capture and utilization materials
- Oxygen carriers

NETL Strengths: Coal-based Carbon Nanomaterials

NATIONAL ENERGY TECHNOLOGY LABORATORY

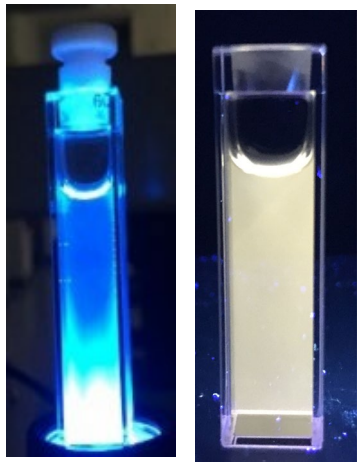
Domestic Char

(Sample from Virginia Carbonite)

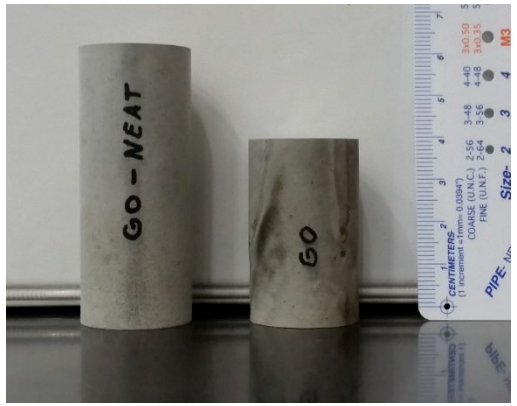
Coal Processing Technology

Low Cost Graphene Inks/Fluids

Carbon Quantum Dots



Graphene-Enhanced Cement



Engineered Plastics

Possible Modern Applications for Coal-derived Carbon Materials

New branches & limbs for a modern coal products tree
This is a small example of what scientists think may be possible

Stain & Water Resistant Textiles

Electronic Displays

Pigments, Dyes, & Paints

Optical Brighteners

Photovoltaics & LEDs

Carbon Fiber

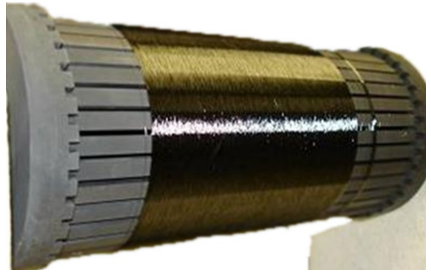


Image: CAER – U Ky, M. Weisenberger

3D Printing Materials

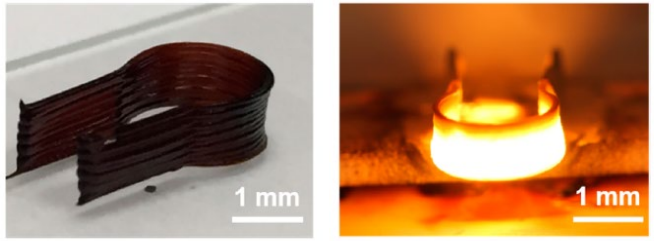
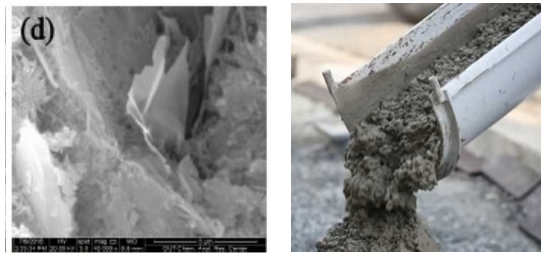


Image: Yao et. al. ACS Nano 2016 pgs 5272-5279

Additives For Construction Materials



SEM: Wang et. al. nanomaterials 2016, 6, 200

Carbon Nanomaterials

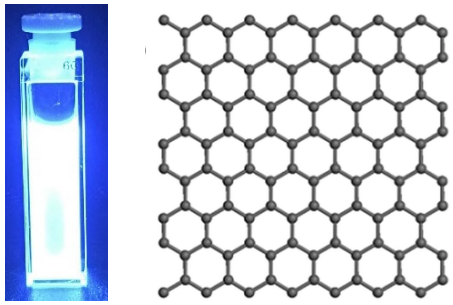


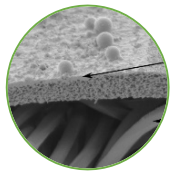
Image: NETL, Functional Materials Team

Domestic Coal for Materials Manufacturing

NATIONAL ENERGY TECHNOLOGY LABORATORY

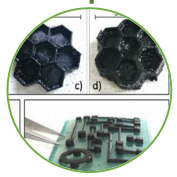
SMART TEXTILES

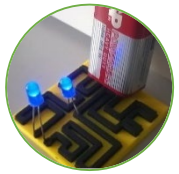
Stain/Water Resistant Clothing



3D PRINTING MATERIALS

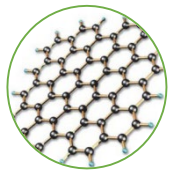
Fluids, Filaments, Plastics, & Devices





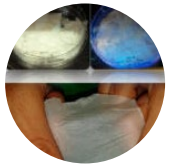
CARBON NANOMATERIALS

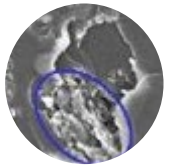
Graphene, Graphene Oxide, & Carbon Quantum



PLASTIC COMPOSITES

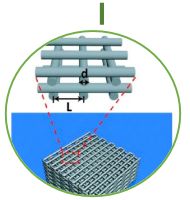
Enhanced Plastics





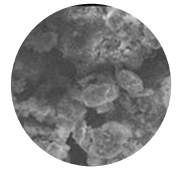
ENERGY STORAGE MATERIALS

Supercapacitors & Electrode Materials



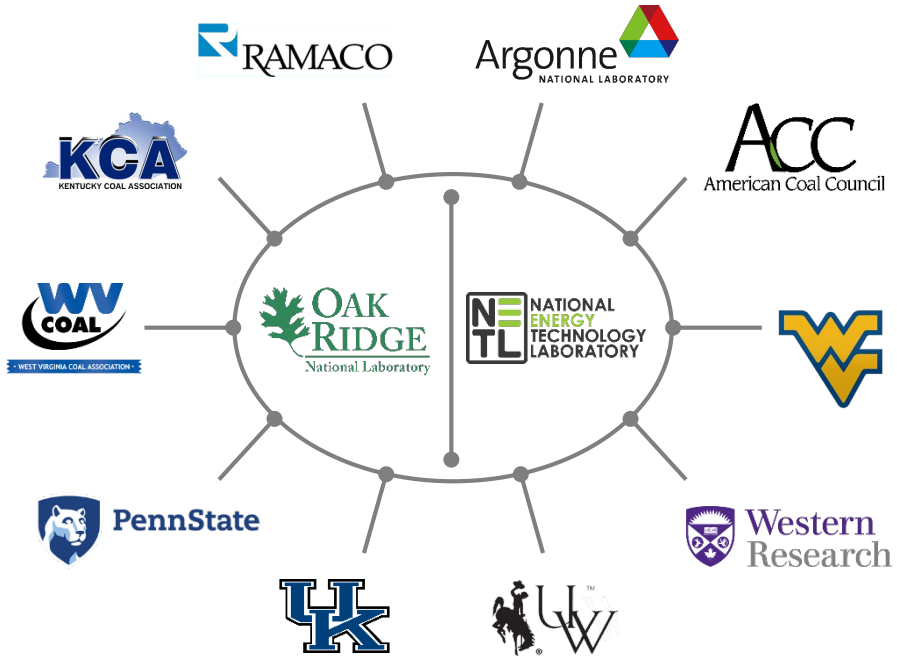
STRUCTURAL & BUILDING MATERIALS

Structural Cements

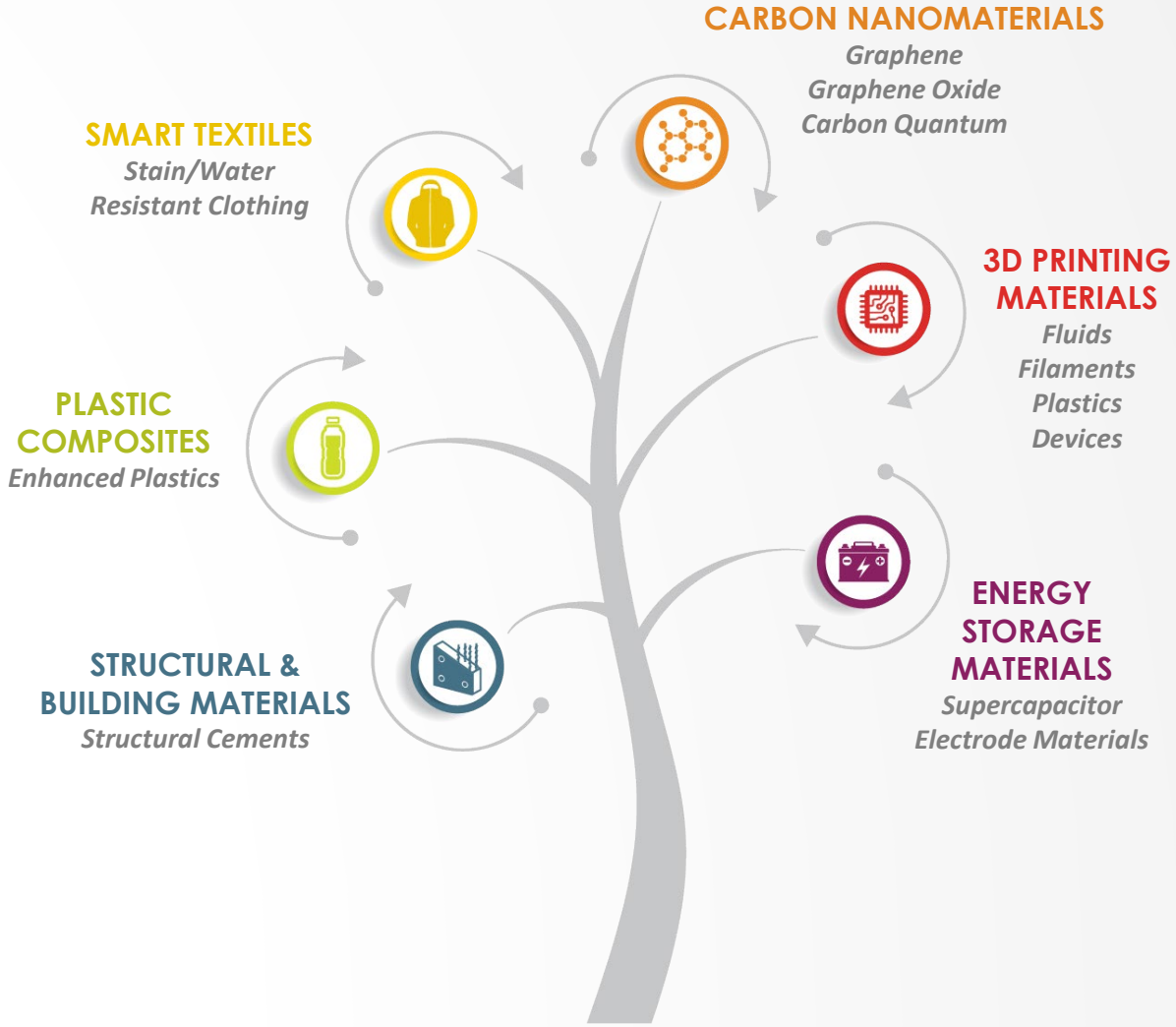


Converting Coal Into High-Value Added Products

Current and Potential Stakeholders for NETL



Consortium with Leading Coal-Producing States, Community Colleges, & Economic Development Programs

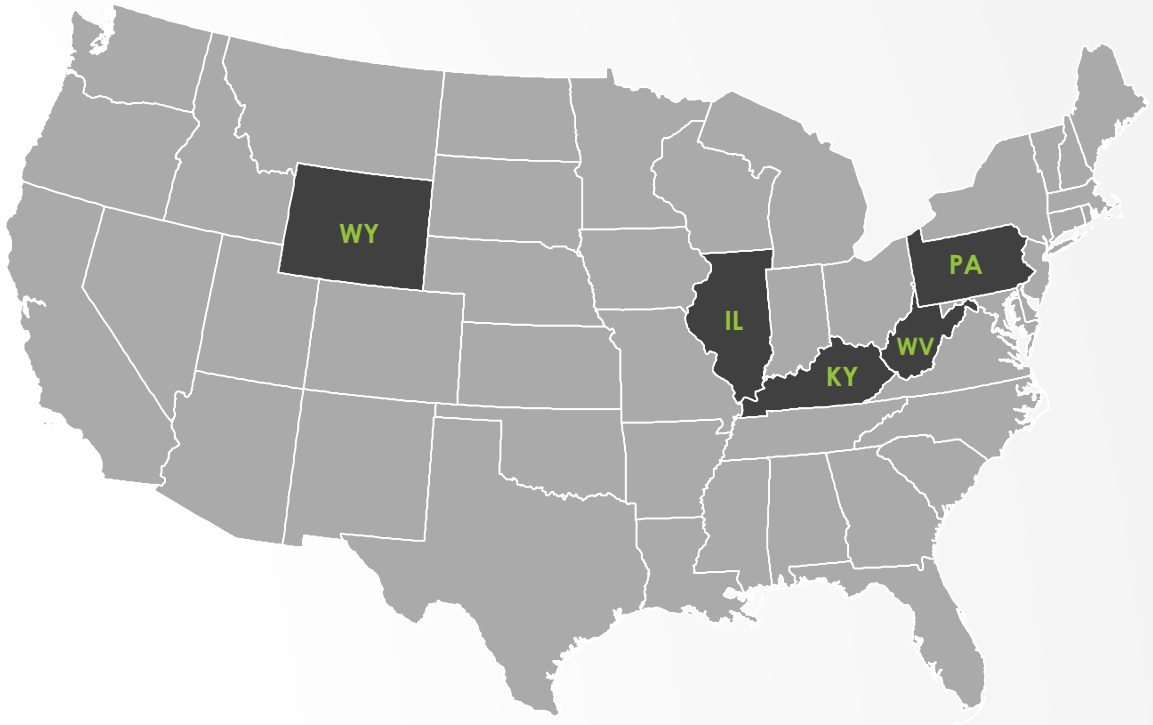


Converting Coal Into High-Value Added Products

Current and Potential Stakeholders for NETL

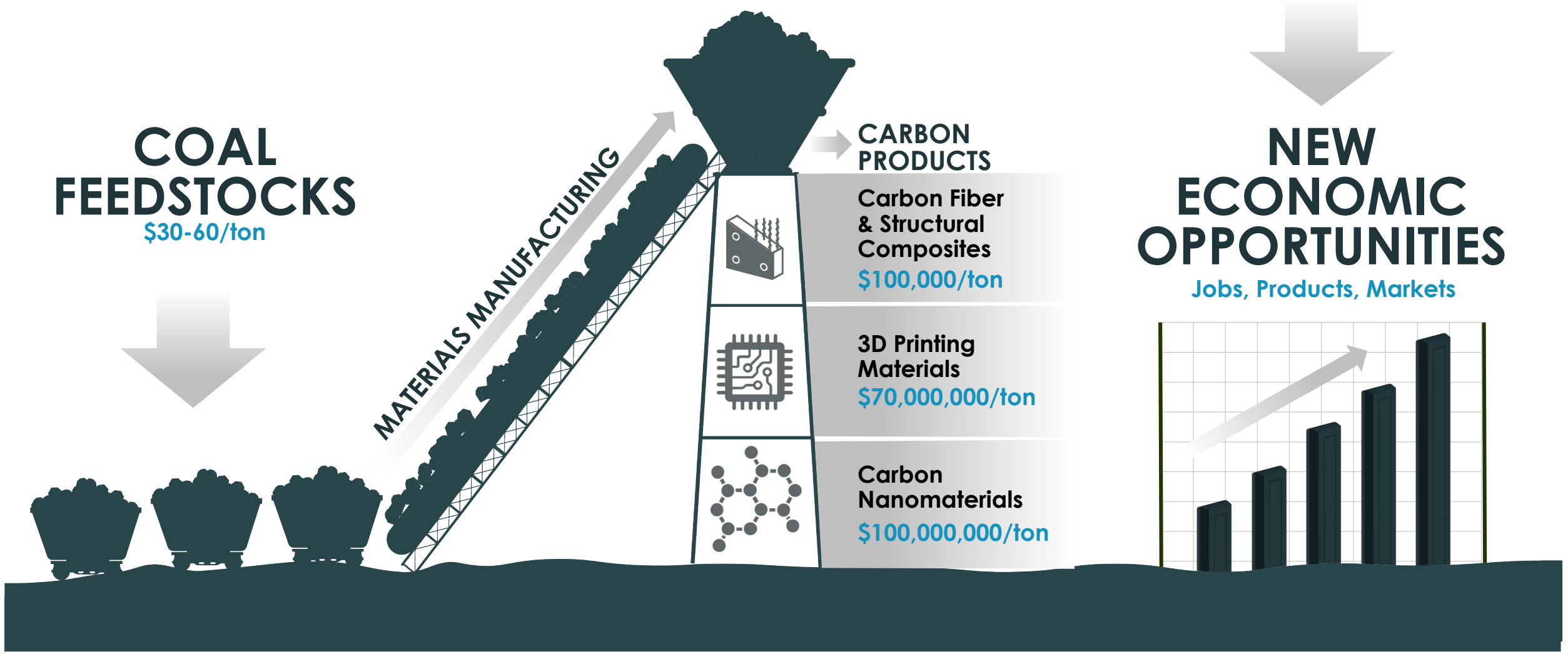
SUPPORTED BY

Community Colleges and State Economic Development Programs



Consortium with Leading Coal-Producing States

High-Value Carbon Products from Domestic Coal



Advanced Manufacturing – Key Partnerships

Carnegie Mellon University (CMU)

The CMU NextManufacturing Center is one of the world's leading research centers for additive manufacturing (AM), commonly known as 3-D printing. The center leverages knowledge from across disciplines to develop an entirely new approach to AM: design optimization, materials selection and characterization, process parameter mapping, software development, final part inspection, and qualification. NETL has the potential to significantly benefit from a R&D partnership with the NextManufacturing Consortium.

University of Pittsburgh (Pitt)

NETL funds several projects at the University of Pittsburgh, including an ongoing multiyear project through the Swanson School of Engineering on a project to develop an innovative approach to providing improved thermal protection for hot-section components in modern and future gas turbines. This project makes use of Oxide Dispersion Strengthened (ODS) material to form a thermal-oxidation protection layer over a single crystal superalloy substrate, in conjunction with the concept of near-wall cooling modules or coupons.

Penn State University (PSU)

In 2016, PSU was selected by the DOE and NETL as the lead institution to establish the University Coalition for Fossil Energy Research, with the goal to bring together researchers from multiple universities across various disciplines to advance fossil-based energy technologies. This six-year initiative is being funded for $20 million.

West Virginia University (WVU)

In 2017, WVU joined RAPID in an effort to turn natural gas into valuable products. WVU was invited to participate as part of the core team to strategize the American Institute for Chemical Engineering. West Virginia's vital resources are abundant, yet untapped. WVU is heading advanced manufacturing research initiatives to lead growth and opportunity in the conversion of natural gas and other hydrocarbons utilizing smaller modular manufacturing reactors. The idea of "mobile factories" has the potential to give WVU a lead in the right direction of a positive economic outlook.

America Makes (National Additive Manufacturing Innovation Institute)

NETL joined America Makes (National Additive Manufacturing Innovation Institute) in December 2016 to team with the nation's leading additive manufacturing and 3D-Printing technology research, discovery, and creation company that also offers a close proximity to the Appalachian region.

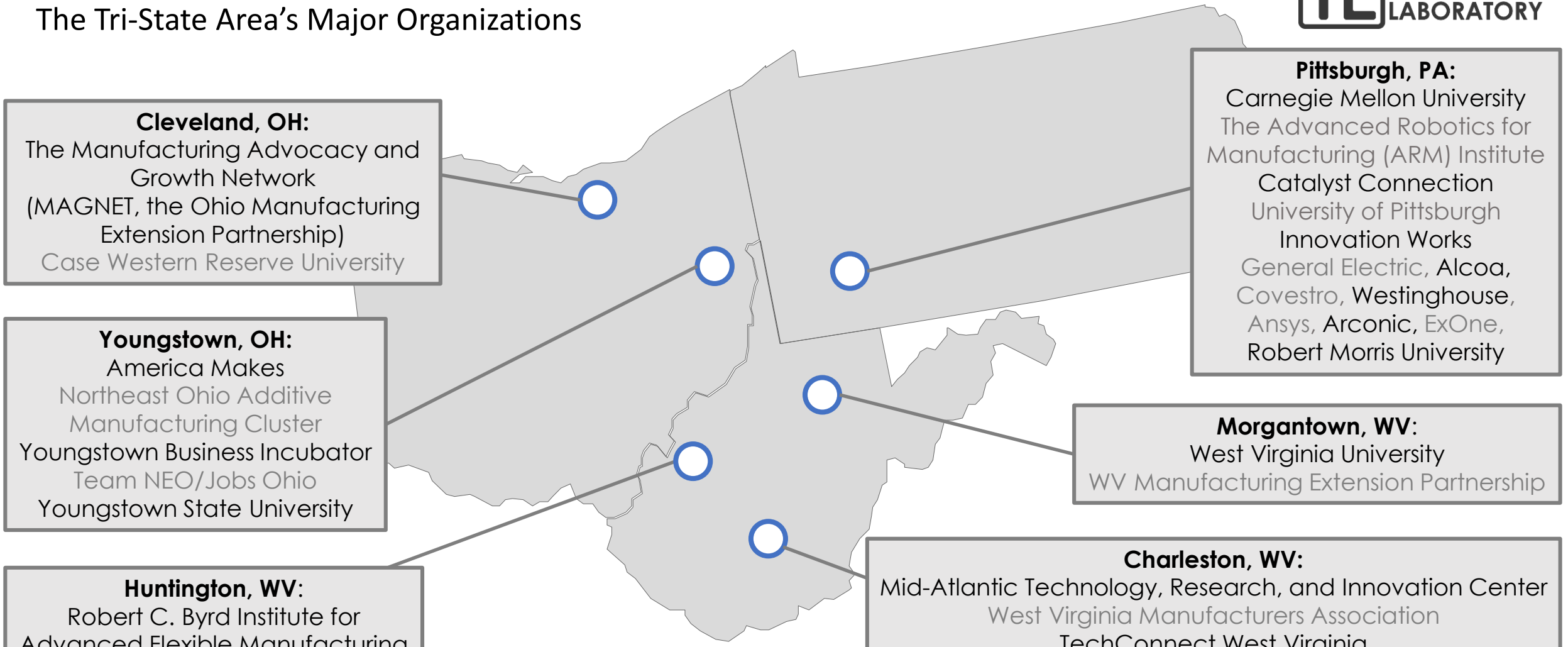
RAPID Manufacturing Institute (AIChE)

In December 2016, the DOE announced that the Rapid Advancement in Process Intensification Deployment (RAPID) Manufacturing Institute of the American Institute of Chemical Engineers (AIChE) will be the newest, and tenth, member of the nation's network of Manufacturing USA Institutes. This partnership will enhance NETL's relationship with manufacturing R&D across government, university, and private sectors.

Advanced Manufacturing: A Regional View

NATIONAL ENERGY TECHNOLOGY LABORATORY

The Tri-State Area's Major Organizations



Cleveland, OH:
The Manufacturing Advocacy and Growth Network (MAGNET, the Ohio Manufacturing Extension Partnership)
Case Western Reserve University

Youngstown, OH:
America Makes
Northeast Ohio Additive Manufacturing Cluster
Youngstown Business Incubator
Team NEO/Jobs Ohio
Youngstown State University

Huntington, WV:
Robert C. Byrd Institute for Advanced Flexible Manufacturing
Marshall University

Pittsburgh, PA:
Carnegie Mellon University
The Advanced Robotics for Manufacturing (ARM) Institute
Catalyst Connection
University of Pittsburgh
Innovation Works
General Electric, Alcoa, Covestro, Westinghouse, Ansys, Arconic, ExOne,
Robert Morris University

Morgantown, WV:
West Virginia University
WV Manufacturing Extension Partnership

Charleston, WV:
Mid-Atlantic Technology, Research, and Innovation Center
West Virginia Manufacturers Association
TechConnect West Virginia

Appalachian Coal Country: Major Stakeholders

NATIONAL ENERGY TECHNOLOGY LABORATORY

Initiating & Enhancing Collaborative Partnerships

INDUSTRY PARTNERSHIPS

covestro
RANGE RESOURCES
EQT
LG
Chevron
EATON
FirstEnergy
LONGVIEW POWER
Battelle
GE
Dominion
Shell
UES Excellence in Science & Technology
PPG
AIR PRODUCTS
AEP AMERICAN ELECTRIC POWER

GOVERNMENTAL PARTNERSHIPS

National Association of Regulatory Utility Commissioners
National Governors Association
National Association of Counties NACo
NASEO National Association of State Energy Officials
OAK RIDGE National Laboratory
National Conference of State Legislatures The Forum for America's Ideas
The Seal of the City of Pittsburgh
Tri-State Shale Coalition
COAL PENNSYLVANIA COAL ALLIANCE

ACADEMIC PARTNERSHIPS

Tri-State University Energy (TrUE) Alliance
Case Western Reserve University
Frostburg State University
Virginia Tech
Carnegie Mellon University
The Ohio State University
Youngstown State University
Penn State
University of Maryland
Marshall
Tennessee State University
West Virginia University
Tennessee Tech Golden Eagles
University of Cincinnati
Ohio University
University of Kentucky
University of Pittsburgh

NONGOVERNMENT PARTNERSHIPS

Appalachia Storage & Trading HUB
Allegheny Conference on Community Development
United Mine Workers of America
America Makes
TECHCONNECT West Virginia
ShaleNET Educate, Collaborate, Succeed.
CURC Carbon Utilization Research Council Advancing Fossil Energy Solutions
SOAR
MATRIC Market-Driven Innovation
CLAUDE WORTHINGTON BENEDUM FOUNDATION
gti
RAPID Manufacturing Institute
MARCELLUS SHALE COALITION
ARC Appalachian Regional Commission
RAND Corporation
NRECA America's Electric Cooperatives
Southern States Energy Board
RCBI Robert C. Byrd Institute ADVANCING MANUFACTURING TECHNOLOGIES

Education and Training for Manufacturing Careers

Attachment B: Tri-State TalentNET (ShaleNET/ManufactureNET) Occupational Pathways

	Industrial Maintenance Multi-Skilled Mechatronics	Automation Robotics	Welding	Tooling & Machining	Process Operations	Industry/Sector Specific Pathways	
	Industries/sectors relevant for each of these occupational pathways: Construction; Oil & Gas; Other Energy; Utilities; Advanced Manufacturing; Logistics					***Oil & Gas***	***Plastics Mfg.***
Bachelors Degree	**1 of 5 colleges (PCT)** • Mechanical Engineer • Mechatronics Engineer • Industrial Engineer	**0 of 5 colleges** • Robotics Engineer • Mechanical Engineer	**1 of 5 colleges (PCT)** • Materials Engineer • Mechanical Engineer	**1 of 5 colleges (PCT)** • Mechanical Eng. • Industrial Engineer	**1 of 5 colleges (PCT)** • Industrial Engineer • Applied Process Engineer	**1 of 5 colleges (PCT)** • Electrical Engineer	**1 of 5 colleges (PCT)** • Chemical Engineer • Materials Engineer
Applied Associates Degree	**5 of 5 colleges (CCBC, PCT, Pierpont, Stark, WCCC)** • Electro-mechanical Technician • Industrial Technician	**3 of 5 colleges (PCT, Stark, WCCC)** • Robotics Technician • Electro-Mechan. Tech. • Mechanical Eng. Tech.	**3 of 5 colleges (PCT, Stark, WCCC)** • Welding Inspector • Pipe/Steamfitter • Tool & Die Maker • Industrial Mechanic	**4 of 5 colleges (PCT, Pierpont, Stark, WCCC)** • CNC Machine Tool Operator/Programmer • Drilling & Boring Machine Tool Setter	**5 of 5 colleges (CCBC, PCT, Pierpont, Stark, WCCC)** • Process Operations Technician • Plant Manager	**5 of 5 colleges (CCBC, PCT, Pierpont, Stark, WCCC)** • Welder • Gas/Oil Plant Manager • Process Manager	**1 of 5 colleges (PCT)** • Machine Tool Operator
Academic Certificates	**4 of 5 colleges (CCBC, PCT, Stark, WCCC)** • Industrial Technician • Instrumentation Technician • Electrical Technician	**2 of 5 colleges (CCBC, Stark)** • Robotics Technician • Electrical & Electronics Technician	**3 of 5 colleges (PCT, Stark, WCCC)** • Steel Metal Worker • Welder/Cutter • Welder Fitter	**3 of 5 colleges (PCT, Stark, WCCC)** • Machinists • Tool & Die Makers	**0 of 5 colleges** • Process Technician	**3 of 5 colleges (Pierpont, Stark, WCCC)** • Pipeline Technician • Process Technician	**0 of 5 colleges** • Pattern Makers
Entry-Level Industry Certificates (Noncredit)	**3 of 5 colleges (PCT, Stark, WCCC)** • Maintenance Worker • Maintenance Apprentice	**1 of 5 colleges (WCCC)** • Electrical/Basic Robotics	**4 of 5 colleges (CCBC, PCT, Stark, WCCC)** • Welder's Helper • Structural Iron/Steel Worker	**2 of 5 colleges (Stark, WCCC)** • CAD Drafter • Precision Machinist • CNC Operator	**1 of 5 colleges (WCCC)**	**5 of 5 colleges (CCBC, PCT, Pierpont, Stark, WCCC)** • Service Unit Operator • Roustabout • CDL	**0 of 5 colleges** • Plating/Coating Machine Setter

Contact Information

For More Information, Contact James Ferguson

James.Ferguson@netl.doe.gov

(412) 386-6043

www.netl.doe.gov

Rare Earth Elements

A Promising Opportunity

Morgan Summers (William.Summers@netl.doe.gov , 304-285-1318)
Thomas Tarka (Thomas.Tarka@netl.doe.gov; 412-386-5434)

TTCs: John Baltrus, Evan Granite, Bret Howard,
Kelly Rose, W. Morgan Summers

Key Contributors: Christina Lopano, Circe Verba, Mac Gray, and too many others to list.

NATIONAL ENERGY TECHNOLOGY LABORATORY

Rare Earth Elements (REE) FWP

BLUF

NETL researchers have made significant advances in developing transformational technologies to reduce the cost and environmental footprint of REE production from coal and related feedstocks:

- Produced "Ore Quality" REE from several feedstocks (>2wt%)
- Developed enabling technologies (e.g. sensors) and performed valuable market and systems analyses, both of which reduce risk to deployment
- Developed methods to locate high concentrations of coal and related REE reserves

Image from https://www.flickr.com/photos/piedmont_fossil/5710636433

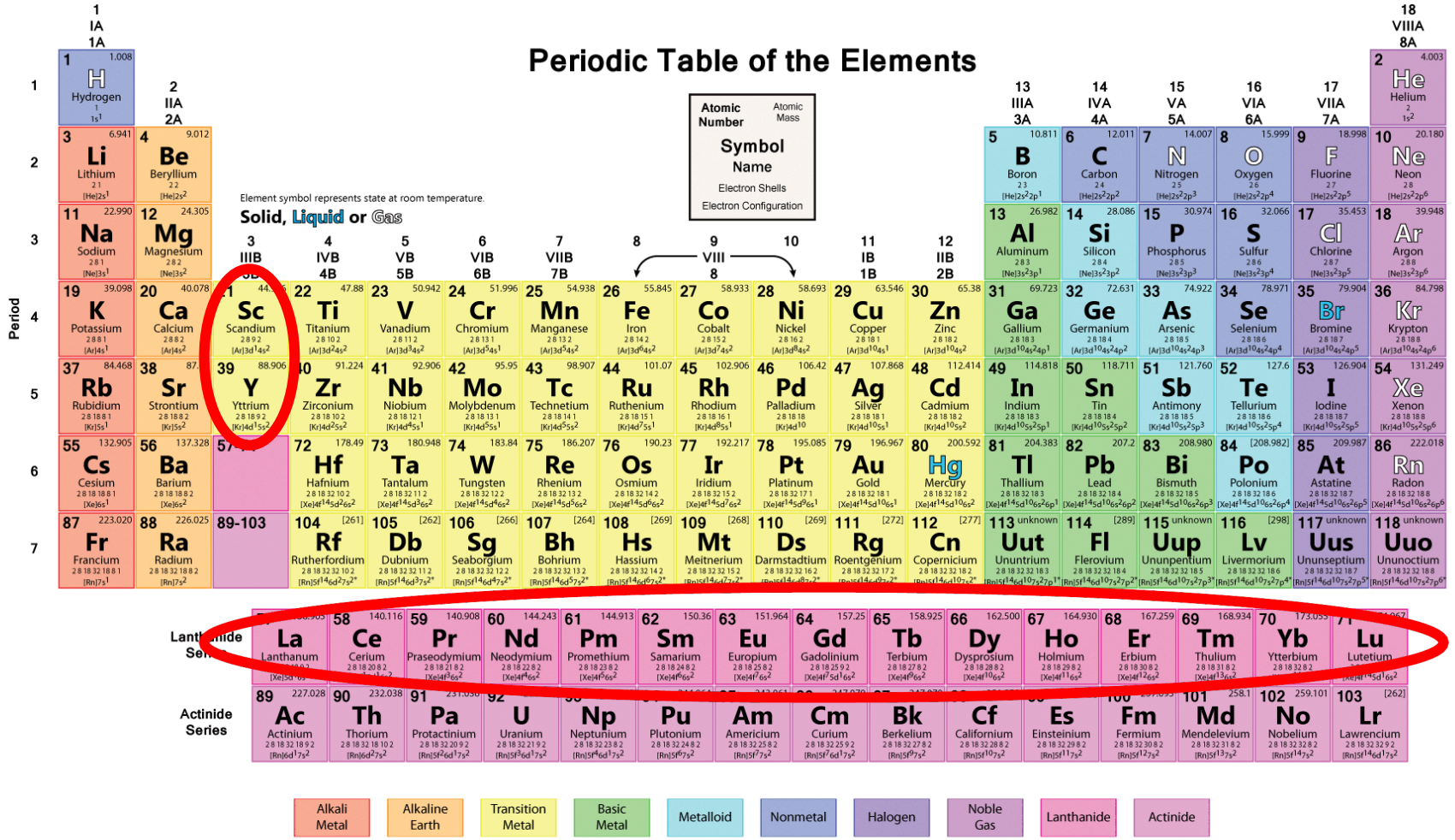
EY19 work focuses on maturing several transformational separations pathways while simultaneously driving innovation through development of tools and capabilities to unlock domestic REE resources:

- Repeatable results at increasing scales (from 1 milligram to grams)
- Identifying commercialization opportunities and partners
- Developing the tools to reduce commercialization time and risk (CFD & Systems Analysis)
- Identifying the best coal-related resources and reserves for a domestic REE industry

Outline

- **Background**
  - Brief Overview of REE
  - Challenges and Opportunities for REE Production from Coal
  - REE FWP Strategy
  - Where We've Been
- **Recent Major Accomplishments**
  - Real-Time, Portable Detection Equipment
  - Production of "Ore Quality" REE from Several Coal-related Feedstocks
  - Continued Strong SEA Support
  - Taking the Next Step in Locating Promising Resources
- **The Path Forward**

What are Rare Earth Elements (REEs)?



Average total crustal concentration = 184 ppm

**Wedephol, 1995*

Uses for Rare Earth Elements

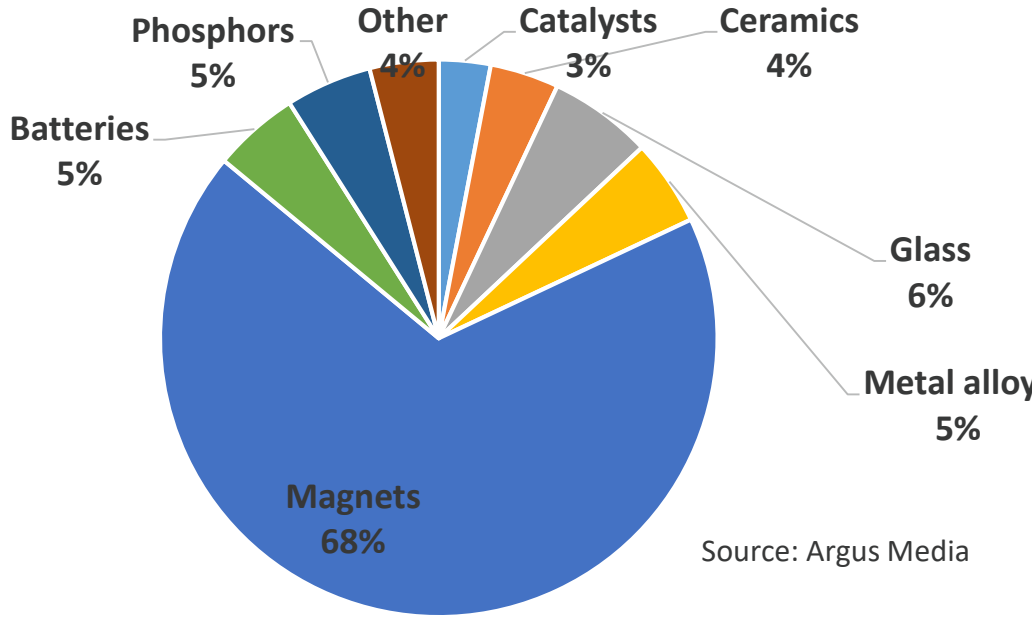
21 44.956 Sc Scandium 2 8 9 2 [Ar]3d¹4s²	57 138.905 La Lanthanum 2 8 18 18 9 2 [Xe]5d¹6s²	58 140.116 Ce Cerium 2 8 18 20 8 2 [Xe]4f¹5d¹6s²	59 140.908 Pr Praseodymium 2 8 18 21 8 2 [Xe]4f³6s²	60 144.243 Nd Neodymium 2 8 18 22 8 2 [Xe]4f⁴6s²	61 144.913 Pm Promethium 2 8 18 23 8 2 [Xe]4f⁵6s²	62 150.36 Sm Samarium 2 8 18 24 8 2 [Xe]4f⁶6s²	63 151.964 Eu Europium 2 8 18 25 8 2 [Xe]4f⁷6s²	64 157.25 Gd Gadolinium 2 8 18 25 9 2 [Xe]4f⁷5d¹6s²	65 158.925 Tb Terbium 2 8 18 27 8 2 [Xe]4f⁹6s²	66 162.500 Dy Dysprosium 2 8 18 28 8 2 [Xe]4f¹⁰6s²	67 164.930 Ho Holmium 2 8 18 29 8 2 [Xe]4f¹¹6s²	68 167.259 Er Erbium 2 8 18 30 8 2 [Xe]4f¹²6s²	69 168.934 Tm Thulium 2 8 18 31 8 2 [Xe]4f¹³6s²	70 173.055 Yb Ytterbium 2 8 18 32 8 2 [Xe]4f¹⁴6s²	71 174.967 Lu Lutetium 2 8 18 32 9 2 [Xe]4f¹⁴5d¹6s²
39 88.906 Y Yttrium 2 8 18 9 2 [Kr]4d¹5s²	89 227.028 Ac Actinium 2 8 18 32 18 9 2 [Rn]6d¹7s²	90 232.038 Th Thorium 2 8 18 32 18 10 2 [Rn]6d²7s²	91 231.036 Pa Protactinium 2 8 18 32 20 9 2 [Rn]5f²6d¹7s²	92 238.029 U Uranium 2 8 18 32 21 9 2 [Rn]5f³6d¹7s²	93 237.048 Np Neptunium 2 8 18 32 23 8 2 [Rn]5f⁴6d¹7s²	94 244.064 Pu Plutonium 2 8 18 32 24 8 2 [Rn]5f⁶7s²	95 243.061 Am Americium 2 8 18 32 25 8 2 [Rn]5f⁷7s²	96 247.070 Cm Curium 2 8 18 32 25 9 2 [Rn]5f⁷6d¹7s²	97 247.070 Bk Berkelium 2 8 18 32 27 8 2 [Rn]5f⁹7s²	98 251.080 Cf Californium 2 8 18 32 28 8 2 [Rn]5f¹⁰7s²	99 [254] Es Einsteinium 2 8 18 32 29 8 2 [Rn]5f¹¹7s²	100 257.095 Fm Fermium 2 8 18 32 30 8 2 [Rn]5f¹²7s²	101 258.1 Md Mendelevium 2 8 18 32 31 8 2 [Rn]5f¹³7s²	102 259.101 No Nobelium 2 8 18 32 32 8 2 [Rn]5f¹⁴7s²	103 [262] Lr Lawrencium 2 8 18 32 32 9 2 [Rn]5f¹⁴6d¹7s²

Average total crustal concentration = 184 ppm

*Wedephol, 1995

Rare Earth Elements Market

- **Annual global market ~$5 billion in 2015**
  - U.S. consumes ~11%, by volume
  - Almost all REEs are imported
- **Majority of REEs imported as part of finished goods, not raw materials**
  - US imported $2.4 trillion worth of REE-containing finished goods in 2017
  - Electronic equipment imports :
    ~$357 billion in 2017 (14.8% of total)
  - Phone devices (e.g. iPhone) almost a third of that at $113 billion
  - Cellular phone can contain as many as 16 different REEs
- **Market remains complicated**
  - Risks of substitution
  - Current oversupply
  - All global enrichment and processing is done in China



Source: Argus Media

2017 Estimated REO Consumption by Industrial (Value)

Source: http://www.worldstopexports.com/united-states-top-10-imports/

Rare Earth Element Usage

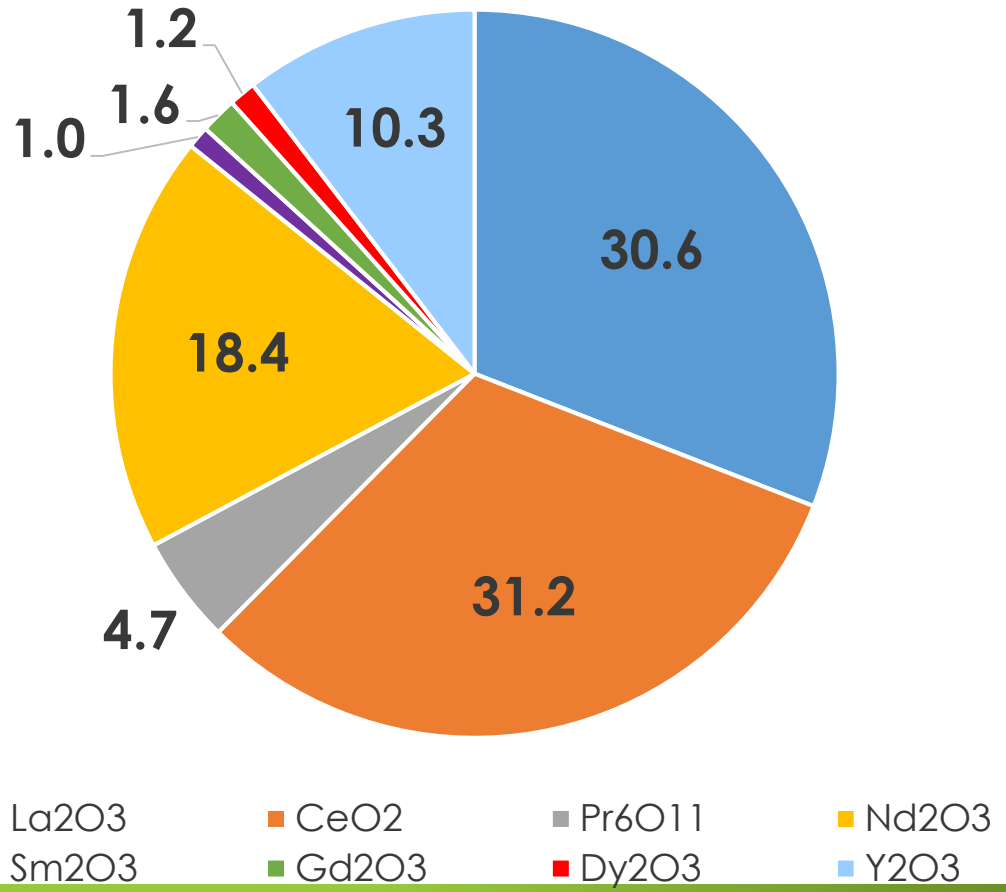
Global Rare Earth Oxide (REO) Usage from 2005-2015

Most used REOs were:

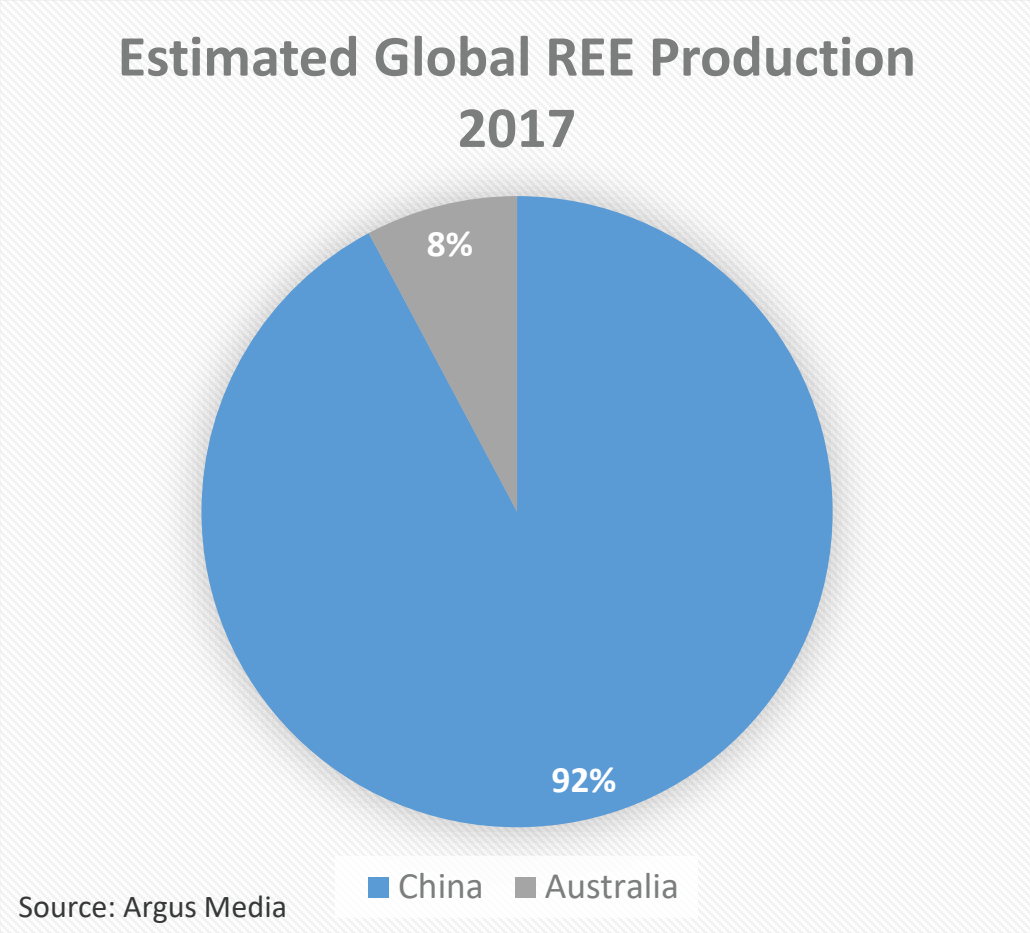
- Cerium Oxide (32%)
  - Catalyst related products and glass polishing powders and additives
- Lanthanum Oxide (31%)
  - Catalyst related products and glass polishing powders and additives
- Neodymium Oxide (18%)
  - Permanent magnets
- Yttrium Oxide (10%)
  - Ceramics, pigments and glazes, and glass polishing and powder additives
- Praseodymium Oxide (5%)
  - Permanent magnets

- **Global consumption of LREOs increased at a CAGR OF 2.8%, while global consumption of HREOs increased at a CAGR of 1.5%**

Average Percentage Consumption from 2005-2015

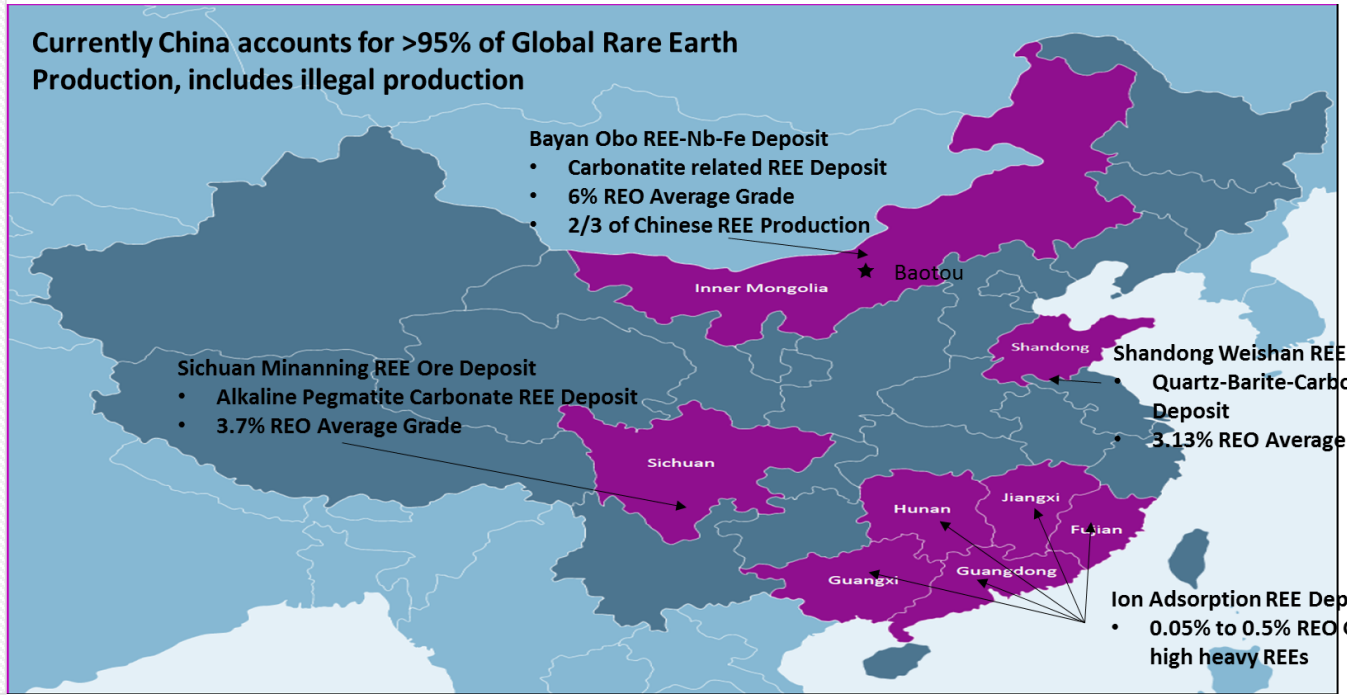


REE Production



Source: Argus Media

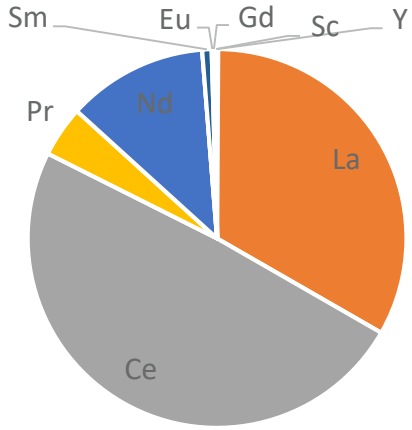
- Total REO Production Estimated at 170,000 tonne/year
- Total REO Demand Estimated at ~150,000 tonne/year
- US accounts for ~11% of Global Demand
- Actual Chinese production >92% including illegal mining



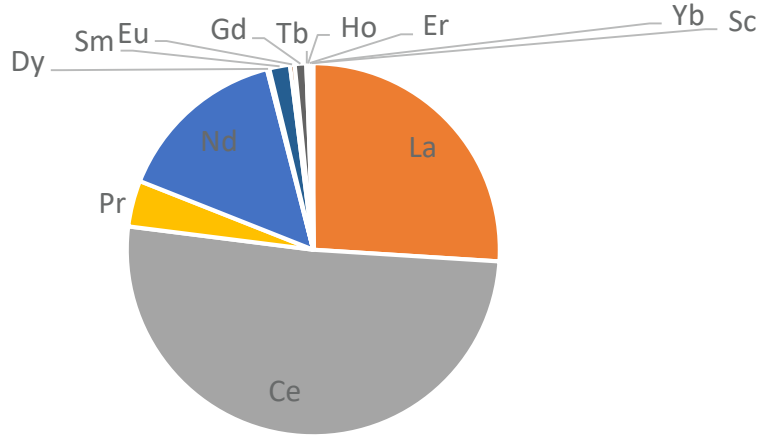
http://www.eurare.eu/docs/eres2014/firstSession/XiaoshengYang.pdf

Rare Earth Deposits

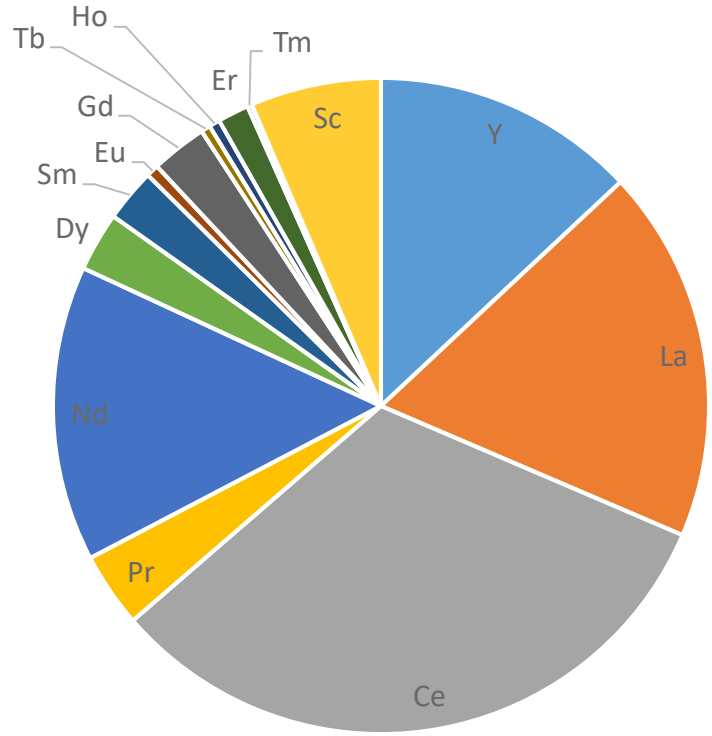
Mountain Pass (Bastnasite) ~8% REO



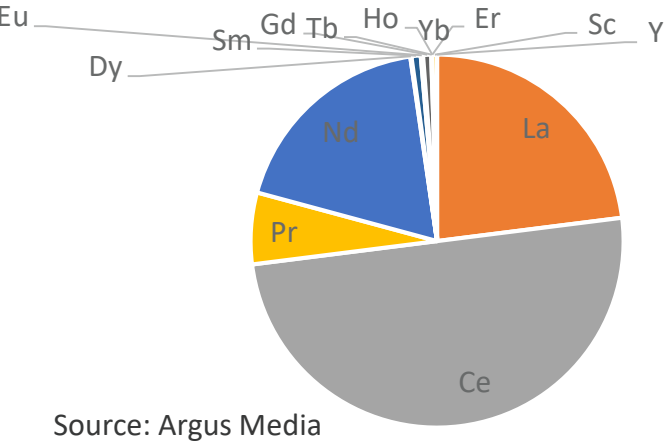
Mount Weld (Monazite) ~8% REO



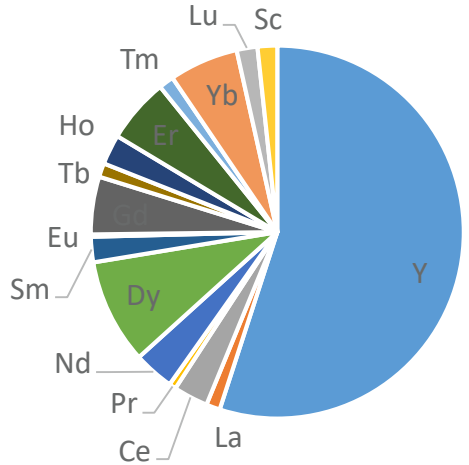
Coal <0.1% REO



Bayan Obo (Bastnasite) ~6% REO



Southeast Guangdong (Xenotime) ~0.5% REO



Source: Argus Media

REE from Coal: The Challenge

Where do we get it? and What do we produce?

- **Low Concentration in Coal Feedstocks**
  - Ranges from parts per billion (ppb) in AMD to ~1,500 parts per million (ppm) in certain ashes
  - Global REE ores in current use range from 0.5 wt% (5,000 ppm) to 50wt% (500,000 ppm) with major deposits generally near 8wt%

- **Currently No Domestic Supply Chain**
  - No clear domestic off-take except for "saleable" (>90+%) REO or "REO baskets"
  - Creates uncertainty as to what concentration domestic processes should target

- **Very Broad Problem**
  - Almost too many coal and related feedstocks to target: which is best?
  - Are REE the product or co-product?
  - Each coal-related feedstock is different, even within same category

REE from Coal: A Unique Opportunity

Importance to the Fossil Energy and DOE Mission

- **National Security**
  - 5% of total domestic demand is deemed "critical" by the Department of Defense (DoD)
  - Required for numerous critical industries (energy, manufacturing, etc.)
  - Necessary for numerous clean energy technologies which have been deemed a national priority

- **Power the U.S. Economy and keep electricity affordable:**
  - Additional value streams make coal more cost competitive & keep electricity prices low
  - Drives U.S. coal competitiveness in international markets, driving exports
  - Creates or maintains jobs in economically hard hit regions, such as Appalachia
  - Provides an important new domestic resource, allowing more manufacturing to locate in the U.S.

- **Environmental Stewardship**
  - Opportunity for remediation, and reducing waste streams from coal production & use
  - Beneficiated coal will burn more efficiently, creating less emissions
  - Produce REEs with a dramatically lower environmental footprint than overseas

REE from Coal: Size of the Opportunity

Coal Refuse Material & Combustion By-Products

Southern West Virginia coal preparation plants have produced over 1.8 billion tons of coarse refuse material over the last 60 years

- Potential value of $31.5 billion at 100% recovery
- Potential value of $9 billion at just 30% recovery

56 active coal preparation plants produce a course refuse with a potential of $3.2 billion annually in the our region.

(Source: University of Kentucky)

"By the year 2000, we will not be wasting our coal ash, in which geochemists have shown there is a notable concentration of rare elements, such as germanium and rare earths. We will be recovering those elements, **which by then will be critical materials in our economy**."

- Dr. Edward Steidle

Dean, PSU College of Earth & Mineral Sciences, **1952**

(Inducted into the National Mining Hall of Fame, October 23, 2015)

REE from Coal: Size of the Opportunity

Acid Mine Drainage Opportunities

- WVU reports that the REE concentration in some acid mine drainage (AMD) sludge samples they have analyzed exceeds most Chinese deposits, and has more of the valuable heavy REE.

- WVDEP's Office of Special Reclamation estimates the potential REE value AMD precipitates (sludge) at one of their treatment sites at $1.9 million
- Significant environmental benefits could come from cleaning up legacy coal refuse disposal sites and wet impoundments for post-combustion ash.
- The tailings/rejects from a future REE recovery process could be used as structural fill to remediate surface mine sites.

NETL REE R&D Strategy

How We are Approaching the Problem

- **Understanding the "Where" and "How" (Characterization)**
  - Driving the understanding of how REEs occur in coal and by-products
  - Developing the technologies needed for prospecting and new production means
- **"Cheap" and Environmentally Benign Production (Separations)**
  - Producing ore-quality and greater REE from coal and related materials
  - Combining processes for further efficiency and enrichment
  - Maturing promising transformational separations technologies and continuing to push the envelope
- **Smarter, Not Harder (CFD & Systems Analysis)**
  - Developing the cutting edge CFD models to help drive commercialization and scale up
  - Identifying process bottlenecks, research targets, and market opportunities through systems analysis
- **Driving Innovation, Unlocking the REE Potential of Coal**
  - Developing the tools for REE prospecting in coal basins
  - Identifying the best resources for exploitation – be it fly ash with high Ca content, underclays, or raw lignite

EY18 Major Accomplishments

Overview

- **Enabling Technologies**
  - Portable Devices for Accurate, Real-Time Detection of REE
  - Models that allow complex reactor modeling without needing to perform expensive experiments

- **Separations and Enrichment**
  - **Produced "Ore Quality" REE (i.e. >2wt%) from 3 Feedstocks**
  - Pursuing three promising pathways that address different feedstocks, from Fly Ash to AMD
  - Transformational Separations Research has Potential for Dramatic Cost Reductions

- **Systems Engineering and Analysis**
  - Understanding Domestic REE Needs through an Embedded Demand Database
  - Quantifying Benefits of Domestic Production by Looking at Existing REE Processes

- **Developed First Model to Predict Where REE Might be Concentrated in Coal**
  - Geo-spatial, Geologic Assessment Methodology to understand where REE occur
  - Currently being validated for Western coals, Appalachia is next

Thanks for your Attention!

NETL RWFI – Energy 101 Series

- Thank you for your participation!
- NETL.gov/RWFI
- Netl.rwfi@netl.doe.gov
- NETL RWFI E-Note

- US Energy and Employment Report Data for PA/WV/OH
- Future Energy 101 Webinars