Rare Earth Elements and Critical Minerals from Coal-Based Resources

NATIONAL ENERGY TECHNOLOGY LABORATORY

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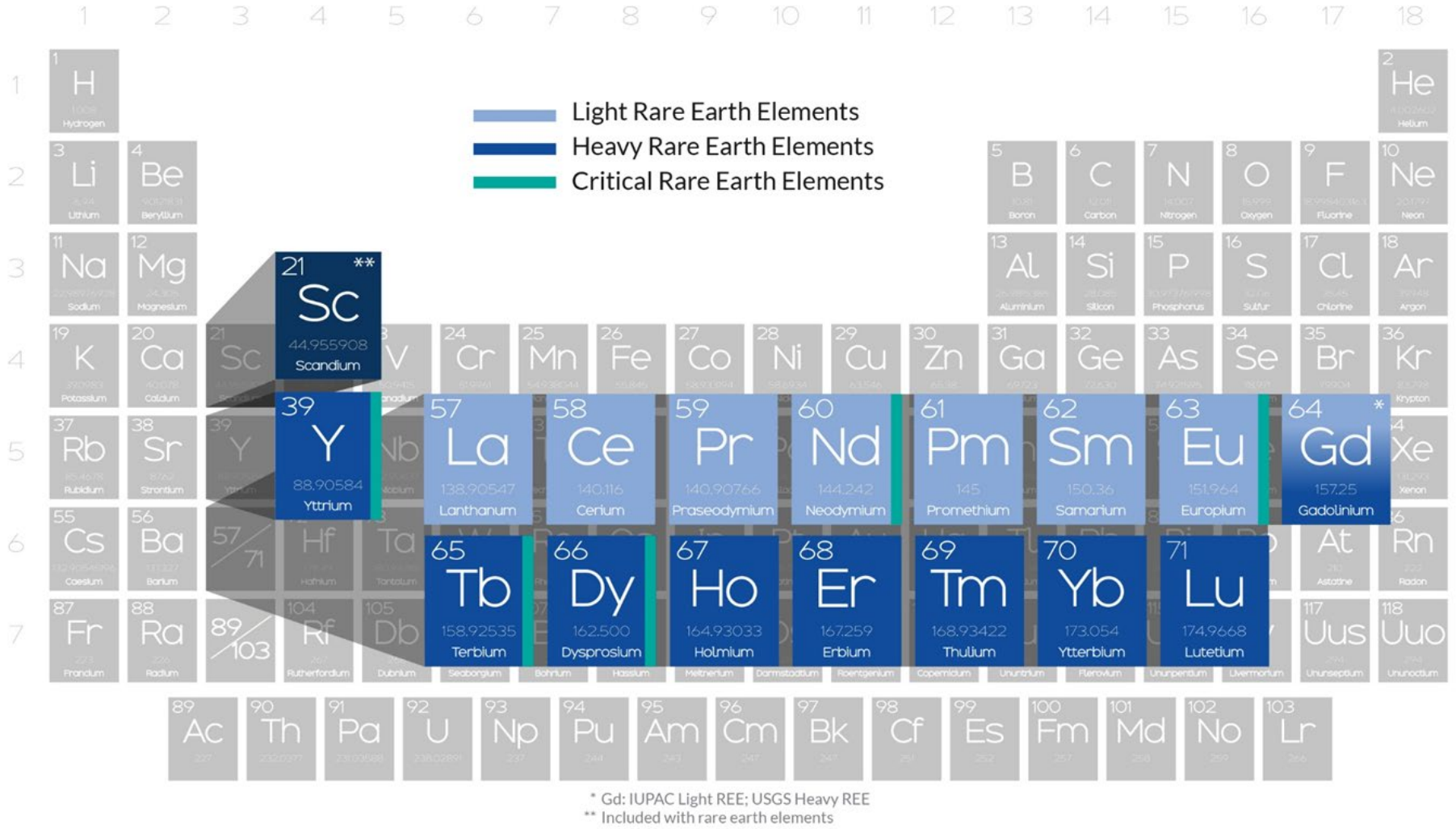
Access to Capital Forum and Workshop

Potential Market Opportunities in Coal-Based Products

Oglebay Resort & Conference Center
Wheeling,WV
March11, 2020

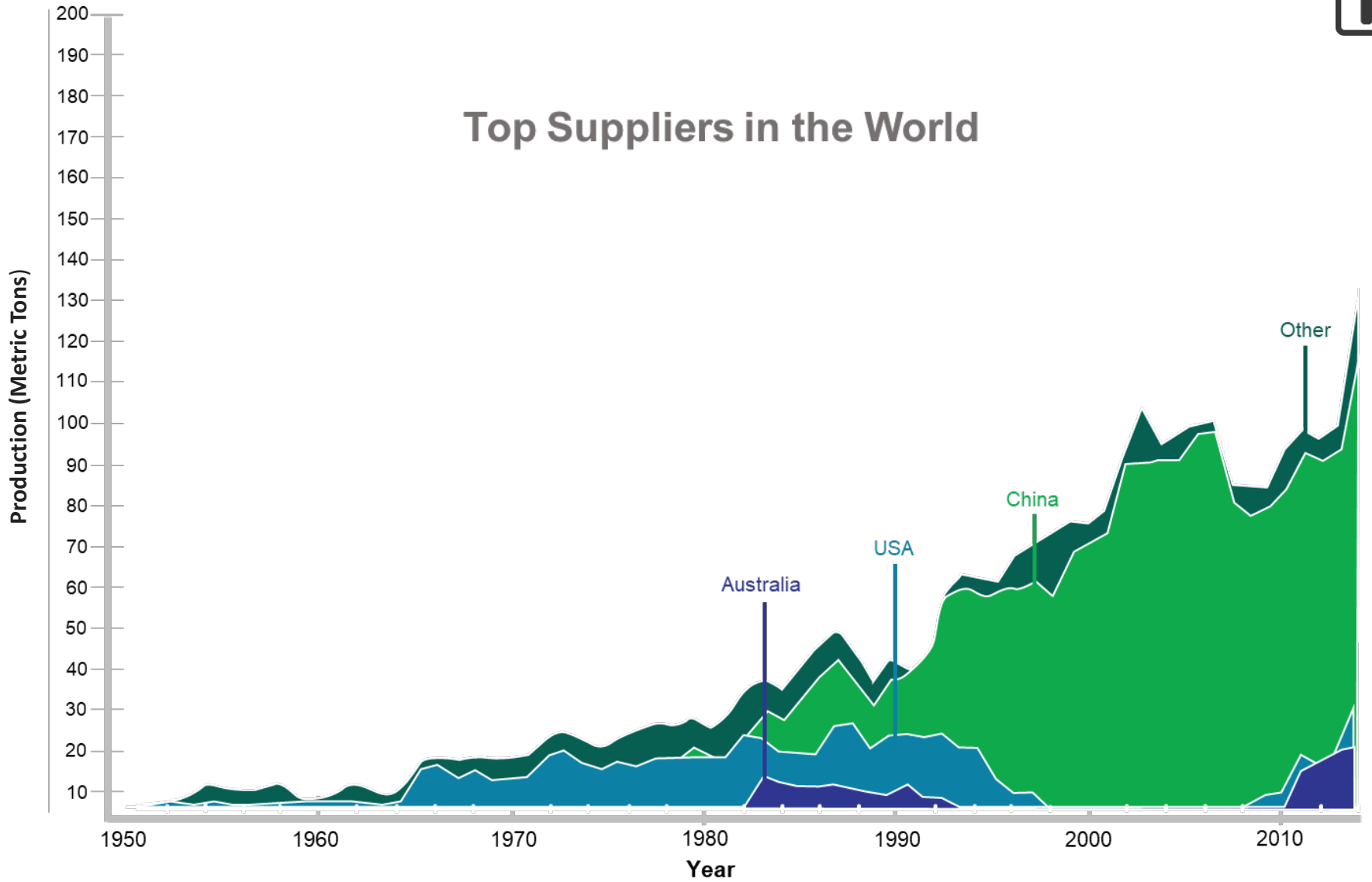
U.S. DEPARTMENT OF ENERGY

Rare Earth Elements (REEs)



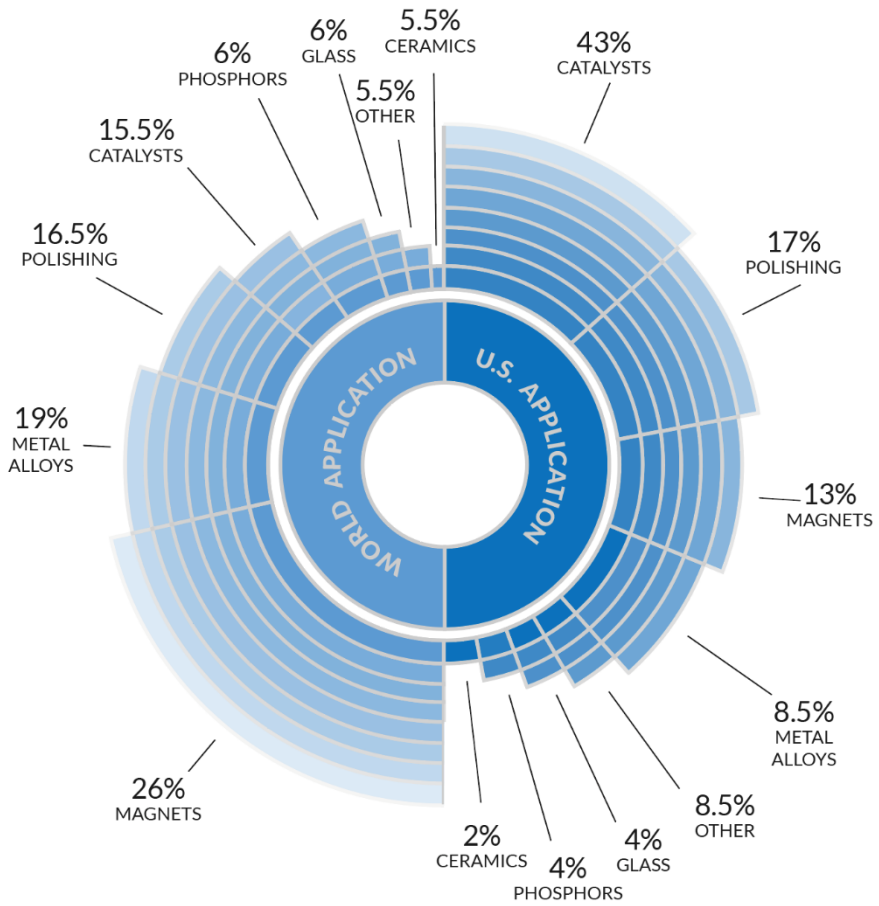
* Gd: IUPAC Light REE; USGS Heavy REE
** Included with rare earth elements

REE Suppliers



https://geology.com/articles/rare-earth-elements

REE Applications – Dual Use Materials



MAGNETICS

Computer Hard Drives
Disk Drive Motors
Anti-Lock Brakes
Automotive Parts
Frictionless Bearings
Magnetic Refrigeration
Microwave Power Tubes
Power Generation
Microphones & Speakers
Communication Systems
MRI

Nd Tb Dy Pr

METAL ALLOYS

NiMH Batteries
Fuel Cells
Steel
Super Alloys
Aluminum/Magnesium

Nd Y La Ce Pr

DEFENSE

Satellite Communications
Guidance Systems
Aircarft Structures
Fly-by-Wire
Smart Missiles

Nd Eu Tb Dy Y Lu Sm Pr La

CATALYSTS

Petroleum Refining
Catalytic Converter
Fuel Additives
Chemical Processing
Air Pollution Controls

Nd La Ce Pr

GLASS & POLISHING

Polishing Compounds
Pigments & Coatings
UV Resistant Glass
Photo-Optical Glass
X-Ray Imaging

Nd Gd Er Ho La Ce Pr

CERAMICS

Capacitors
Sensors
Colorants
Scintillators
Refractories

Nd Y Eu Dy Lu Gd La Ce Pr

PHOSPHORS

Display phosphors- CRT,LPD,LCD
Fluorescents
Medical Imaging
Lasers
Fiber Optics

Nd Eu Tb Y Er Gd Ce Pr

REE Market

Annual Global Rare Earth Market

- ~$5B in 2015 (~149,000 tonnes/yr)

U.S. Consumes

- 11% ($550M) or ~16,000 tonnes/yr (~44 tonnes/day) in 2015

Approximately 750M Tons of Coal Burned in U.S. Annually

- ~75M tons of coal ash generated
- Average concentration of ~470 ppm REE+Y, yields ~31,980 tonnes of REE+Y annually

Lynas Advanced Materials Plant, Malaysia

- Capacity: 22,000 tonnes/yr REO (Nd/Pr, Ce, La..)
- Capital Cost: $546M (2011)

Magnet Industry – International Consumption (2015)

- 21,727 tonnes/yr Nd_2O_3
- 5,542 tonnes/yr Pr_6O_{11}

REE-CM Program

Mission

Development of an economically competitive and sustainable domestic supply of rare earth elements (REEs) and critical materials (CMs) to assist in maintaining our Nation's economic growth and National Security

Objectives

- Recovery of REEs from coal and coal by-product streams, such as coal refuse, clay/shale over/under-burden materials, aqueous effluents, power generation ash
- Advance existing and/or develop new, second-generation or transformational technologies to improve process systems economics, and reduce the environmental impact of a coal-based REE value chain

Goals

- Validate the technical and economic feasibility of small domestic, pilot-scale, prototype facilities to generate, in an environmentally benign manner, high purity 90-99 wt% (900,000-990,000 ppm), salable, rare earth element oxides (REOs) from 300 ppm coal-based resources.

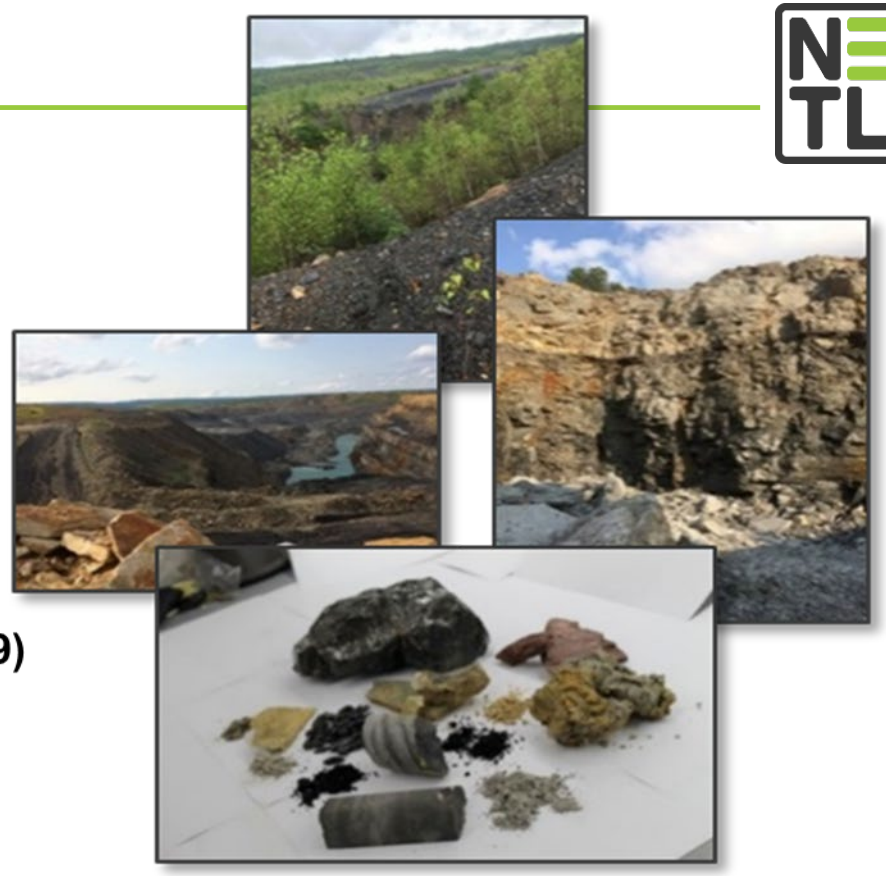
REE-CM Program

Program Budget

$15M/FY14-FY18

$18M/FY19

$23M/FY20



Stakeholders – 25-30 Active Projects (FY18-FY19)

- Universities
- National Labs – NETL, LANL, LLNL, INL, PNNL
- Industry – Small Business

Feedstock Materials

Run-of-Mine Coal

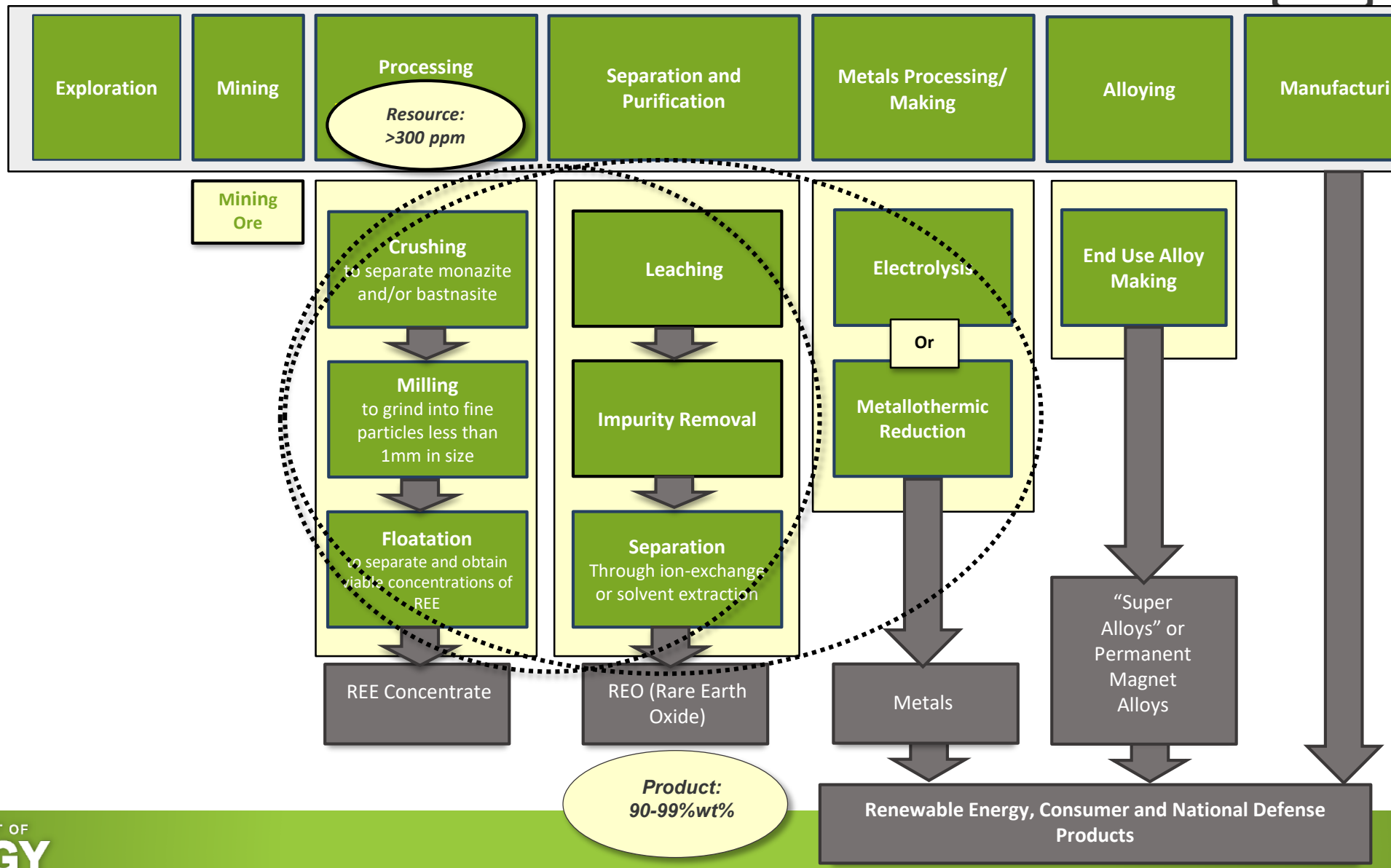
Overburden & Underlying Clays/Shales/Sediments

Coal Prep Plant Refuse

Power Generation Ash

Acid Mine Drainage Sludge

REE-CM Program – Value Chain



REE Program – Pilot-Scale Processing

West Virginia University

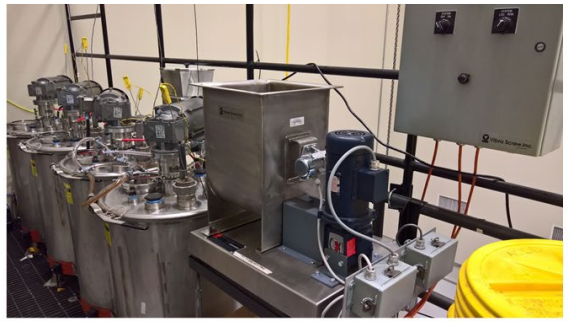
Acid Mine Drainage (AMD)
July 2018 Commissioned Facility
~100% REE Recovery from Feedstocks
Production of ~96% REO

Courtesy of Paul Ziemkiewicz, WVU

REE Program – Bench/Pilot-Scale Processing

University of North Dakota

Low-Rank Coals – Lignite
High Organic REE Association
One-Step Selective Mineral Acid Leaching Process
~43% REE Recovery
Production of ~65% REO

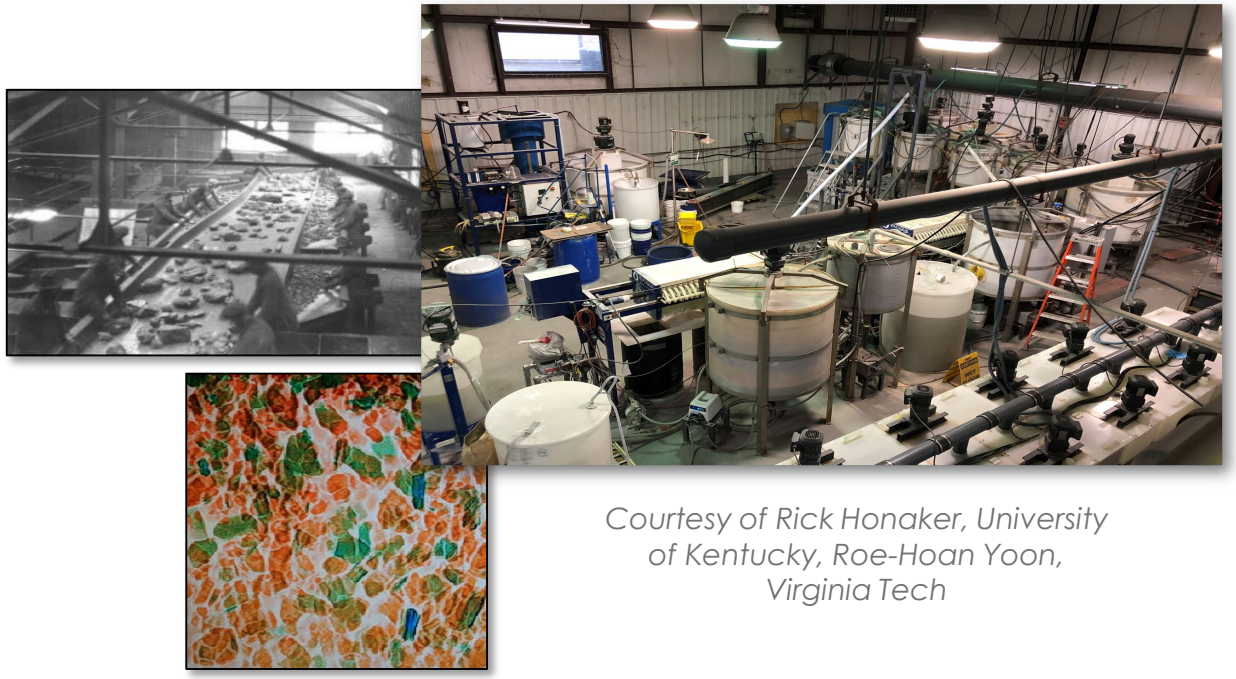


Courtesy of Nolan Theaker, UND

REE Program – Modular Pilot-Scale Processing

University of Kentucky

Coal Refuse – Central Appalachian & Illinois Coal Basins
Initiated Operation in June 2018
Production of REE in October/November 2018
80-90% REE Concentrate Produced



Courtesy of Rick Honaker, University of Kentucky, Roe-Hoan Yoon, Virginia Tech

Youtube video link: https://www.youtube.com/watch?v=jR70j-MzWNE

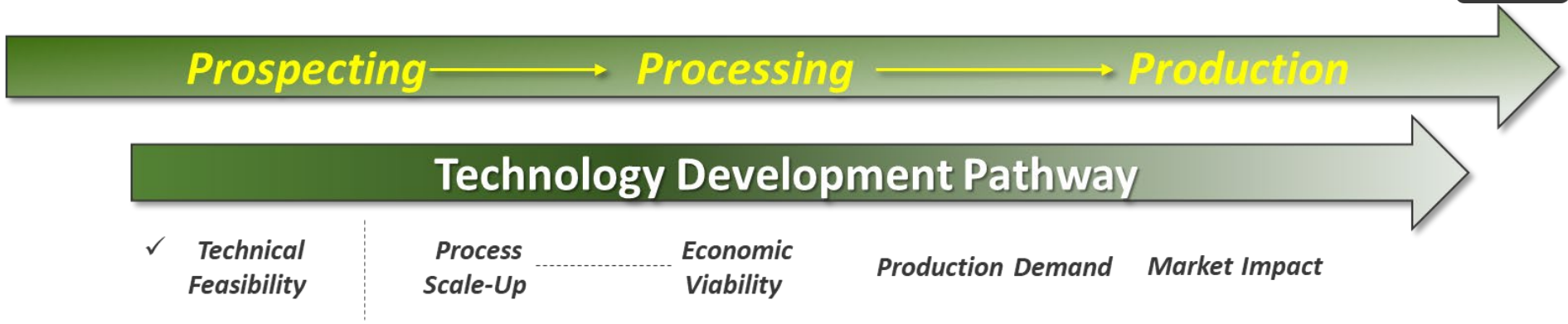
REE Program – Pilot-Scale Processing

Physical Sciences Inc. (PSI)
Center for Applied Energy Research (CAER)
Winner Water Service (WWS)

Coal Ash from Eastern Kentucky Coal
Physical Processing Pilot: 0.4 tpd Operational – CAER
Micro-Pilot Plant: 0.5 kgpd Operational – PSI
Chemical Processing Pilot: 0.5 tpd Operational November 2019 – WWS

Courtesy of Prakash Joshi & David Gamliel, PSI

REE-CM Program - Summary

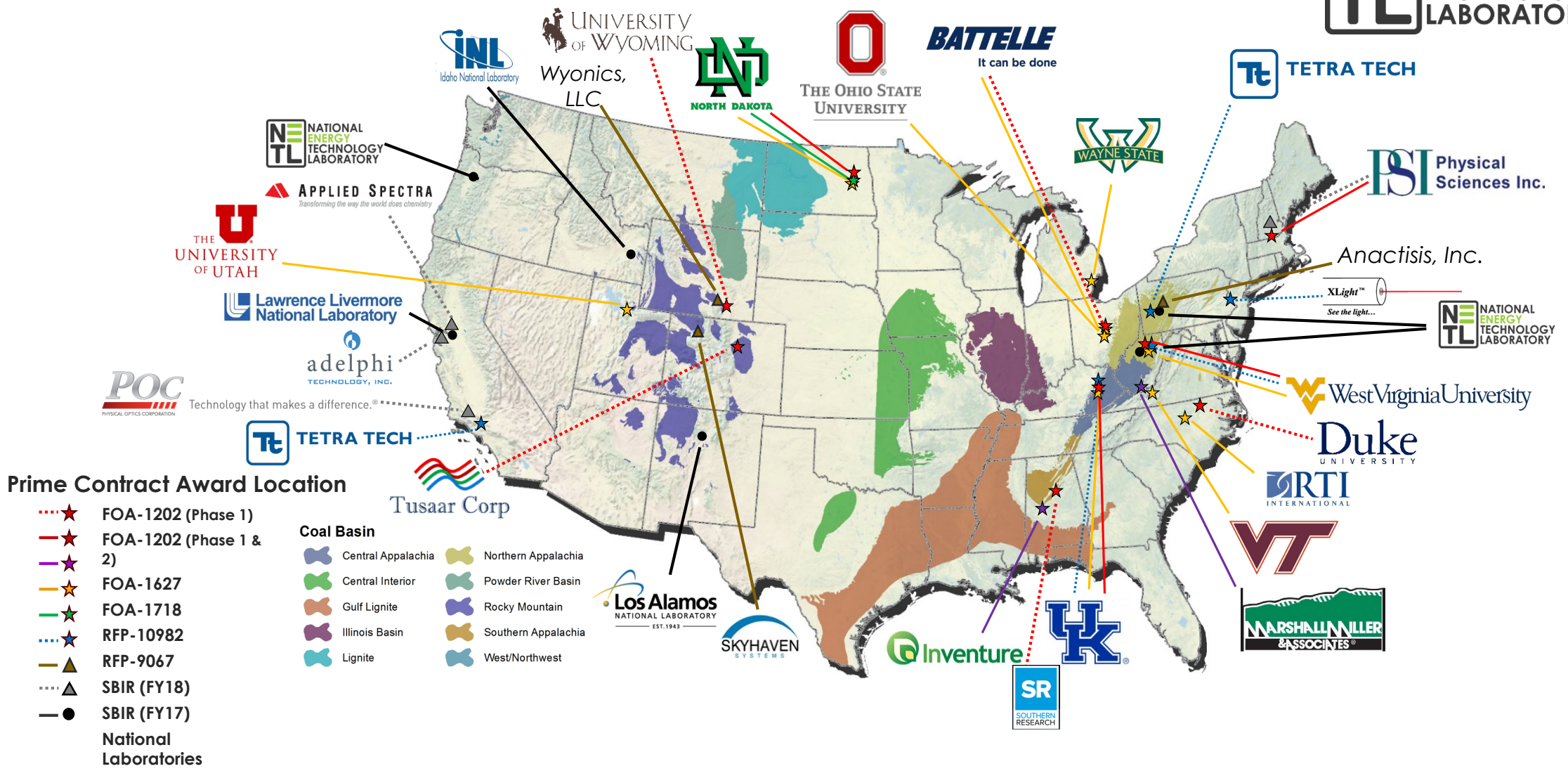


Courtesy of Inventure Renewables

Where We Are Today

- ✓ **Technical Feasibility** of Extracting REE from Coal-Based Resources Demonstrated
- ✓ **Three Domestic, First-of-a-Kind, Extraction/ Separation Test Facilities**, Producing Small Quantities of REEs from Coal-Based Materials,
- ✓ **Fully Integrated REE Program**
  - Spanning Basic/Fundamental Technology Development (TRL 1-3) through to Small Pilot-Scale Facility Validation (TRL 5-7)
  - Maintaining Broad Feedstock Base – Coal Refuse/Tailings, Clays/Shales, Power Generation Ash, Acid Mine Drainage

REE-CM Program - Acknowledgments



REE-CM Program – Contact Information

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National Energy Technology Laboratory

http://www.netl.doe.gov/research/coal/rare-earth-elements/

https://edx.netl.doe.gov/ree/