

# Rare Earth Elements and Critical Minerals 2020 Virtual Project Review Meeting

**Mary Anne Alvin**

*Rare Earth Elements & Critical Minerals  
Technology Manager*

September 15-16, 2020



*Courtesy of NETL REE-CM Website*

## ***Tuesday, September 15, 2020***

- 10:30 AM**      Program Overview, **Mary Anne Alvin, National Energy Technology Laboratory**
- 11:00 AM**      Pilot-Scale Testing of an Integrated Circuit for the Extraction of Rare Earth Mineral and Elements from Coal and Coal By-Products Using Advanced Separation Technologies, **Rick Honaker, University of Kentucky**
- 11:30 AM**      High Yield and Economic Production of Rare Earth Elements from Coal Ash, **Dorin Preda, Physical Science Inc.**
- 12:00 PM**      Development and Testing of an Integrated AMD Treatment and Rare Earth/Critical Mineral Plant, **Paul Ziemkiewicz, West Virginia University**

***Lunch 12:30 PM – 1:00 PM***

## ***Tuesday, September 15, 2020***

- 1:00 PM**      **Rare Earth Element Extraction and Concentrate at Pilot-Scale from North Dakota Coal-Related Feedstocks, *Nolan Theaker, University of North Dakota***
- 1:30 PM**      **Pilot-Scale Testing of an Integrated Circuit for the Extraction of Rare Earth Mineral and Elements from Coal and Coal By-Products Using Advanced Separation Technologies, *Rick Honaker, University of Kentucky***
- 2:00 PM**      **Low Temperature Reduction of Rare Earth Metals Using Ionic Liquids, *Holly Garich, Faraday***

***Adjourn 2:30 PM***

## ***Wednesday, September 16, 2020***

- 10:30 AM**      **Silicon-Calcium Based Reduction of Rare Earth Oxides, *Xiaobiong Xie, Materials Research, LLC***
- 11:00 AM**      **Rare Earth Elements from Coal and Coal By-Products - Embedded Demand Database and Economics, *Morgan Summers, National Energy Technology Laboratory***
- 11:30 AM**      **Evaluation of Laser-Based Analysis of Rare Earth Elements in Coal-Related Materials, *Sam Clegg, Los Alamos National Laboratory***
- 12:00 PM**      **Rare Earth Elements from Coal and Coal By-Products - Separations Technology, *Christina Lopano, Circe Verba, National Energy Technology Laboratory***

***Lunch 12:30 PM – 1:00 PM***

## ***Wednesday, September 16, 2020***

- 1:00 PM**      **Evaluation of Novel Strategies and Processes for Separation of Rare Earth Elements for Coal-Related Materials, *George Goff, Los Alamos National Laboratory***
- 1:30 PM**      **Rare Earth Elements from Coal and Coal By-Products - Geospatial Sedimentary Modeling, *Kelly Rose, National Energy Technology Laboratory***
- 2:00 PM**      **Application of Biosorption from REE Recovery from Coal By-Products, *Yongqin Jiao, Lawrence Livermore National Laboratory***
- 2:30 PM**      **New Sensing Mechanisms for Rare Earth Detection in Coal and Coal By-Product, *Yoshiko Fujita, Idaho National Laboratory***

***Adjourn 3:00 PM***

# Rare Earth Elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18														
1	1 H Hydrogen																	2 He Helium														
2	3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon														
3	11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon														
4	19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton														
5	37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon														
6	55 Cs Cesium	56 Ba Barium	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
7	87 Fr Francium	88 Ra Radium	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Uus Ununseptium	118 Uuo Ununoctium

Light Rare Earth Elements

Heavy Rare Earth Elements

Critical Rare Earth Elements

- Light Rare Earth Elements
- Heavy Rare Earth Elements
- Critical Rare Earth Elements

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



# Rare Earth Elements and Critical Minerals

## Mission

- Develop Economic, Competitive, Sustainable Domestic Supply
- National and Economic Security

## Objectives

- Recovery from Coal-Based Resources
- Advanced REE-CM Separation Systems

## Drivers/Challenges

- Off-Shore Supplier Dominance
- Market Volatility & Potential Price Manipulation
- Low REE-CM Content in Coal-Based Resources



# REE-CM Program Goals & Metrics

## Goals

- Validate Technical-Economic Production
- Accelerate Domestic Prototype Facility Demonstration
- Produce Commercial-Grade REO Mixed Concentrates & Beyond
- Environmentally Benign Processing

## Metrics

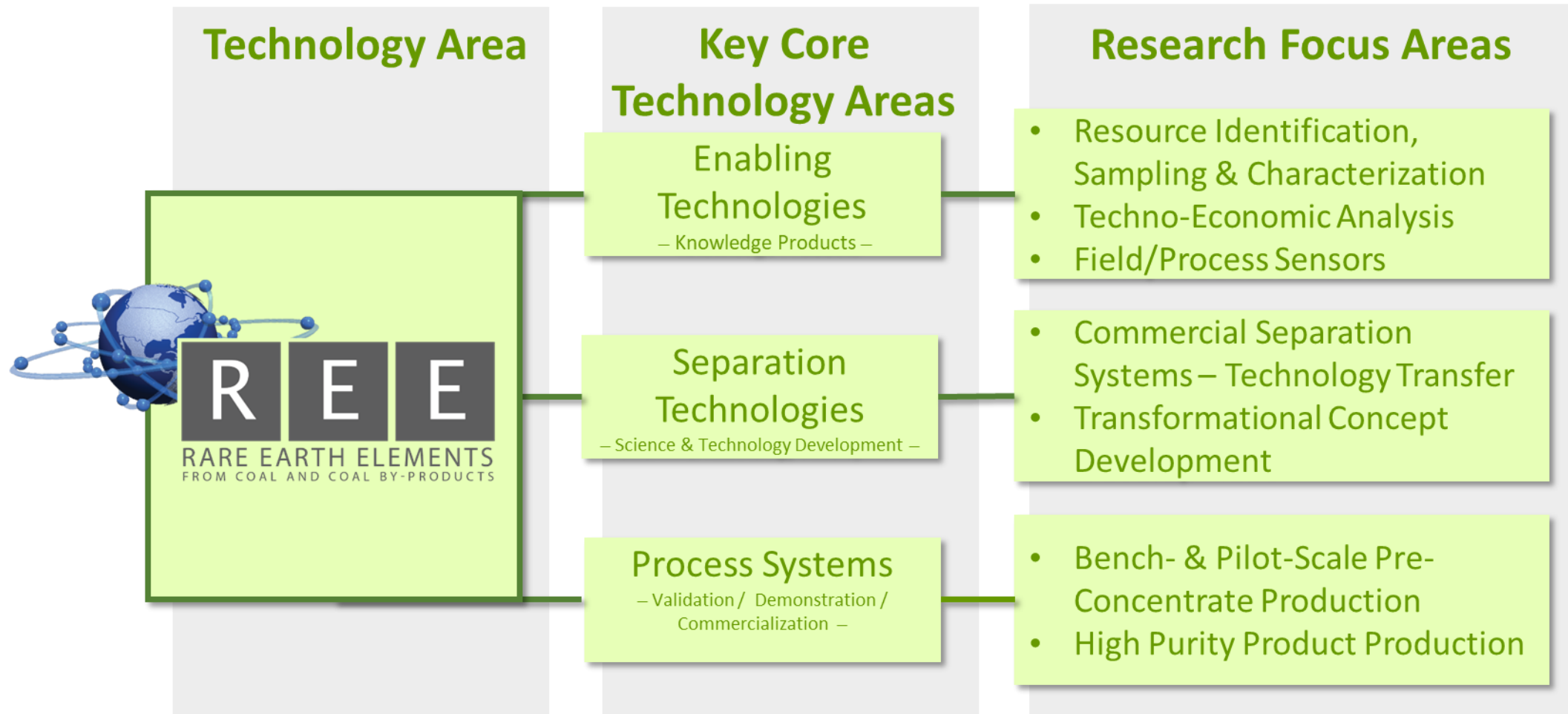
- Production of 1-3 tonnes (MT)/day of Mixed REO/RES
- Minimum REO/RES Concentration – 75% by weight



### U.S. Demand (2015)

- 11% of Annual Global REE Market
- ~16,000 tonnes/yr (~44 tonnes/day)

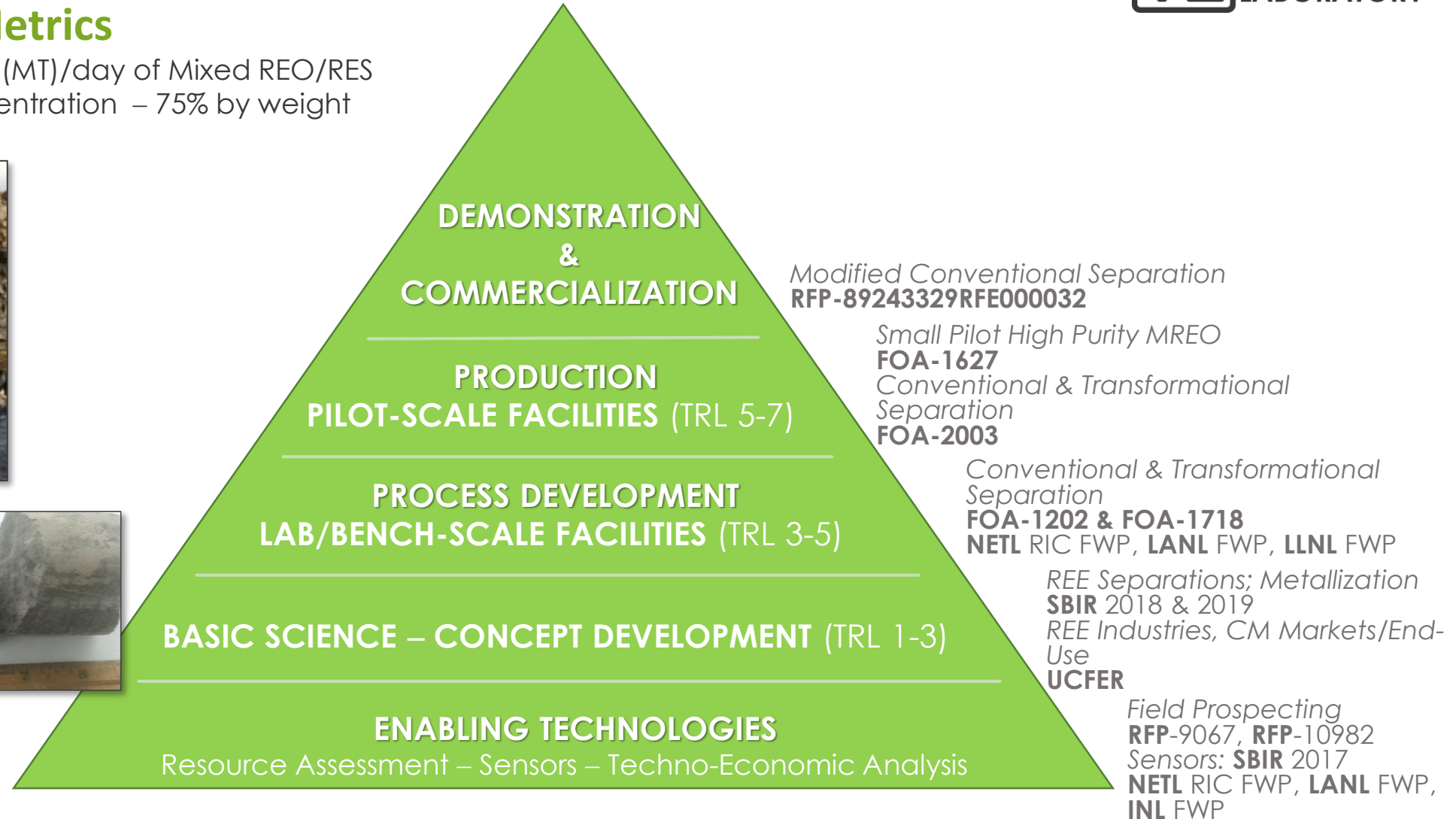
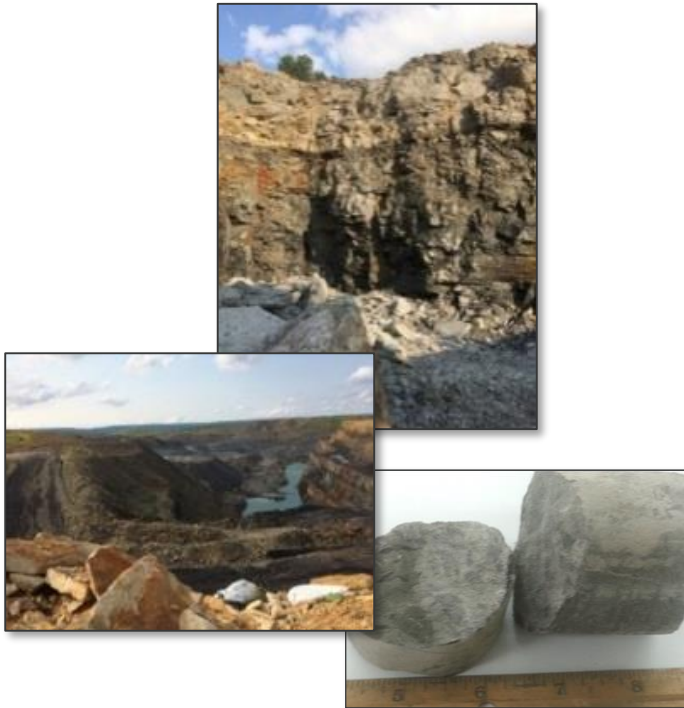
# REE-CM Program Structure (2014-2020)



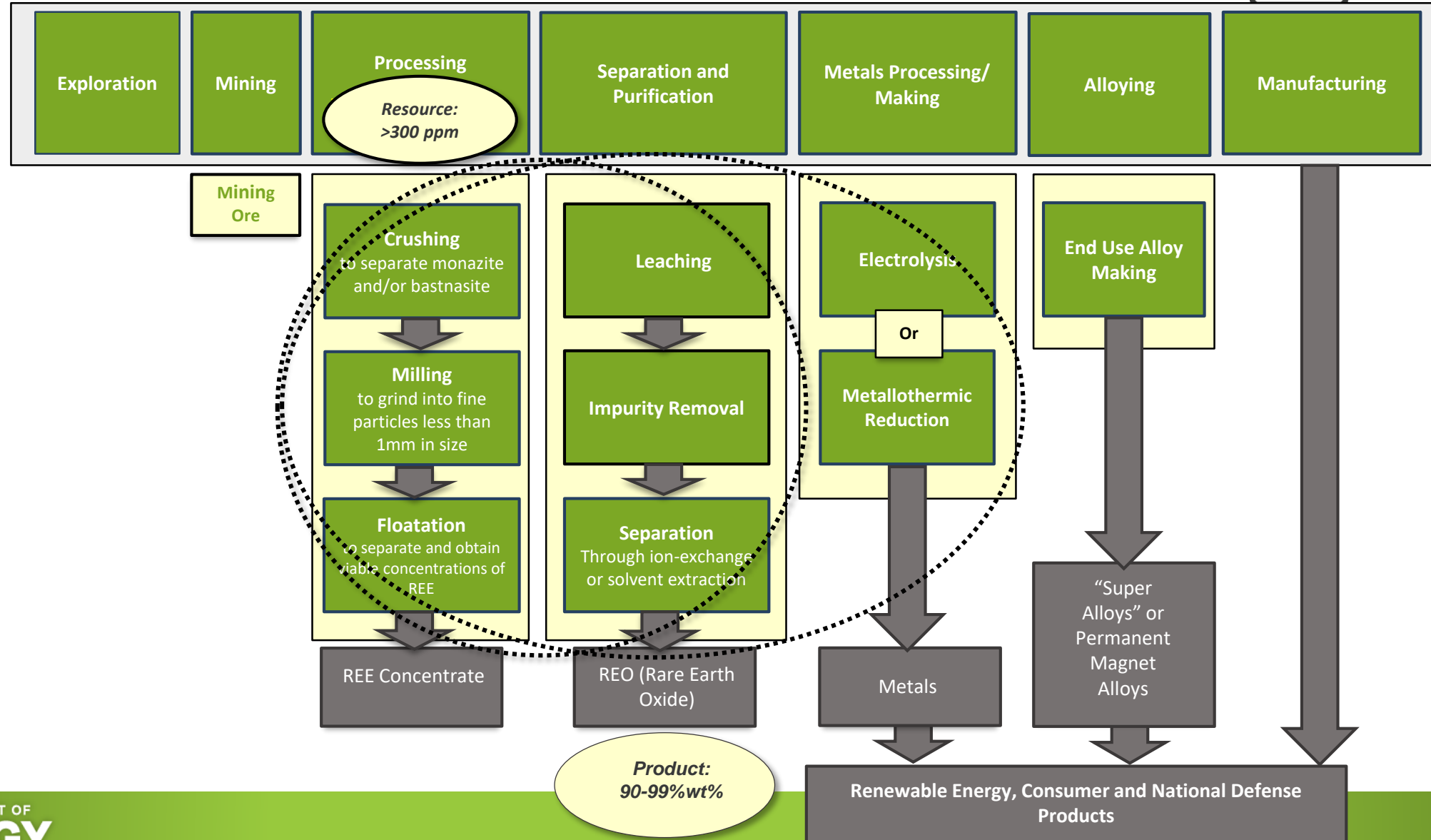
# REE-CM Program Portfolio (2014-2020)

## Metrics

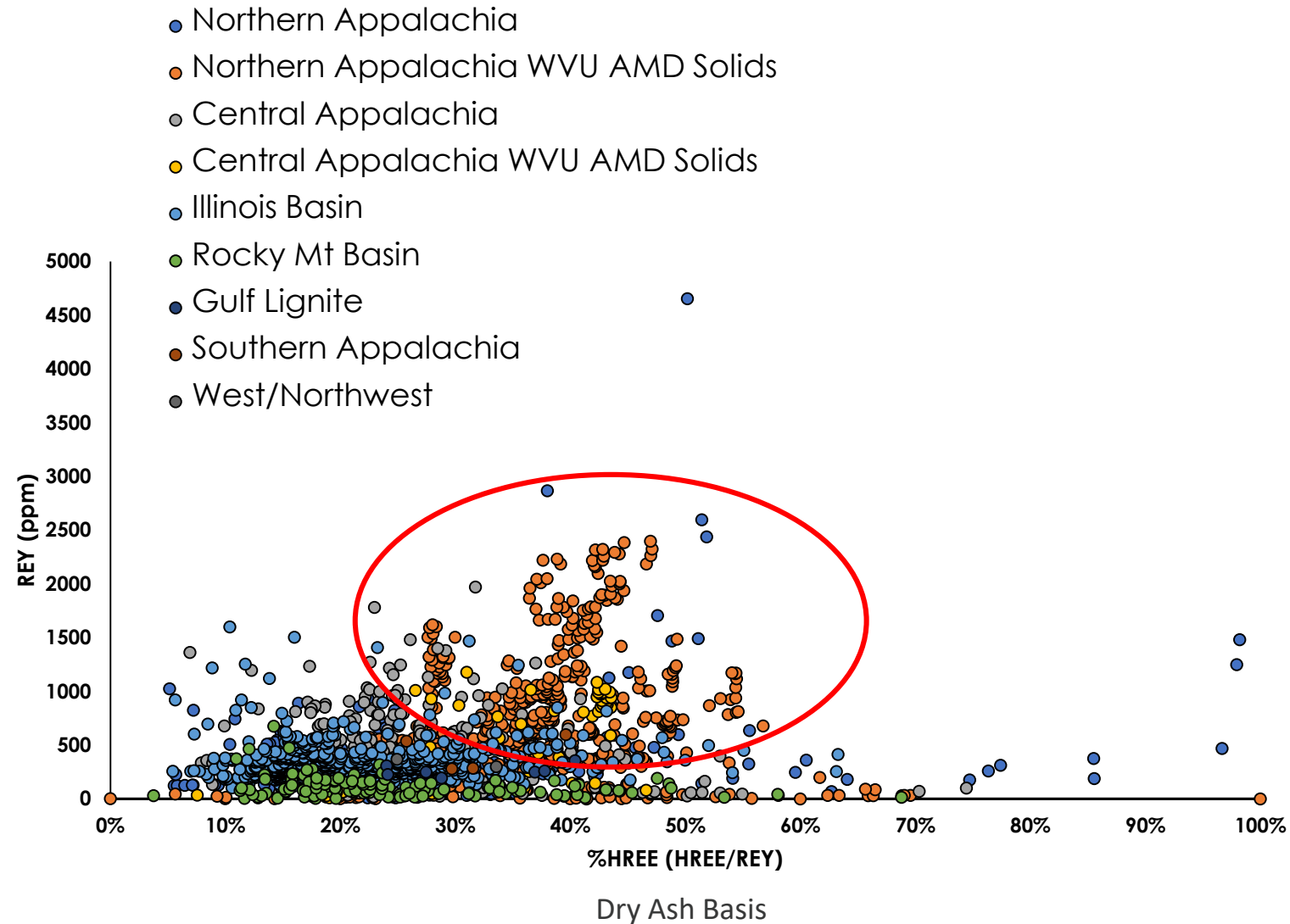
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# REE-CM Program: Value Chain

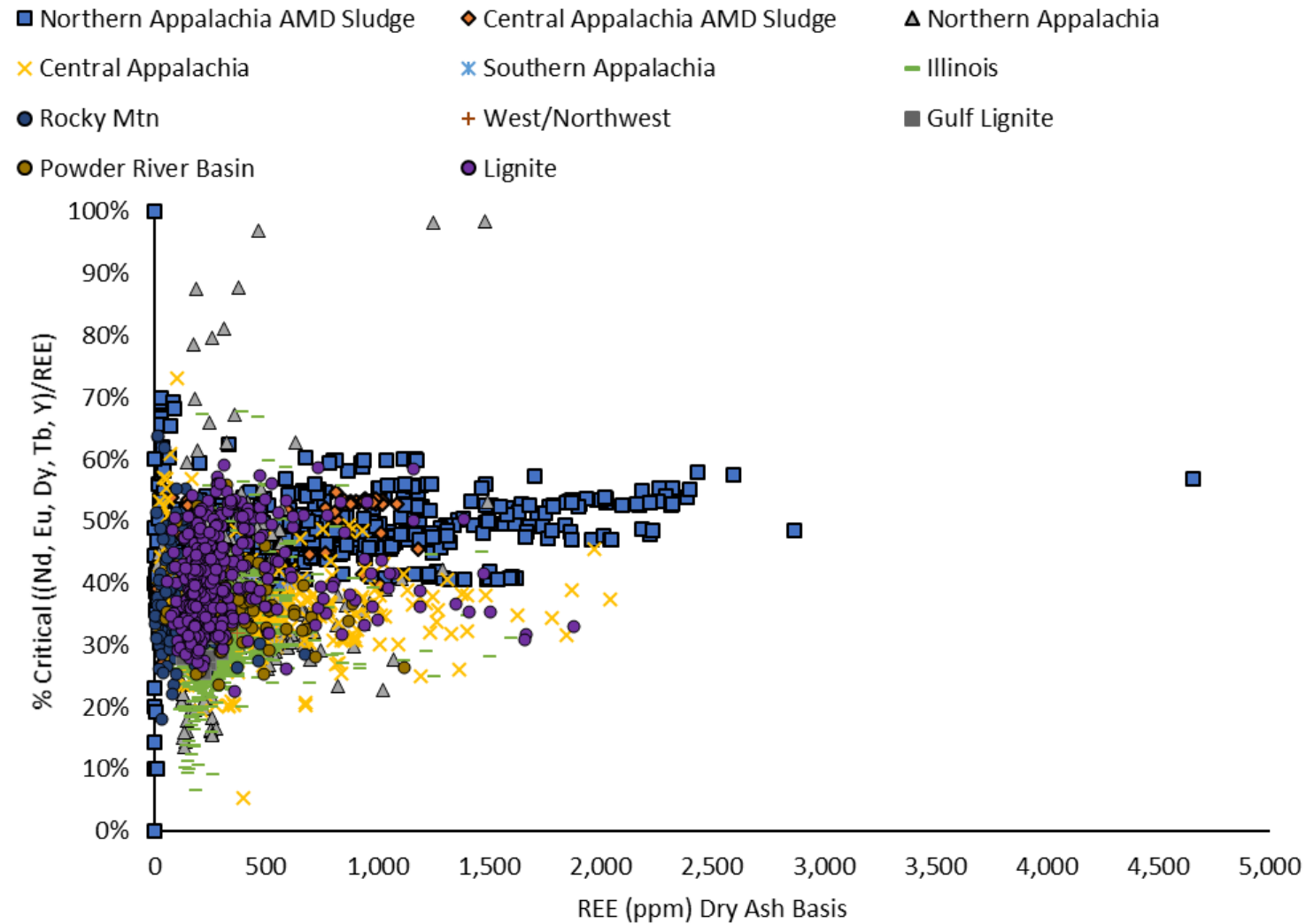


# REE-CM Program: Prospecting





# REE-CM Program: Prospecting



## REE Separation-Recovery

### Bench-to-Pilot-Scale REE Separation Facilities



### Pilot-Scale REE Separation Facilities



# REE-CM Program: Processing



Acid Mine Drainage (AMD)

July 2018 Commissioned Facility

~100% REE Recovery

Production of ~98% Mixed REO

CM Recovery

**Small AMD sludge drying cell**  
0.5 ac, 10 ft deep, 80% moisture  
Sludge DW 1,300 ton  
\$190/ton of sludge DW  
In situ REE value = **\$247,000**



Courtesy of Paul Ziemkiewicz, WVU



# REE-CM Program: Processing



Low-Rank Coals – Lignite

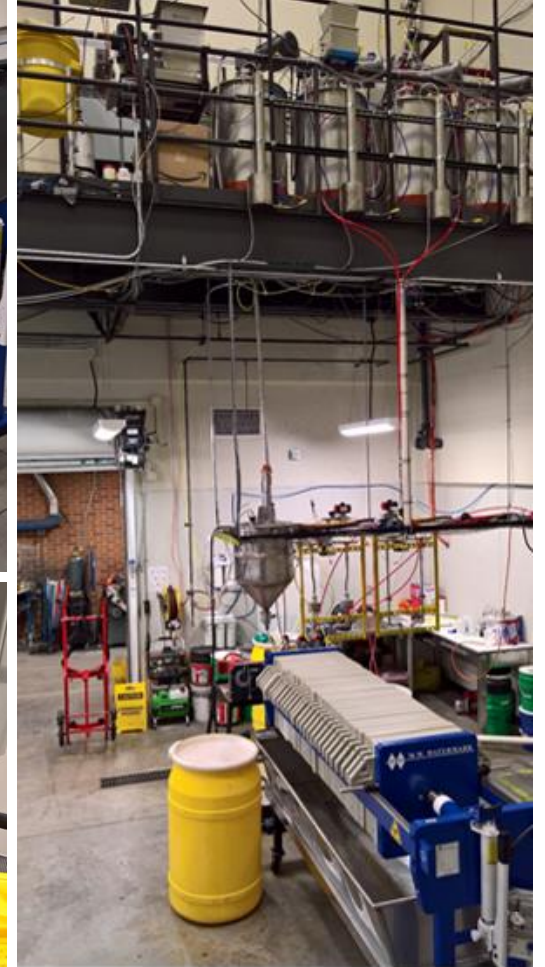
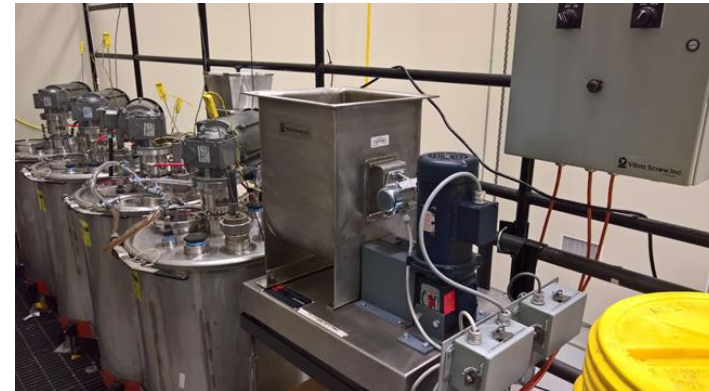
High Organic REE Association

One-Step Selective Mineral Acid  
Leaching Process

~43% REE Recovery

Production of ~65% Mixed REO

CM Recovery



*Courtesy of Nolan Theaker, UND*

# REE-CM Program: Processing



Coal Refuse – Central Appalachian  
& Illinois Coal Basins

Initiated Operation in June 2018

Production of REE in October- November  
2018

~98% Mixed REO Concentrate Produced

CM Recovery

Youtube video link:

<https://www.youtube.com/watch?v=jR70j-MzWNE>

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





# REE-CM Program: Processing

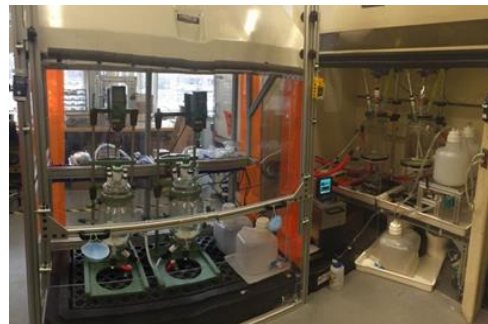


Coal Ash from Eastern Kentucky

Coal Physical Processing Pilot:  
0.4 tpd Operational – CAER

Micro-Pilot Plant: 0.5 kgpd – PSI

Chemical Processing Pilot: 0.5 tpd  
Operational November 2019 –  
Winner Water



*Courtesy of Prakash Joshi & David Gamliel, PSI*

# REE-CM Program: NETL Intramural Project



NETL Research & Innovation Center (RIC)

## Field Prospectivity & Materials Characterization

### Real-Time Aqueous REE Detection

- Fiber Optic Probe (10s ppb)
- Miniaturized LIBs Prototype (1 ppm)

### U.S. Coal Basin Sedimentary Assessment

- National-Level Geological, Geochemical & Geospatial Assessment Database Development
- REE-Enriched Powder River Basin (PRB) Core Materials (>2,000 ppm) Identified

## REE Separation-Recovery & TEA Process Economics

### Acid Mine Drainage Solids

- Staged Leaching – Production of 95% REOs

### Fly Ash

- 96% REO Production at 10% Normal Acid Consumption

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### NETL BIAS Sorbent

- Production of 95% REE from Synthetic AMD
- Field Testing Initiated March 2020

### Central Appalachian Basin Underclays

- Mild Acid Extraction Testing with BIAS Sorbent

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### Process Economics

- TEA Cost Analysis Tool Developed

## Materials Characterization & Monitoring



- Chemistry & Mineralogy of Coal-Based Resources
- Raman-LIBS Back-Pack Instrumentation (Mars)



- Rapid Luminescent Sensing of Lanthanides in Fluoride Hosts (Coal Fly Ash Leachates)

## REE Separation & Recovery



- Technology Transfer of Actinide Separation to REE Lanthanide Recovery



- Si Sol-Gel Microbial Media for 2-Stage Sc/Ln+Y Recovery from Coal-Based Leachates
- Continuous Packed-Bed Bioreactor System for REE Capture

## DE-FOA-0002003

Process Scale-Up and Optimization/Efficiency Improvements for Rare Earth Elements (REE) and Critical Materials (CM) Recovery from Coal-Based Resources

**Issued:** January 31, 2019

**Awarded:** September 30, 2019

**Definitized:** January 1, 2020

## RFP-89243320RFE000032

Production of Mixed Rare Earth Oxides (REOs) from Coal-Based Resources

**Issued:** April 22, 2020

# REE-CM Program: Where We Are Today

- ✓ Fully Integrated Program – Basic Science (TRL 1-3) to Pilot Facilities (TRL 5 to 7)
- ✓ >4,000 Domestic Field Program Samples
- ✓ Coal HREE/LREE >1
- ✓ Licensed NETL REE-Sorbent Technology
- ✓ Fiber Optic & LIBS Prototype Sensors – ppm REE Concentrations in Fluids
- ✓ Demonstrated Technical Feasibility of REE Recovery
  - ✓ Diversity of Coal-Based Feedstocks
  - ✓ Multiple Processing Approaches
  - ✓ Complete Extraction from AMD
  - ✓ High REE-Organic Association in Lignite
  - ✓ U.S. REE Clay Association
  - ✓ High Purity (>98%) MREO Achieved
- ✓ Three Domestic, First-of-a-Kind, Coal-Based Pilot-Scale Separation Facilities
  - Small Quantities of REEs Produced*
- ✓ Cobalt (Co) & Other CM Production Demonstrated



*Courtesy of Inventure Renewables*



## Program Direction

Engineering Prototype Facility – High Purity Mixed REO Concentrates

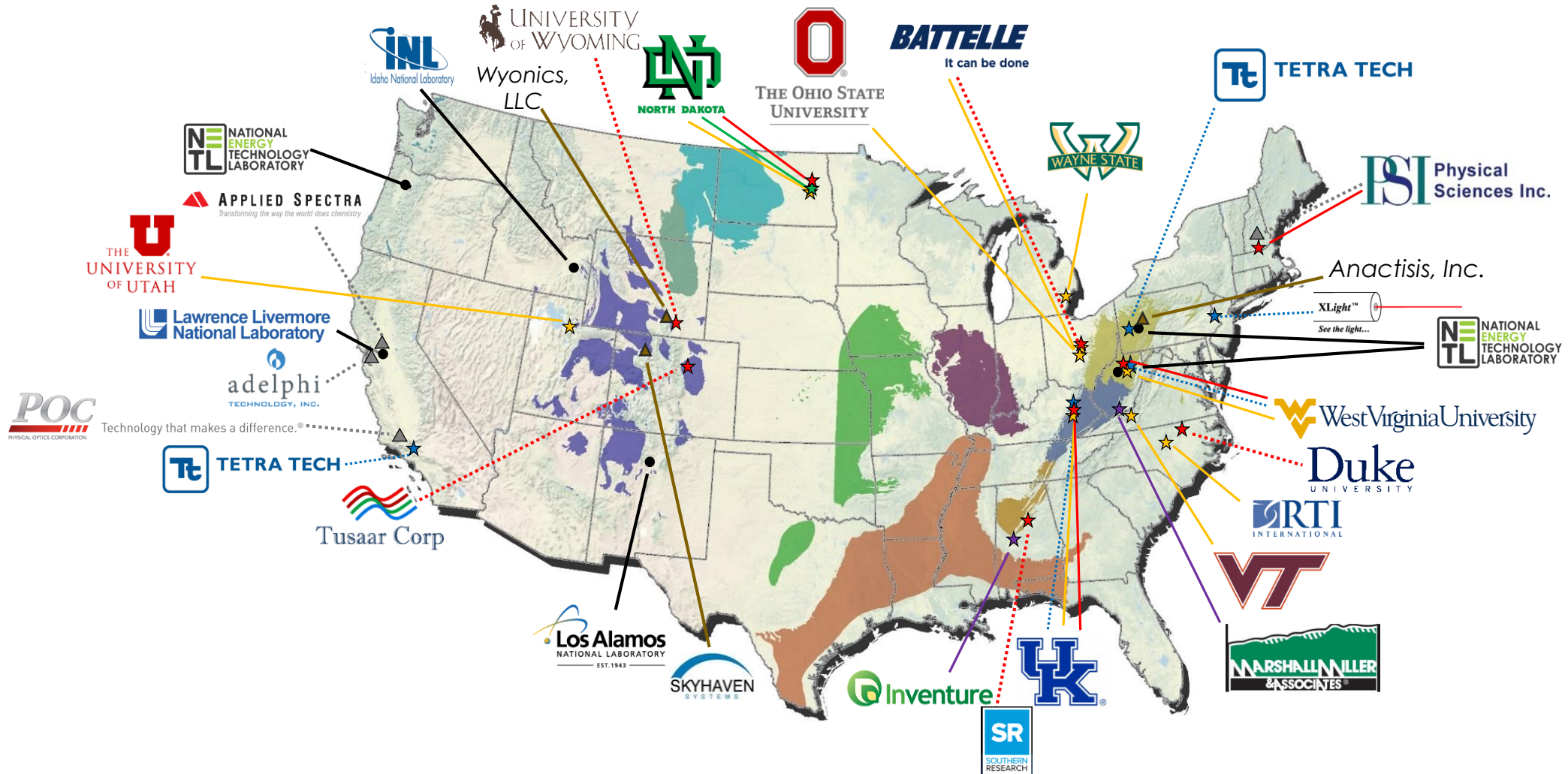
Economic & Process Efficiency Improvements

Address Technology Gaps

REE-CM Co-Production

Metallization

# REE-CM Program: Acknowledgments



# REE-CM Program – Contact Information



*Courtesy of NETL REE-CM Website*

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