

Feasibility of Recovering Rare Earth Elements

Mary Anne Alvin
NETL REE Technology Manager

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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/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

- 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 – Project Portfolio

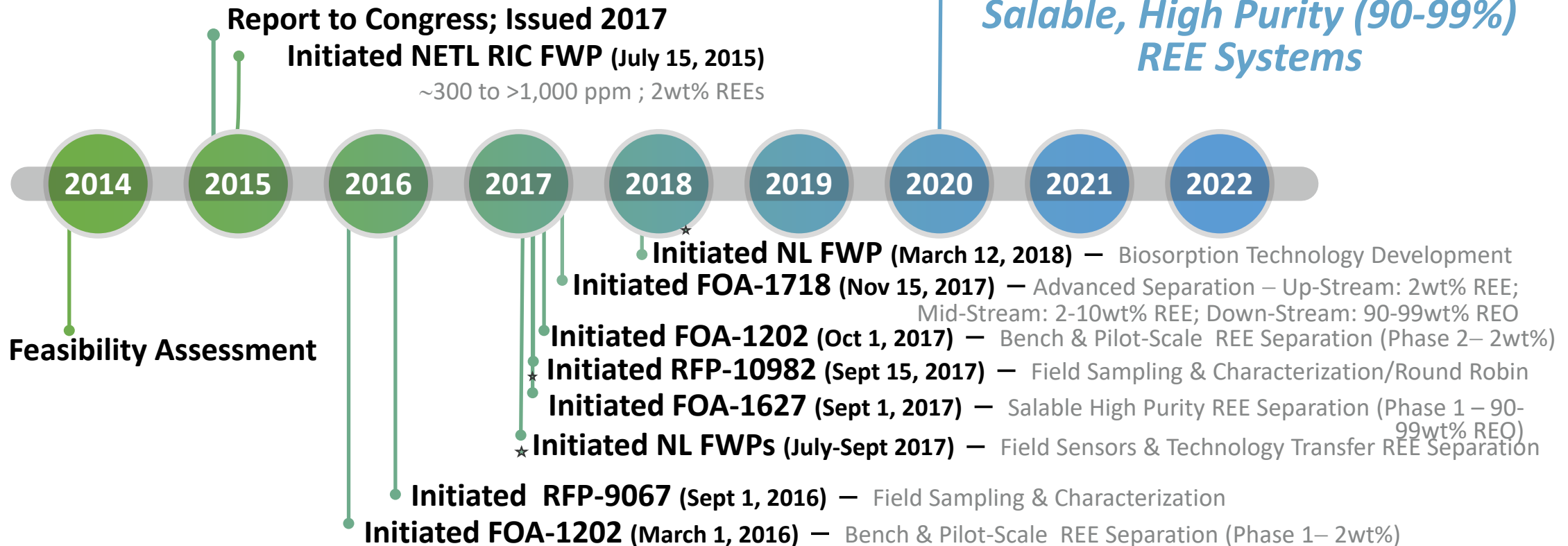


Key Drivers

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

FY17: 15 Active Projects
FY18: >25-30 Active Projects
Budget: \$15M/FY
\$18M/FY19

2020 GOAL
Validate Technical & Economic Feasibility of Prototype, Salable, High Purity (90-99%) REE Systems



FY16-FY17 FOA DE-FE-0001627 Phase 1 – Production of Salable Rare Earth Elements from Domestic U.S. Coal and Coal By-Products

- Marshall Miller & Associates
 - Arch Coal, Mineral Refining Co., Outotec, Blue Line Corp., Anchor House, Cumberland Mine Services, Virginia Tech, University of Kentucky, West Virginia University
- Inventure Renewables Inc.
 - Texas Minerals Resources Corp. (TMRC), K-Technologies, Inc., Penn State University

FY15 FOA DE-FE-0001202 Phase 2 – Opportunities to Develop High Performance, Economically Viable, and Environmentally Benign Technologies to Recover Rare Earth Elements (REEs) from Domestic Coal and Coal Byproducts

- AOI-1 Bench-Scale (18 Months)
 - West Virginia University (March 2019)
 - University of North Dakota (September 2019)
- AOI-2 Pilot-Scale (30 Months)
 - University of Kentucky (March 2020)
 - Physical Sciences Inc. (March 2020)

FY17-FY18 FOA DE-FE-0001718 — Development of Transformational Separations and Extraction Processes for Production of Rare Earth Elements from Domestic U.S. Coal and Coal By-Products (3 AOIs)

2wt% REE Pre-Concentrates (AOI-1)

- University of Kentucky, Virginia Tech, Blackhawk Mining, and Alliance Coal
- Virginia Tech
- Cerahelix, Veolia Water Technologies
- University of North Dakota, Pacific Northwest National Laboratory
- The Ohio State University

2-10wt% REE Pre-Concentrates (AOI-2)

- University of Utah, Virginia Tech
- Wayne State University, Los Alamos National Laboratory, UCLA

90-99wt% High Purity REE (AOI-3)

- Battelle Memorial Institute, Rare Earth Salts
- West Virginia University, Virginia Tech

National Labs

- **FY15-FY19 NETL R&IC FWP** – Rare Earth Elements from Coal and Coal By-Products
- **FY17 LANL FWP** – Evaluation of Laser-Based Analysis of REE in Coal-Related Materials
- **FY17 LANL FWP** – Evaluation of Novel Strategies and Processes for Separation of REE from Coal-Related Materials (Actinide Technology Transfer)
- **FY17 INL/LLNL/Rutgers/OLI/Univ. California-Davis FWP** – Bio-Illuminescence REE Sensor Development
- **FY18 LLNL/Duke Univ/Purdue Univ FWP** – Application of Biosorption for REE Recovery from Coal Byproducts

Technology Commercialization Fund (TCF) – Completed

- **FY17 LLNL** – Rare Earth Metal Extraction for Clean Technologies

FY17 Small Business (SBIR) Projects – Completed

- **Physical Optics Corp** – REE Mass Analyzer
- **Physical Sciences Inc.** – Spectro-chemical Detection/Monitoring of REE during Extraction
- **Adelphi Technology** – Nondestructive Bulk REE Measurement System from Coal
- **Applied Spectra, Inc.** – Sensor for Direct, Rapid and Complete Elemental Analysis of Coal

FY18 Small Business (SBIR) Projects – Completed

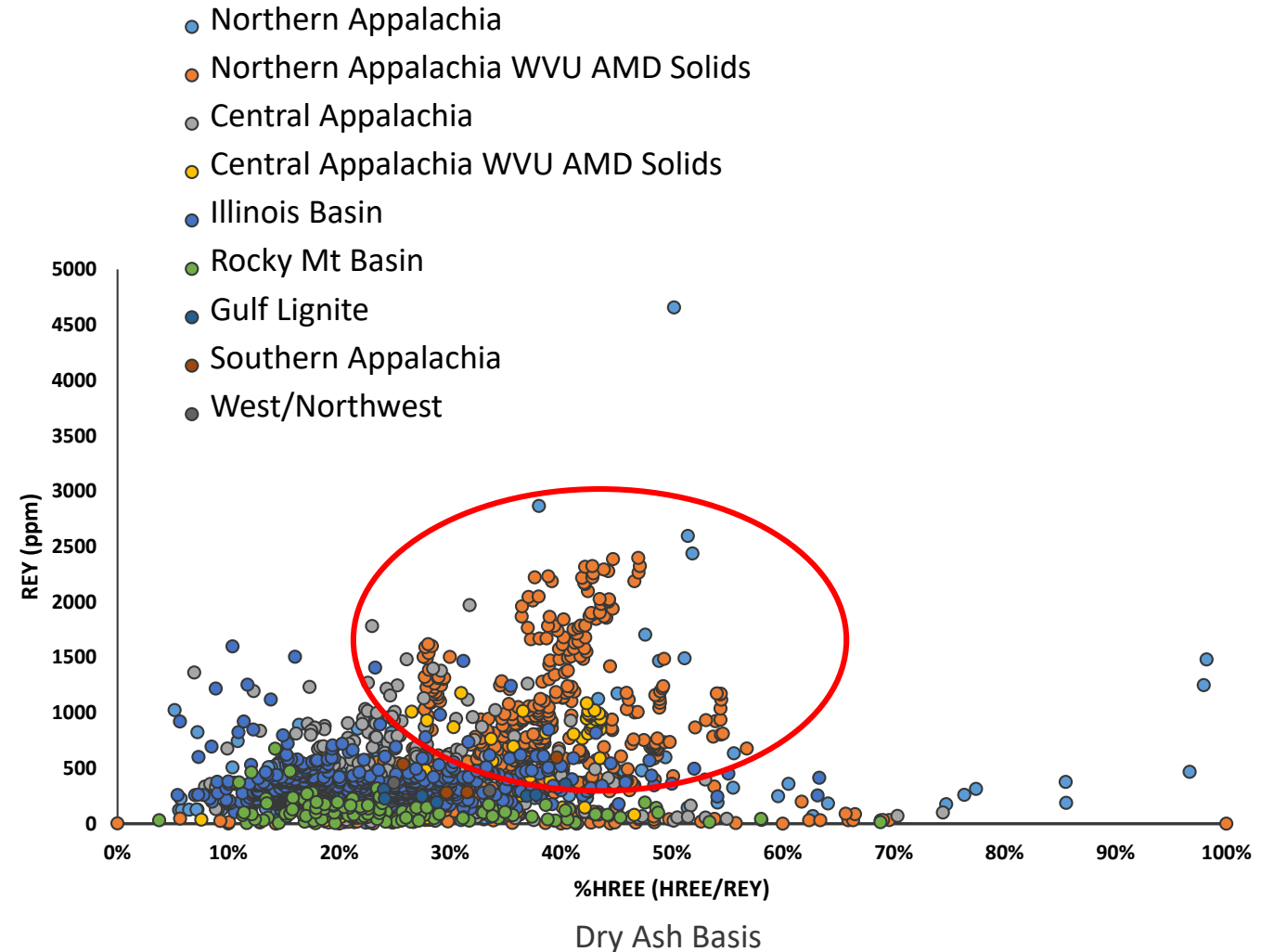
- **Skyhaven Systems, LLC** – Rare Earth Extraction from Coal Fly Ash
- **Wyonics LLC** – Ionic Liquids as Advanced Solvents for the Extraction of Rare Earth Elements from Coal Products
- **Anactisis LLC** – Coal Ash Beneficiation through Critical Material Extraction and Recovery

FY19 Small Business (SBIR) Projects

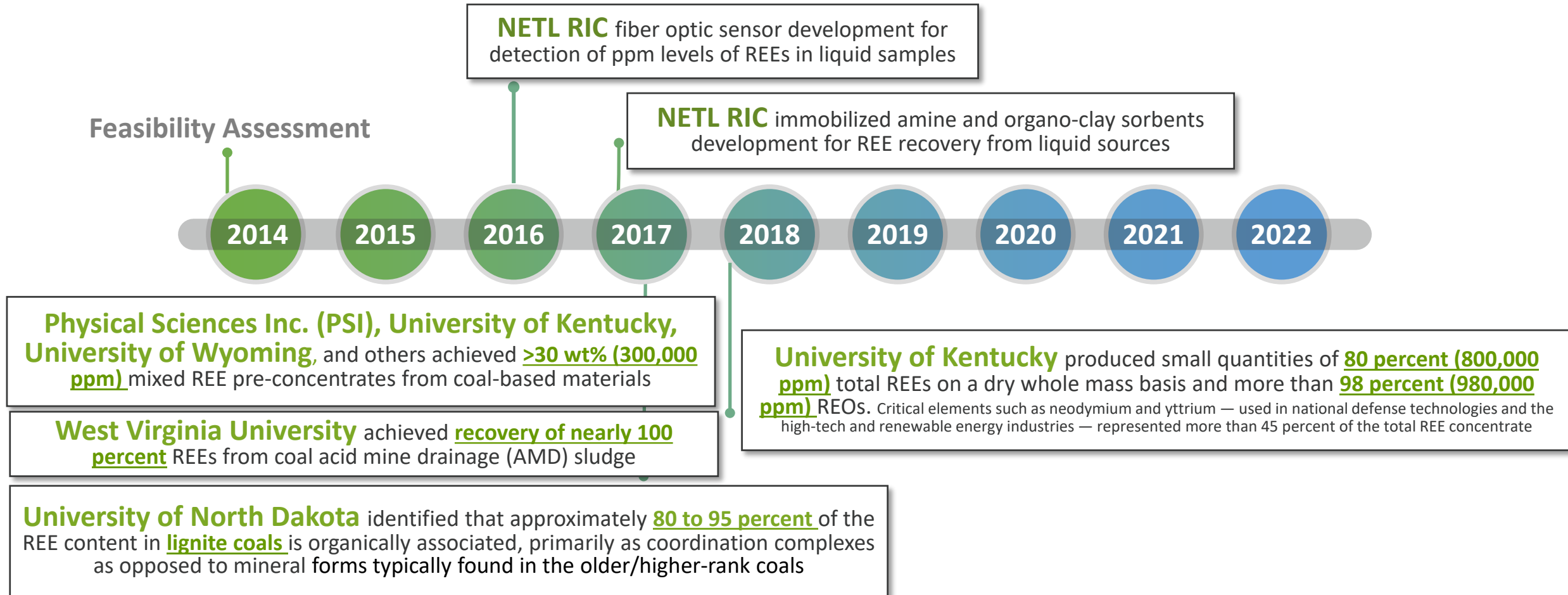
Topic: Production of Rare Earth Metals

REE Program Portfolio

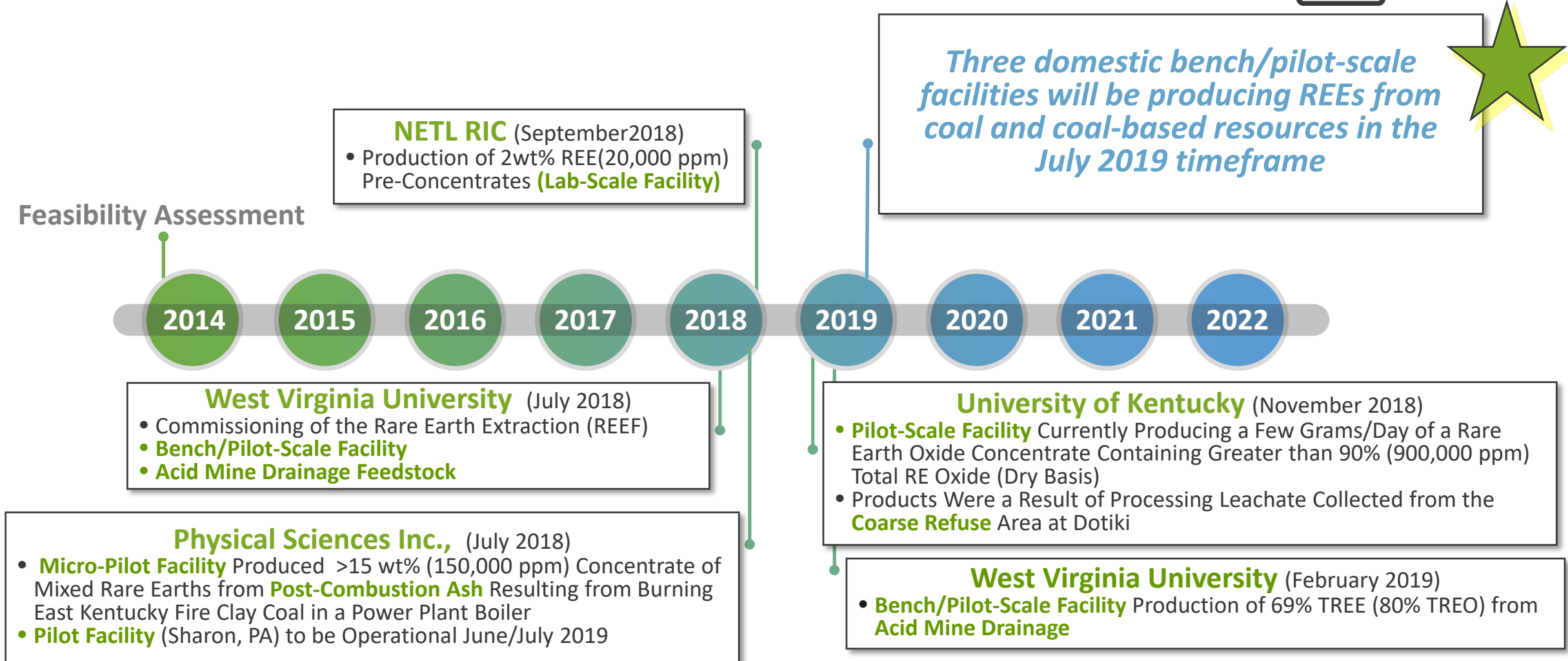
- **FY16 RFP DE-SOL-0009067** – Domestic Field Sampling & Characterization (Contracts Completed)
 - **University of Kentucky:** Western Kentucky bituminous coal in the Illinois Coal Basin
 - **West Virginia University:** Acid mine drainage (AMD) from bituminous coal mines in Northern and Central Appalachian Coal Basins
 - **TetraTech, Inc. (PA, CO):** Bituminous, subbituminous, and anthracite coals in Northern and Central Appalachian Coal Basins; Rocky Mountain
 - **XLight Corporation:** Coals in the Eastern Pennsylvania Anthracite Region
- **FY17 RFP DE-SOL-0010982** – Domestic Field Sampling & Characterization; Round Robin Analyses (Sept 2019)
 - **University of North Dakota,** Energy & Environmental Research Center, North Dakota Geological Survey, University of Kentucky, Kentucky Geological Survey, North American Coal Corporation (NACoal), Westmoreland Coal Company, Kiewit Mining Company, BNI Coal Company:
 - Coals from Fort Union Group within the Lignite/Williston Basin and Powder River Basin; Gulf Coast lignite and Appalachian Basins

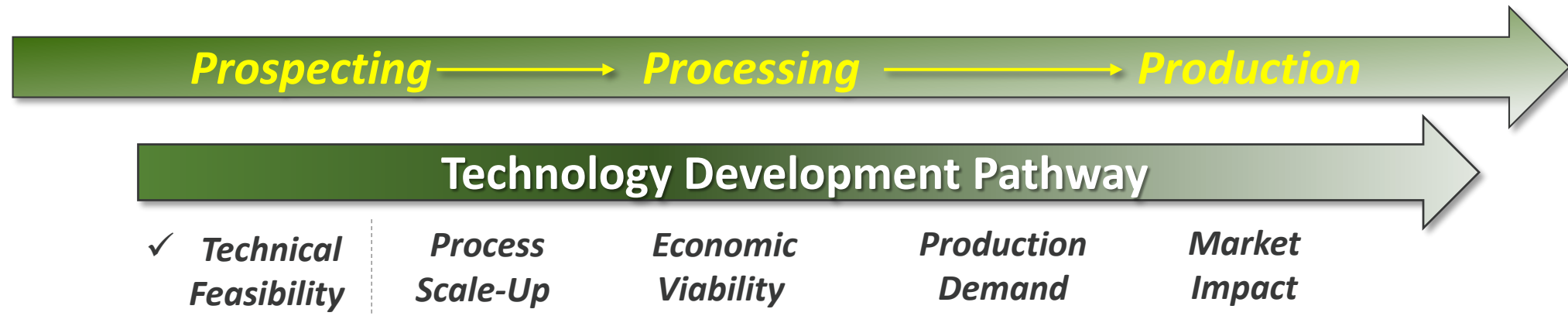


REE Program – Major Accomplishments: 2016-2017



REE Program – Major Accomplishments: 2018-2019





Heavy-Light vs Critical REEs – Product Impacting Process Economics

Critical Materials – EO-13817

Process Operation – Resources & Fuel Flexibility

NETL REE Website

Where We Are Today

- ✓ **Technical Feasibility** of Extracting REE from Coal-Based Resources Demonstrated at Laboratory/Bench-Scale
- ✓ **Three Domestic, First-of-a-Kind, Extraction/Separation Test Facilities**, Producing REEs from Coal-Based Materials, Are Targeted to be Operational in **the July 2019 Timeframe**
- ✓ **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

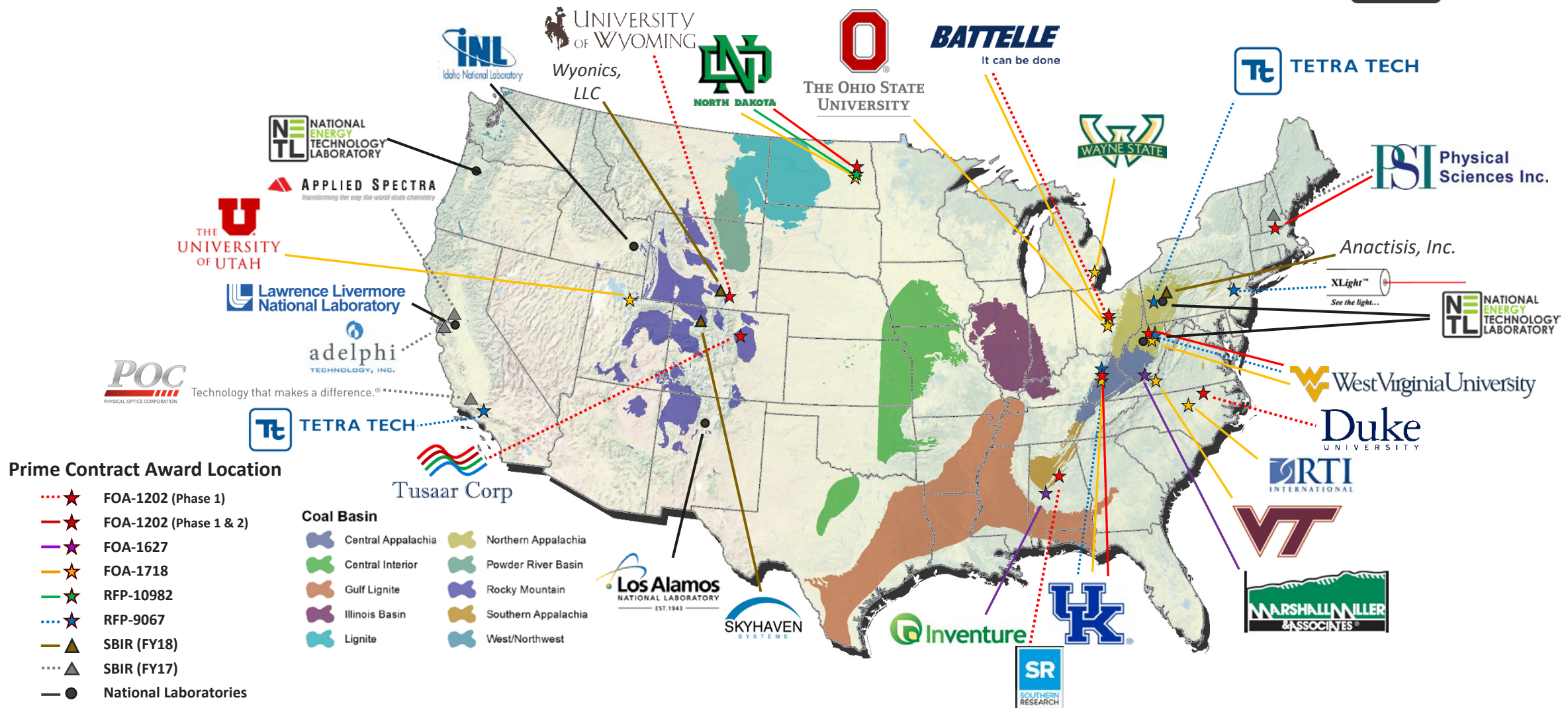
What Is Needed for Tomorrow

- ✓ **Process Scale-Up & Economic Feasibility** Need to be Demonstrated
- ✓ Impact of REE Production on **International Market** Needs to Be Addressed
- ✓ **Commodity-to-Product Integration**: REE Metallization through On-Shore Manufacturing Supporting Entire Supply Chain

Overall Benefits & Impact

- ✓ **National Independence** from Off-Shore Production
- ✓ Impact of REE Production on Ash Pond, AMD, Coal Refuse Wastes **Remediation**
- ✓ REE Processing & Critical Materials Production
- ✓ **REEs & Advanced Materials Development**: *Advanced High Temperature Alloys & Coatings, etc.*
- ✓ Product Development of **Dual Use REEs**: *Incorporation into Advanced Defense and Energy Equipment*
- ✓ **Technology Transfer** to Alternate Separation Industries: *Battery/Magnet Re-Cycling*

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/>
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