Rare Earth and Critical Elements from Coal-Based Materials

Mary Anne Alvin

NETL REE Technology Manager

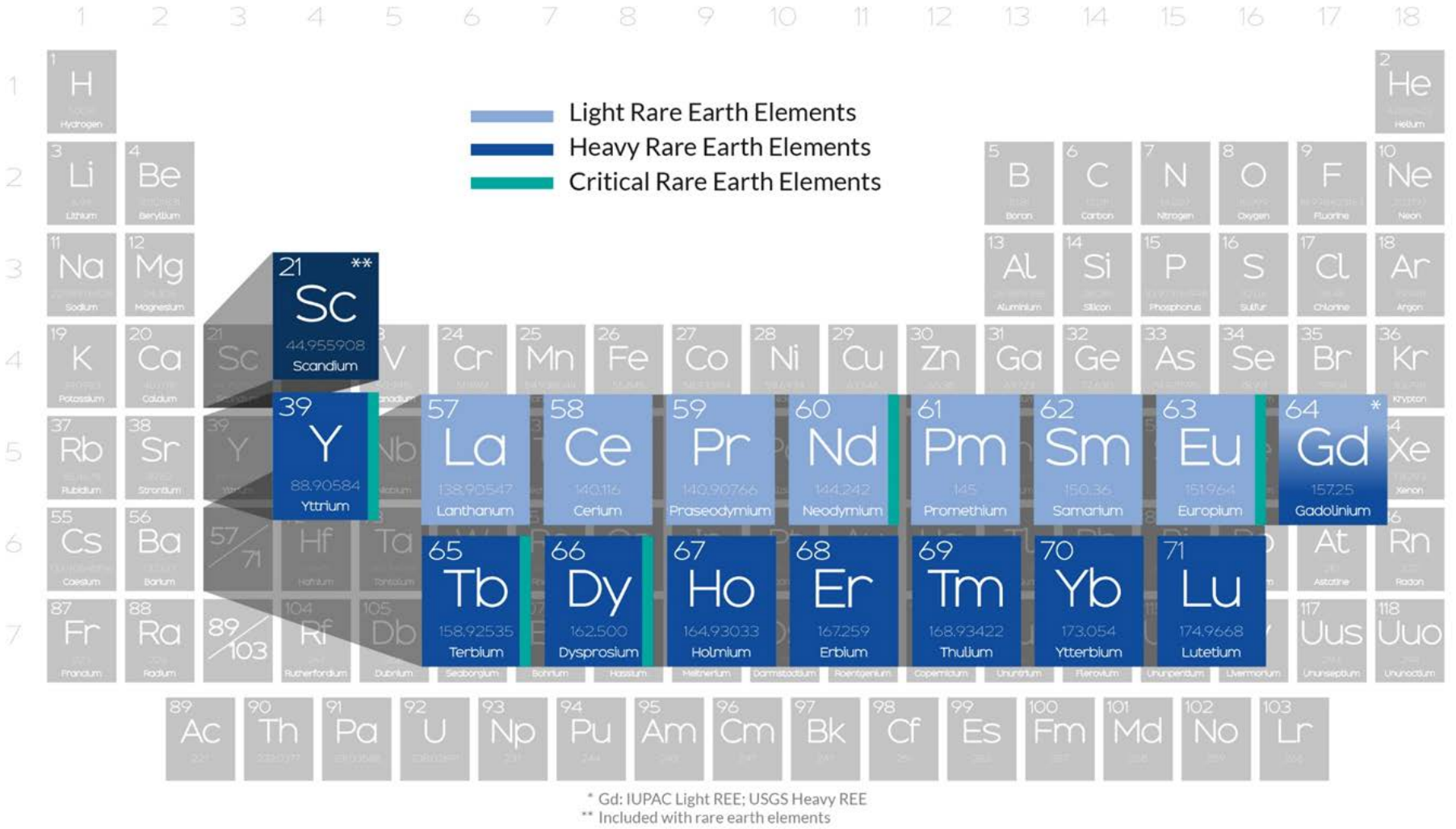
Critical Minerals and Materials

– Committee on Earth Resources –

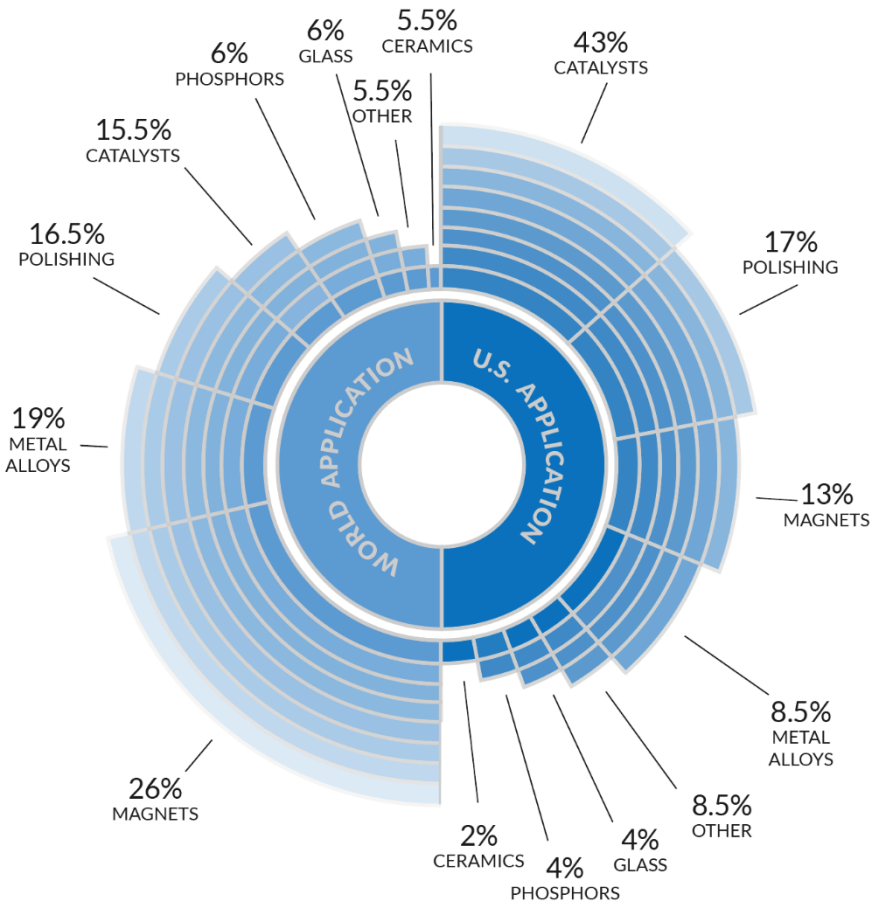
Collaborative Solutions for Developing the US Resource – Panel Discussion

Washington, DC | May 9, 2018

Rare Earth Elements (REEs)



REE Applications



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

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

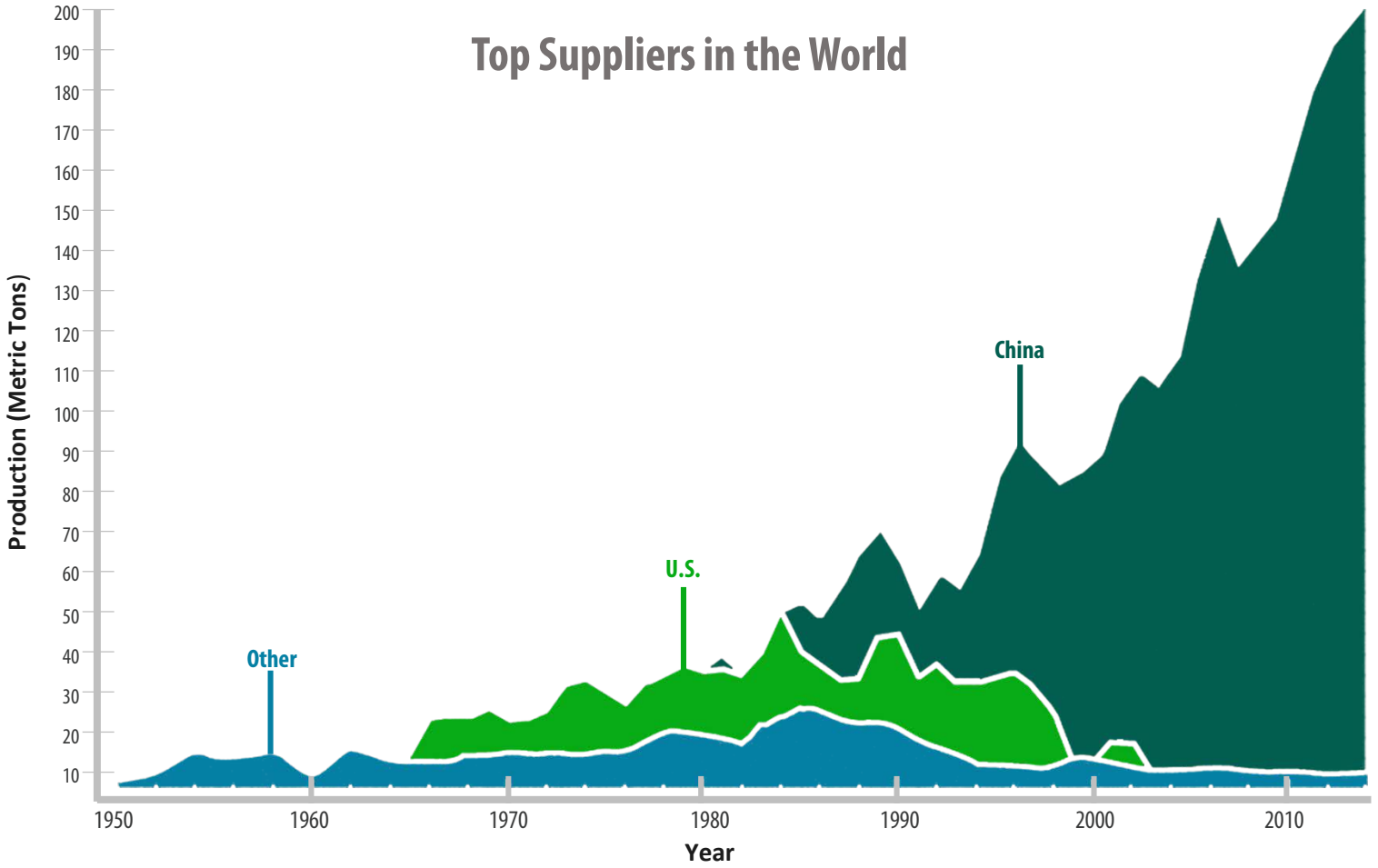
Nd Y Eu Dy Lu Gd La Ce Pr

PHOSPHORS

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

Nd Eu Tb Y Er Gd Ce Pr

REE Suppliers



Congressional Language
– Feasibility of Recovering Rare Earth Elements (REEs) –

FY14 to perform an assessment and analysis of the feasibility of economically recovering rare earth elements from coal and coal by-product streams, such as fly ash, coal refuse, and aqueous effluents

FY15 to continue activities to economically recover rare earth elements from coal and coal by-product streams, such as refuse, and aqueous effluents

FY16-FY17 to expand its external agency activities to develop and test commercially viable advanced separation technologies at proof-of-concept or pilot scale that can be deployed near term for the extraction and recovery of rare earth elements and minerals from U.S. coal and coal by-product source showing the highest potential for success

FY18 APPROPRIATIONS ACT, 2018 to expand its external agency activities to develop and test commercially viable advanced separation technologies at proof-of-concept or pilot-scale that can be deployed near-term for the extraction and recovery of rare earth elements and minerals from U.S. coal and coal byproduct sources having the highest potential for success.

REE Program

Feedstock Materials

Run-of-Mine Coal
Overburden & Underlying Clays/Shales/Sediments
Coal Prep Plant Refuse
Power Generation Ash
Acid Mine Drainage Sludge

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/sandstone 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

- By 2020, validate the technical and economic feasibility of small, domestic, pilot-scale, prototype facilities to generate, in an environmentally benign manner, 10 lbs/day, 1,000 pounds, high purity 90-99 wt% (900,000-990,000 ppm), salable, rare earth element oxides (REOs) from 300 ppm coal-based resources.

REE Program

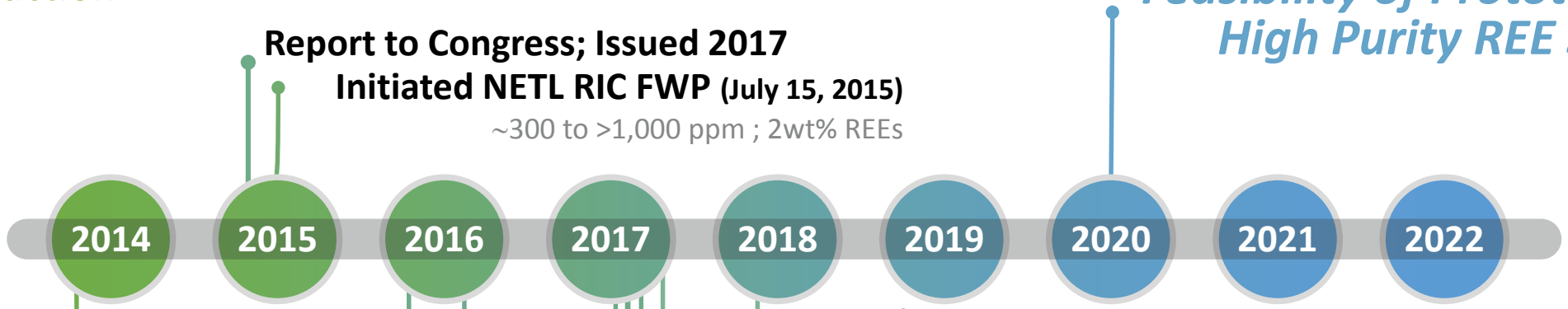
Key Drivers

- National Security & Economy
- Environmental Impact
- Economic Targets
- Build U.S. Domestic Infrastructure for On-Shore Production

FY17: 15 Active Projects
FY18: >30 Active Projects
Budget: $15M/FY

2020 GOAL

Validate Technical & Economic Feasibility of Prototype Salable High Purity REE Systems



Report to Congress; Issued 2017

Initiated NETL RIC FWP (July 15, 2015)
~300 to >1,000 ppm ; 2wt% REEs

Feasibility Assessment

Initiated NL FWP (March 12, 2018) – Biosorption Technology Development

Initiated FOA-1718 (Nov 15, 2017) – Advanced Separation – Up-Stream: 2wt% REE; Mid-Stream: 2-10wt% REE; Down-Stream: 90-99wt% REO

Initiated FOA-1202 (Oct 1, 2017) – Bench & Pilot-Scale REE Separation (Phase 2– 2wt%)

Initiated RFP-10982 (Sept 15, 2017) – Field Sampling & Characterization/Round Robin

Initiated FOA-1627 (Sept 1, 2017) – Salable High Purity REE Separation (Phase 1 – 90-99wt% REO)

Initiated NL FWPs (July-Sept 2017) – Field Sensors & Technology Transfer REE Separation

Initiated RFP-9067 (Sept 1, 2016) – Field Sampling & Characterization

Initiated FOA-1202 (March 1, 2016) – Bench & Pilot-Scale REE Separation (Phase 1– 2wt%)

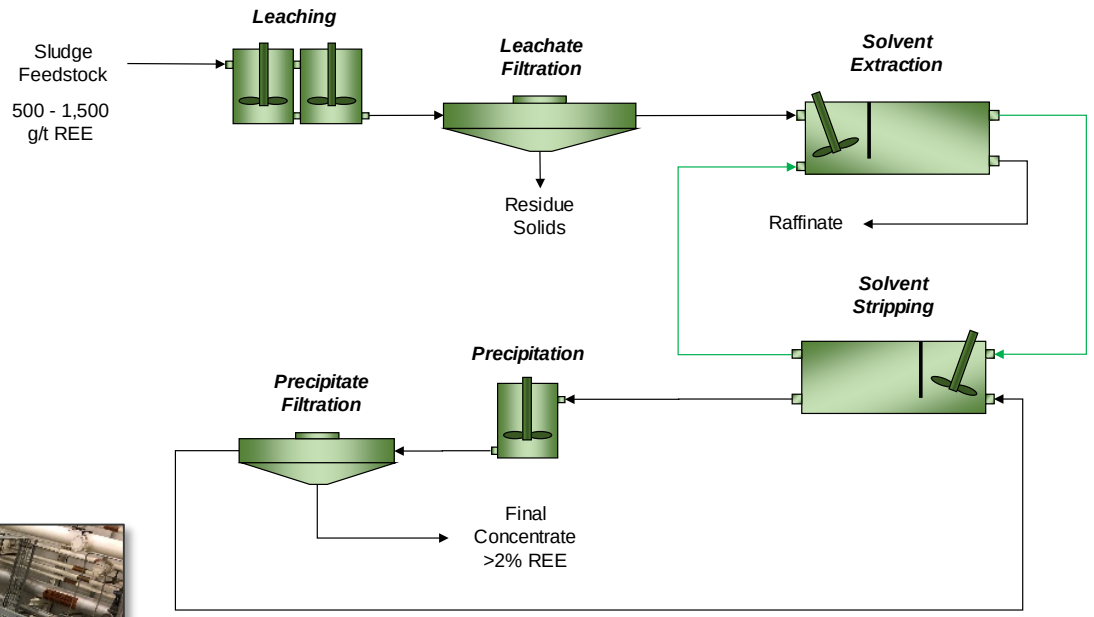
Initiated OTT TCF Project (Sept 2017) – LLNL EERE CMI REE Biosorption Extraction

Initiated OSC SBIRs (June 2017) – Field Sensors

NATIONAL ENERGY TECHNOLOGY LABORATORY

FOA-1202 Phase 2: REE Extraction System – Conventional Technologies (Minimum 2wt%)

Courtesy of Paul Ziemkiewicz, WVU

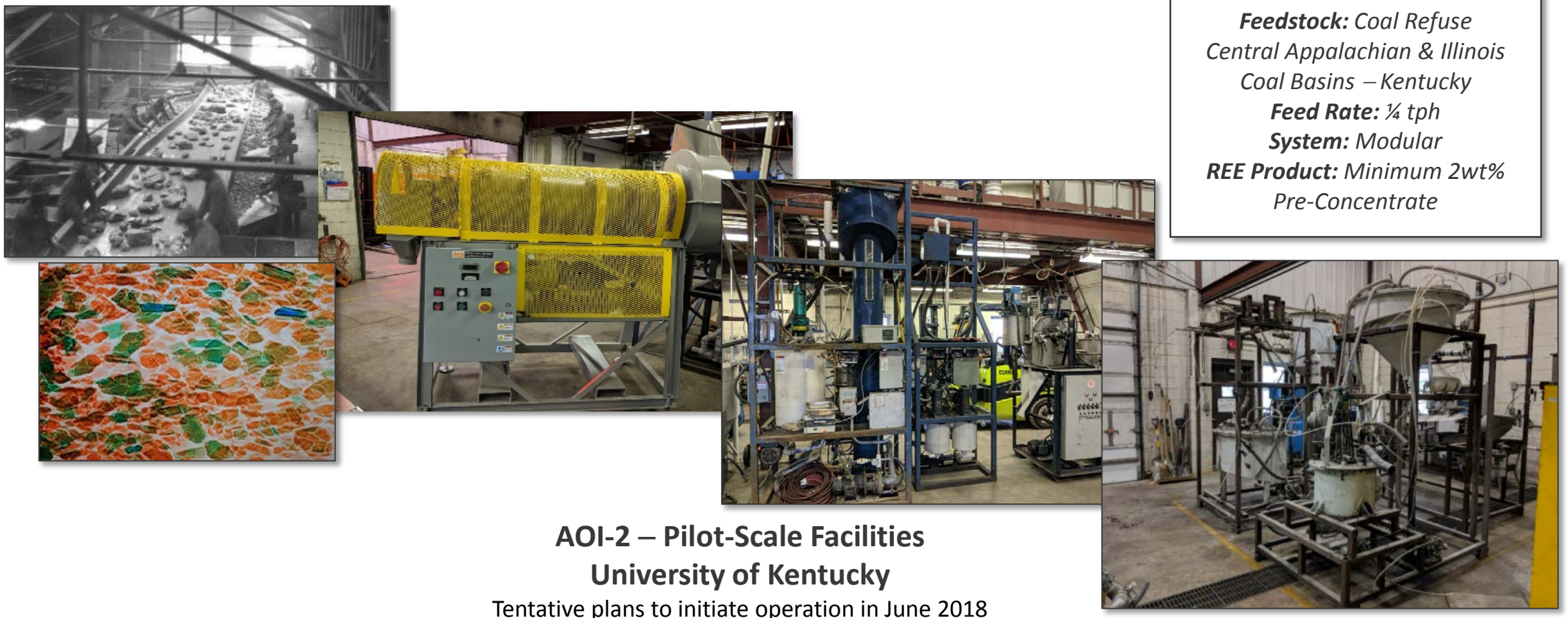


AOI-1 Bench-Scale Facilities
West Virginia University

Schematic of an acid mine drainage (AMD) treatment system
Tentative plans to initiate operation early May 2018

NATIONAL ENERGY TECHNOLOGY LABORATORY

FOA-1202 Phase 2: REE Extraction System – Conventional Technologies (Minimum 2wt%)

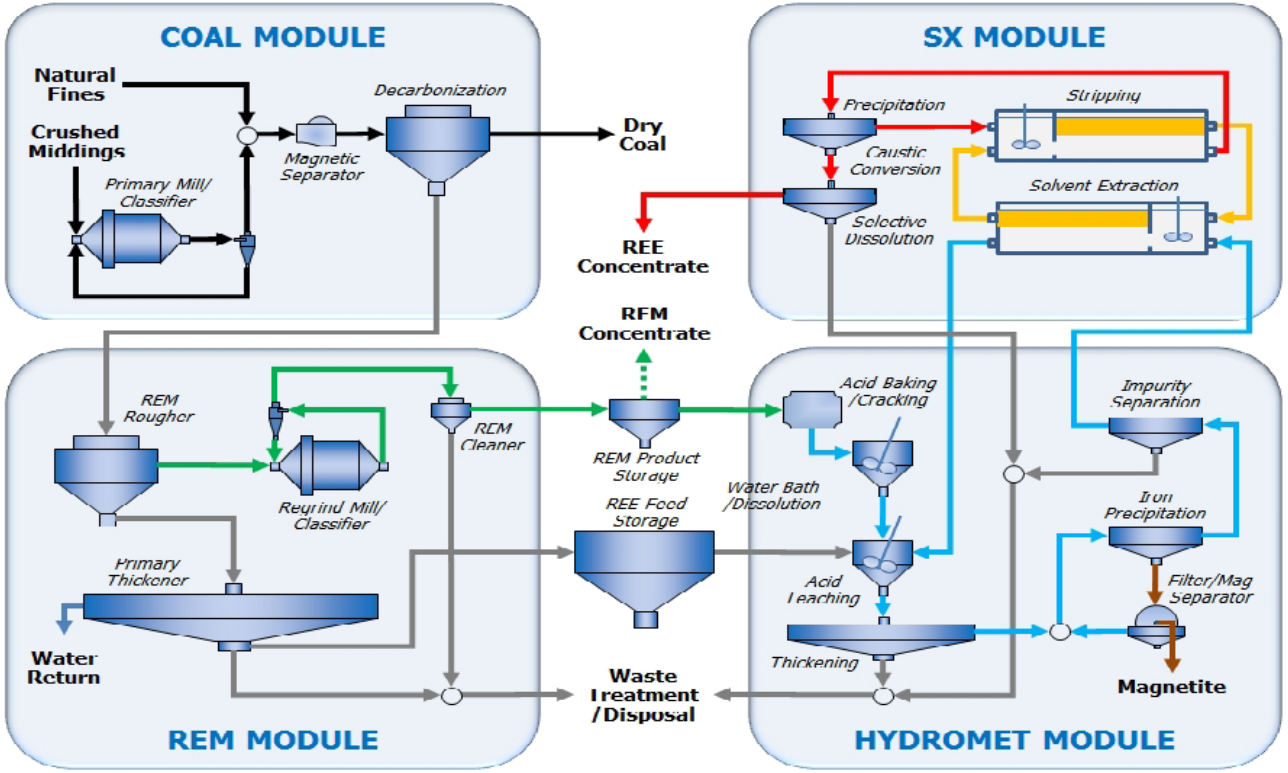


Feedstock: *Coal Refuse Central Appalachian & Illinois Coal Basins – Kentucky*
Feed Rate: *¼ tph*
System: *Modular*
REE Product: *Minimum 2wt% Pre-Concentrate*

AOI-2 – Pilot-Scale Facilities
University of Kentucky
Tentative plans to initiate operation in June 2018
Production of REEs in December 2018

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

FOA-1627 Phase 1: REE Extraction & Separation System – Conventional Technologies (90-99wt%)



Marshall Miller & Associates
Small Pilot-Scale Validation

Marshall Miller & Associates, Inc. process block diagram for the proposed REE recovery facility

***Phase 1:* Design, TEA, Supplemental Testing**
Feedstock: *Coal Refuse WV Coal Prep Plant*
System: *Stationary*
REE Product: *Salable, High Purity, REOs*

Competitive Down-Selection

Phase 2, If Awarded:
Construction & Operation
REE Product: *Salable, 90-99wt% High Purity 3 REOs,*
10 lb/day
1,000 lbs (total)

Courtesy of Steve Keim, Marshall Miller & Associates
Rick Honaker, University of Kentucky

REE Program – Major Accomplishments

Key Drivers

- National Security & Economy
- Environmental Impact
- Economic Targets
- Build U.S. Domestic Infrastructure for On-Shore Production

2020 GOAL

Validate Technical & Economic Feasibility of Prototype Salable High Purity REE Systems

NETL RIC fiber optic sensor development for detection of ppm levels of REEs in liquid samples

NETL RIC immobilized amine and organo-clay sorbents development for REE recovery from liquid sources

Feasibility Assessment

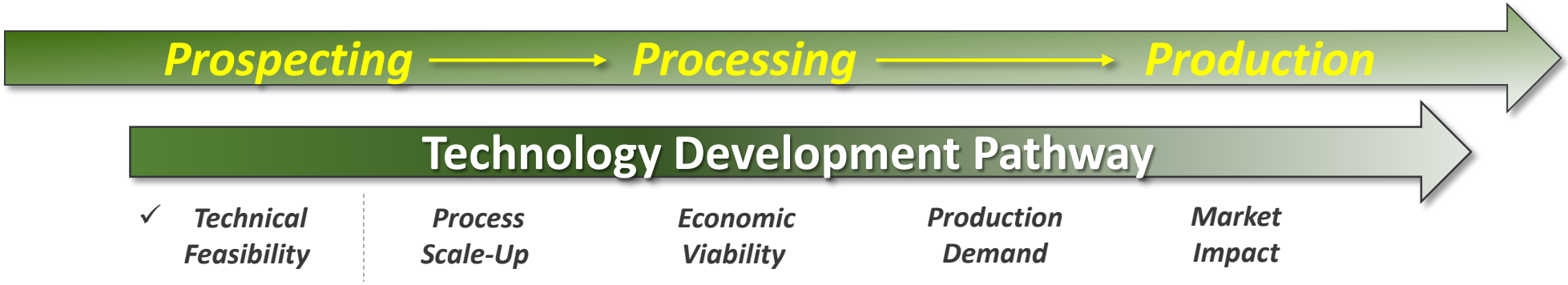
Physical Sciences Inc. (PSI), University of Kentucky, University of Wyoming, and others achieved >30 wt% (300,000 ppm) mixed REE pre-concentrates from coal-based materials

West Virginia University achieved recovery of nearly 100 percent REEs from coal acid mine drainage (AMD) sludge

University of North Dakota identified that approximately 80 to 95 percent of the REE content in lignite coals is organically associated, primarily as coordination complexes as opposed to mineral forms typically found in the older/higher-rank coals

University of Kentucky produced small quantities of 80 percent (800,000 ppm) total REEs on a dry whole mass basis and more than 98 percent (980,000 ppm) REOs. Critical elements such as neodymium and yttrium — used in national defense technologies and the high-tech and renewable energy industries — represented more than 45 percent of the total REE concentrate

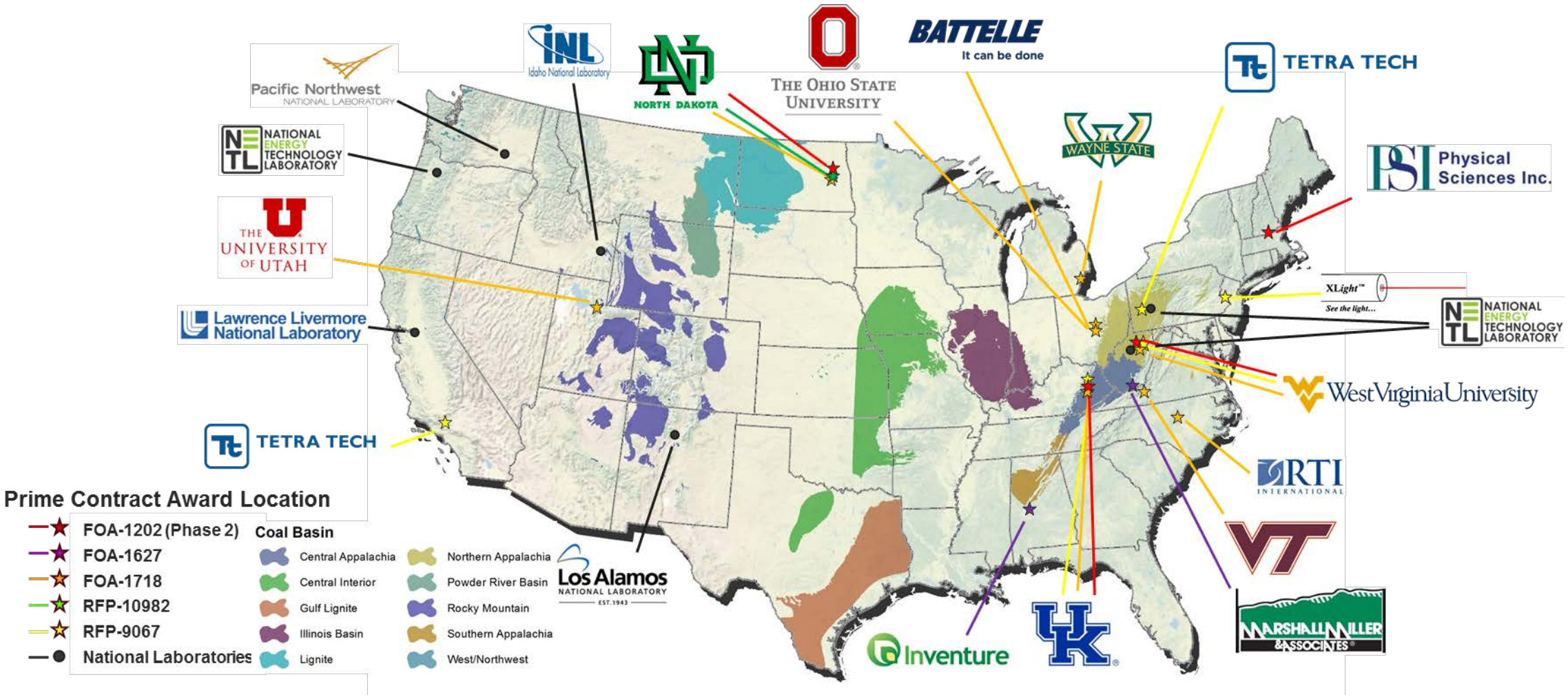
REE Program – Conclusions/Final Comments



- ✓ Technical Feasibility of Extracting REE from Coal-Based Resources Demonstrated at Laboratory/Bench-Scale
- ✓ 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

- ❖ *Process Scale-Up and Economic Viability Need to Be Demonstrated*
- ❖ *Impact of REE Production on International Market Needs to Be Demonstrated*

REE Program – Acknowledgments



REE Program – Contact Information

Mary Anne Alvin
NETL Technology Manager, REE
maryanne.alvin@netl.doe.gov
412.386.5498

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

This information was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.