Supply Chains Of Recovered Elements

A commercialization accelerator for domestic critical element production

from Waste to Economic and Workforce Development

Virtual Briefing July 9 2024
Commonwealth of PA DEP Citizens Council

Bernie Lynch, on behalf of SCORE Consortium
Ned Eldridge, ELoop, at the request of PA DEP Citizen's Council

WWW.SCORECONSORTIUM.ORG

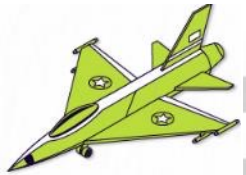
The Critical Minerals Problem: US Dependence on Imports

US supply chains for 30 critical and strategic elements are non-existent.

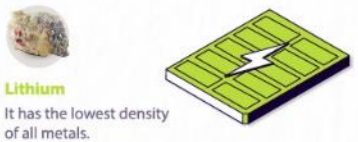
Critical Minerals		EXAMPLE USES
Hafnium	E	Nuclear control rods, alloys
Beryllium	11%	Alloying agent in aerospace, defense industries
Aluminum	13%	Power lines, construction, electronics
Zirconium	25%	High-temperature ceramics production
Palladium	40%	Catalytic converters
Germanium	50%	Fiber optics, night vision applications
Lithium	50%	EV rechargeable batteries
Magnesium	50%	Car seats, luggage, laptops
Nickel	50%	Stainless steel, rechargeable batteries
Tungsten	50%	Wear-resistant metals
Barite	75%	Hydrocarbon production
Chromium	75%	Stainless steel
Tin	75%	Coatings, alloys for steel
Cobalt	76%	Rechargeable batteries, superalloys
Platinum	79%	Catalytic converters
Antimony	81%	Lead-acid batteries, flame retardants
Zinc	83%	Metallurgy to produce galvanized steel
Titanium	88%	White pigment or metal alloys
Bismuth	94%	Medical, atomic research
Tellurium	95%	Solar cells, thermoelectric devices
Vanadium	96%	Alloying agent for iron, steel
Arsenic	100%	Semi-conductors, lumber preservatives, pesticides
Cerium	100%	Catalytic converters, ceramics, glass, metallurgy
Cesium	100%	Research, development
Dysprosium	100%	Data storage devices, lasers
Erbium	100%	Fiber optics, optical amplifiers, lasers
Europium	100%	Phosphors, nuclear control rods
Fluorspar	100%	Manufacture of aluminum, cement, steel, gasoline
Gadolinium	100%	Medical imaging, steelmaking
Gallium	100%	Integrated circuits, LEDs
Graphite	100%	Lubricants, batteries
Holmium	100%	Permanent magnets, nuclear control rods
Indium	100%	Liquid crystal display screens
Lanthanum	100%	Catalysts, ceramics, glass, polishing compounds
Lutetium	100%	Scintillators for medical imaging, cancer therapies
Manganese	100%	Steelmaking, batteries
Neodymium	100%	Medical, industrial lasers
Niobium	100%	Steel, superalloys
Praseodymium	100%	Permanent magnets, batteries, aerospace alloys
Rubidium	100%	Research, development in electronics
Samarium	100%	Cancer treatment, absorber in nuclear reactors
Scandium	100%	Alloys, ceramics, fuel cells
Tantalum	100%	Electronic components, superalloys
Terbium	100%	Metal alloys, lasers
Thulium	100%	Metal alloys, lasers
Ytterbium	100%	Catalysts, scintillometers, lasers, metallurgy
Yttrium	100%	Ceramic, catalysts, lasers, metallurgy, phosphors
Iridium	?**	Coating of anodes for electrochemical processes
Rhodium	?**	Catalytic converters, electrical components
Ruthenium	?**	Electrical contacts, chip resistors in computers

INDICATES GOVERNMENT STOCKPILE

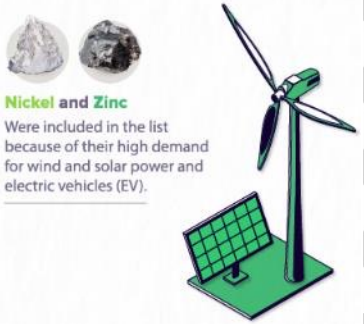
NET EXPORTER / NET IMPORT RELIANCE



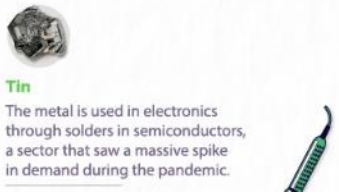
Beryllium
In military fighter jets, pure beryllium saves weight critical to speed and maneuverability.



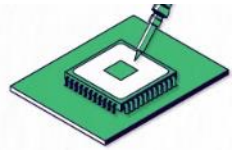
Lithium
It has the lowest density of all metals.



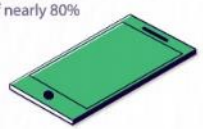
Nickel and Zinc
Were included in the list because of their high demand for wind and solar power and electric vehicles (EV).



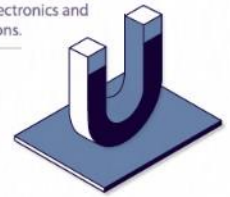
Tin
The metal is used in electronics through solders in semiconductors, a sector that saw a massive spike in demand during the pandemic.



Rare Earths
Elements like cerium are widely used in batteries and electronics. China is the source of nearly 80% of U.S. imports.

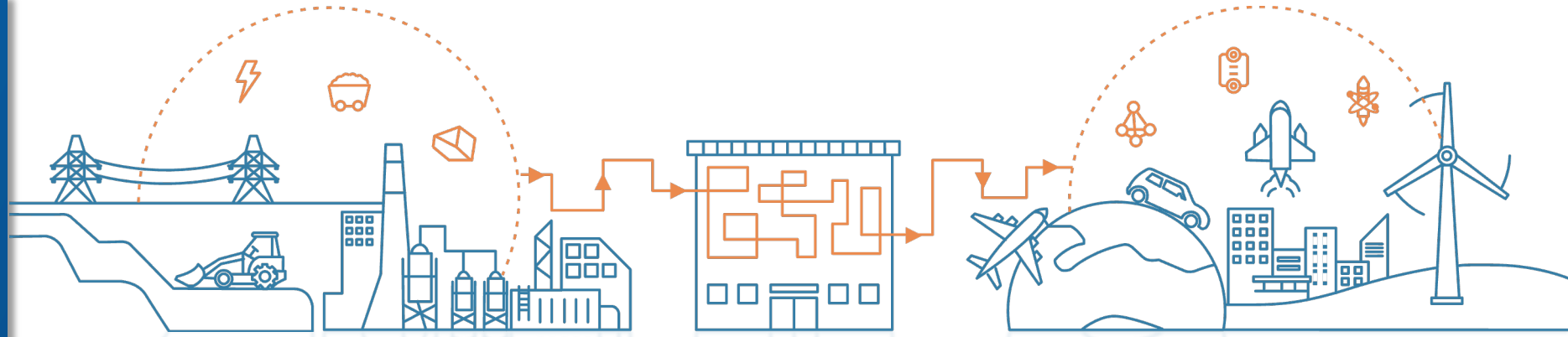


Neodymium and Samarium
Alloys of these rare earths are used in magnets that withstand high temperatures, making them ideal for a wide variety of mission-critical electronics and defense applications.



** No data available
Source: U.S. Department of the Interior, U.S. Geological Survey

SCORE



Mission/Vision

To build fully capable supply chains for domestic sourcing and production of critical minerals from waste streams

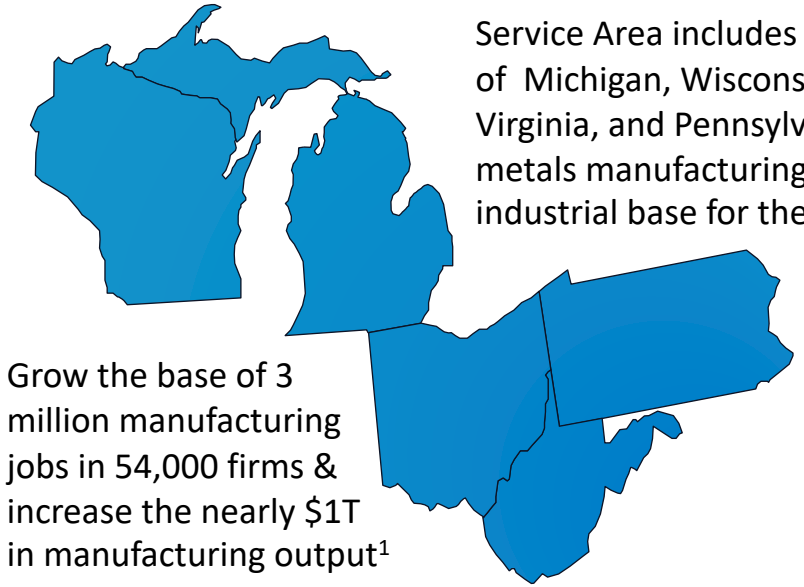
Project Summary

Within 3 years, create a stable domestic supply of scandium through extraction from mine and industrial wastes while collaboratively establishing an integrated supply chain for the incorporation of domestic scandium into US-manufactured aluminum alloys and components for end users.

Create and validate a repeatable commercialization accelerator framework for adaptation to other critical minerals, waste streams, and supply chains.

SCORE

SCORE Service Area Identification



Service Area includes a 5-state region of Michigan, Wisconsin, Ohio, West Virginia, and Pennsylvania with strength in metals manufacturing to form a new industrial base for the region.

Grow the base of 3 million manufacturing jobs in 54,000 firms & increase the nearly $1T in manufacturing output[1]

The defense manufacturing community supply chain to be developed is scandium when alloyed with aluminum.

Uniquely qualified as a region for the early development of the scandium supply chain, manufacturing as of 2020 employed more than 3 million individuals in at an average wage rate of $78,100, or nearly $20,000 more per year than the average wage for the region[2].

Given the 500,000 mine and industrial sites nationally, recovery from stockpiled waste alone has the potential to satisfy US demand for dozens of critical minerals for more than 50 years.

National Ranking

This 5-state region represents one third (33%) of foundry products and nearly one fourth (23%) of aluminum production nationally, key to the supply chain processes for scandium in recovery, refining, smelting, alloying, wire forming, additive powder and equipment production, as well as R&D, testing and material standards for end users in automotive, aerospace, space, energy, and to light-weight materials for warfighter use in applications relevant. Additional required capabilities point to a high national rank:

Five State Region as a % of US total in:

27%	Stamping & Forging % of US
35.3%	Ferrous Metal Foundry Products
31.3%	Nonferrous Metal Foundry Products
24.4%	Nonferrous Metal Rolling & Alloying in the US
22.6%	Aluminum Manufacturing in the US
20.1%	Nonferrous Metal Refining in the US
22.1%	Circuit Board & Electronic Component Manufacturing
11.5%	Space Vehicle & Missile Manufacturing
12.1%	Aircraft, Engine & Parts Manufacturing

Ultimately, all states will be beneficiaries for these reasons:

--- Feedstocks for scandium recovery exist in all 50 states
--- Each waste site becomes a manufacturing process site with employment on location
--- Moves dormant waste to active manufacturing
--- Environmental clean-up with waste stream management is a by-product
--- High yields of scandium and high rates of return enable economic development
--- Occupational standards are portable for apprenticeship & industry credentialling
--- The business case for scandium recovery creates economic value from waste

SCORE

1 US Census Manufacturing: Summary Statistics
2 National Association of Manufacturers

SCORE Consortium: Leveraged $6M+ in Defense Funding and Match Partners

U.S. Department of Defense
Office of Local Defense Community Cooperation

- Defense Manufacturing Community Support Program Designee for an initial 5-Year Period
- Supports long-term community investments that strengthen national security innovation and expand the capabilities of the defense manufacturing industrial ecosystem.
- Awarded a $4.7M grant, $1.6 M match for $6.3M project
- A 3-year effort to create a stable domestic supply of scandium through extraction from mine and industrial wastes while concurrently and collaboratively establishing an integrated supply chain for the incorporation of domestic scandium into US-manufactured aluminum alloys and components for end users.
- Pilot and Demonstrate extraction technology for scale
- Simultaneous development of downstream applications and workforce preparedness

SCORE

SCORE Project: Massive waste liability into commercially viability and value

Waste Streams

- Coal Ash
- Bauxite Residue
- Mine Tailings
- Titanium Dioxide
- Phosphogypsum

Target Minerals

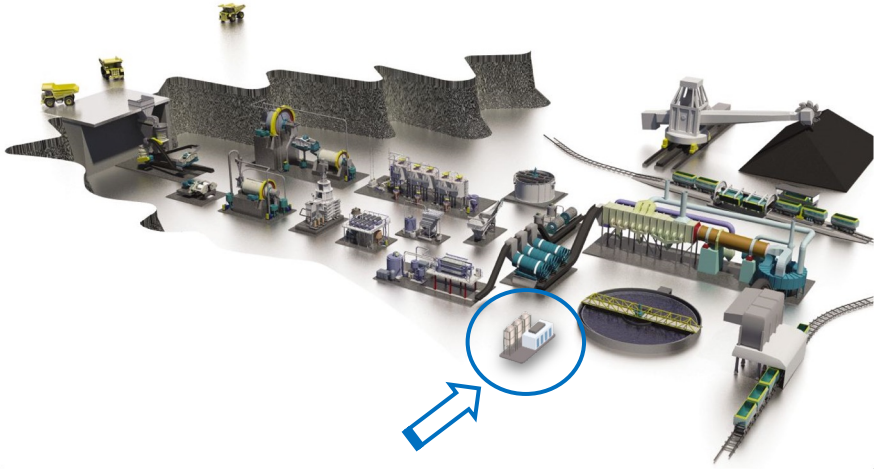
		Target Mineral Uses
Sc	Scandium	Defense, alloys, space, aviation, automotive, additive manufacturing, fuel cells
Ge	Germanium	Solar cells, fiber optics, electronics, polymer catalysis
Ga	Gallium	5G Networks, LEDs, biomedical, radio-pharmaceuticals
Nb	Niobium	Alloys, electronics, shielding, platings, defense
V	Vanadium	Aerospace, alloys, catalysts, redox batteries, energy storage
Pt	Platinum Group	Catalysts, automotive, pharma, rubber, fuel cells, high technology

SCORE: Enabling Technology Targeting High Value Minerals

Anactisis

Modular, economical separations technology

Low-cost relative to mining, low disruption, flexible, scalable with demand



Green
No organic solvents
Less waste

Economical
40% lower costs make extraction feasible

Sustainable
Marginal added effort to existing processing, landfill reduction

Modular & Scalable
No supply limitations
Growing market

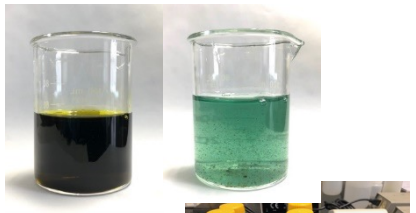
Flexible
Costs responsive to demand

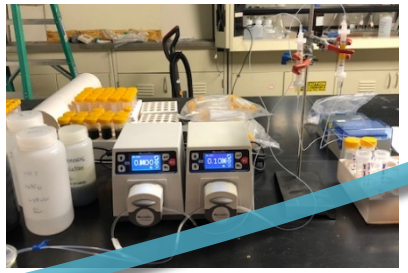
Small Footprint
Minimal infrastructure
Rapid capital recovery

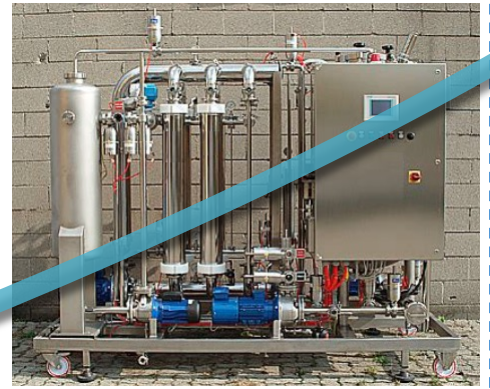
SCORE

Path to Market

Anactisis







FIDELITY

SCORE

SBIR Phase II

SCALE	1x	10x	100x	2500x	10^6x
	Batch testing with real industrial waste	Column testing in semi-manual mode	Scaleup and column optimization	15 lph field-trial pilot	6,000 lph demonstration

Commercial-scale: 50,000 liters per hour

SCORE

Biotechnology (BEER)

Tri-Service Biotechnology for a Resilient Supply Chain (T-BRSC) Government

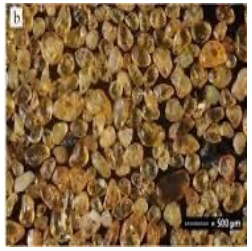
Ed Perkins, Army Senior Scientist (ST) Environmental Networks & Genetic Toxicology,
USACE Engineer Research and Development Center

10 July 2023

Vision: Enable domestic recovery/purification of Rare Earth Elements

Domestically sourced feedstock

Ore, mine waste



E-Waste, recycling

Acid mine drainage

Dredged sediment & ground water

leachate/ concentrate

Domestically processed critical minerals

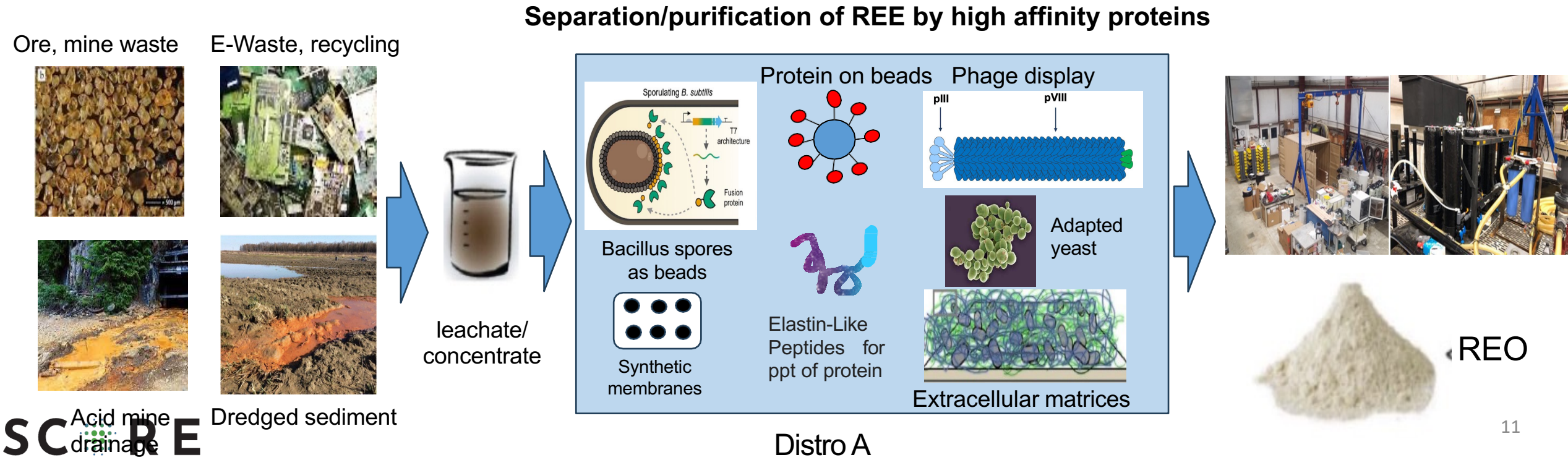
Separation/purification of REE by high affinity proteins

Domestically produced critical minerals

Domestic production/recovery of individual Rare Earth Elements

Tech Product Description

- Tailored processes to separate and purify individual REE with high affinity proteins
- Reduction/elimination of costly and repeated solvent extractions.
- Eliminates need for OCONUS processing and makes alternative REE sources viable feedstock.



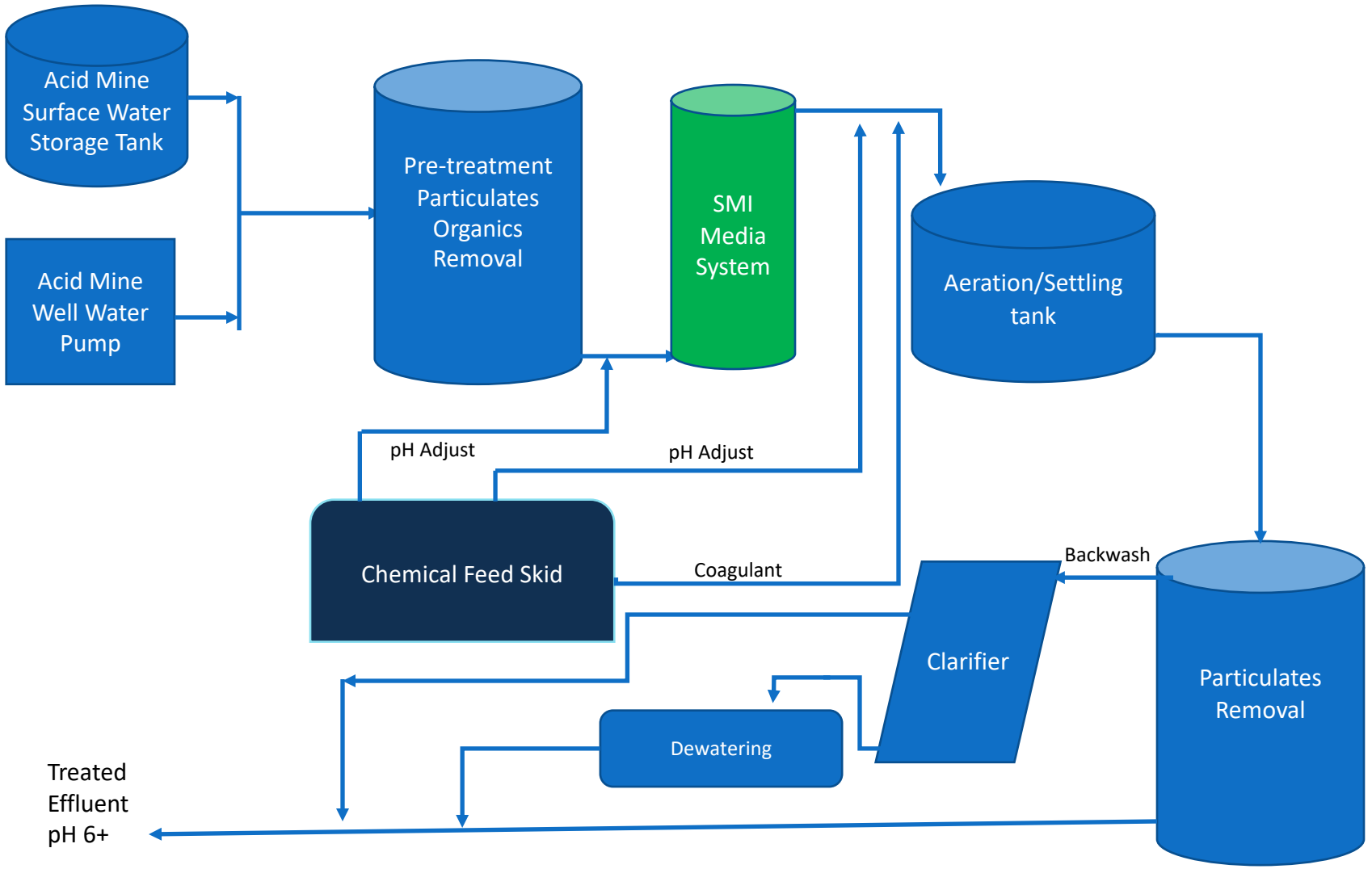
Army Corps Commercialization Project: SMI Solutions Acid Mine Drainage

- SMI-PS Inc. holds the exclusive patent rights to water treatment technology based on the use of sulfur-modified iron, an extremely effective and economic media for removing a wide assortment of contaminants from water.
- SMI® represents a significant departure from current methods of removing contaminants from water and wastewater and creates substantial competitive advantages for SMI-PS Inc
- SMI® is an effective water treatment solution for a wide range of inorganic and organic contaminants
- To date, SMI has been successfully tested on arsenic, nitrate, hexavalent chromium (Cr VI), vinyl chloride, selenium, trichloroethelene (TCE), chlorinated solvents, halogenated pesticides, technetium and a variety of petroleum hydrocarbons.
    - SMI is capable of removing contaminants down to non-detectable levels (e.g. < 2 µg/l) in most applications
- SMI also has the demonstrated capability to extract rare earth elements (REEs).
    - In laboratory tests on WV AMD (specifically at A34 site), SMI has been indicated to retain >99% of Heavy, Critical Heavy, and Critical Light REEs, plus Uranium

- West Virginia (2014) – Patriot Coal, 200 gpm system selenium removal
- California (2016) – P66, 80 gpm system selenium removal
- Maryland (2018) – Genon, 100 gpm system Coal Ash Pile
- Virginia (2018) – closure of Coal Ash Pond, 100,000,000 gallons treated
- West Virginia (2023) – ERP Receivership 100 gpm selenium removal Hobet Mine
- Future project – West Virginia DEP 150 gpm system on AMD
- Future project - Middle East Oil Refinery 300 gpm selenium removal
- Future project – Italian Oil Refinery 150 gpm selenium removal

SMI Process Flow Diagram – Removal System

$7M in Congressional Support from WVA



Selective Recovery of REE/CM from E-Waste

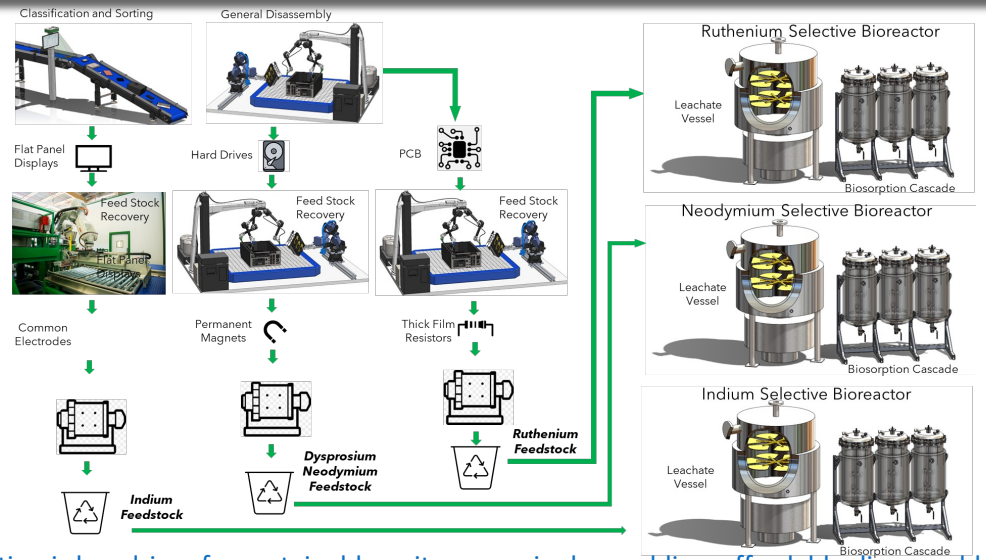
Objective

- Construct Bio Factory for efficient recovery of CM/REE from E-waste.
- Stockpile CM/REE rich E-waste Components for harvesting.
- Automate Extraction/Aggregation of E-Waste Components to enable economies of scale.

CM/REE	Leaching Microbe	Recovery Residue	Recovery Efficiency
Neodymium	A. thiooxidans	C. crescentus	99%
Dysprosium	A. thiooxidans	Penidiella sp. T9	50%
Europium	G. oxydans	T. scotoductus	68%
Erbium	A. thiooxidans	Algae strains: ChlSG, EugVP	10%
Indium	A. thiooxidans	Shanwella algae	99%
Ruthenium	G. oxydans	C. crescentus	60%

Current Focus is on 6 Critical Minerals (CM)

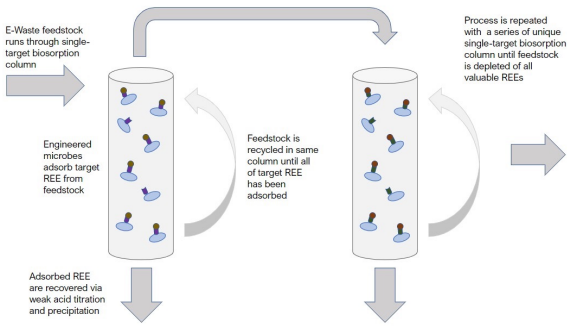
- Prove initial concept for Bio Factory in the recovery of Indium from Flat Panel Displays (FPDs)
- Sustainable Unit Economics for recovery of REE from consumer and DoD E-waste streams.
- Scale Bio Factory to recovery 12 REE/CM from the SCORE consortium list.



Automation is key driver for sustainable unit economics by enabling affordable disassembly and selective aggregation of REE/CM rich components

Approach

- BAIR:
  - Biohydrometallurgy (B)
  - Artificial Intelligence (AI)
  - Robotics (R)
- **AI:** identification and dis-assembly planning of ad-hoc e-Waste.
- **R:** Automated e-Waste disassembly and REE rich component aggregations
- **B:** Selective, efficient, safe recovery of REE/CM using Bioreactors



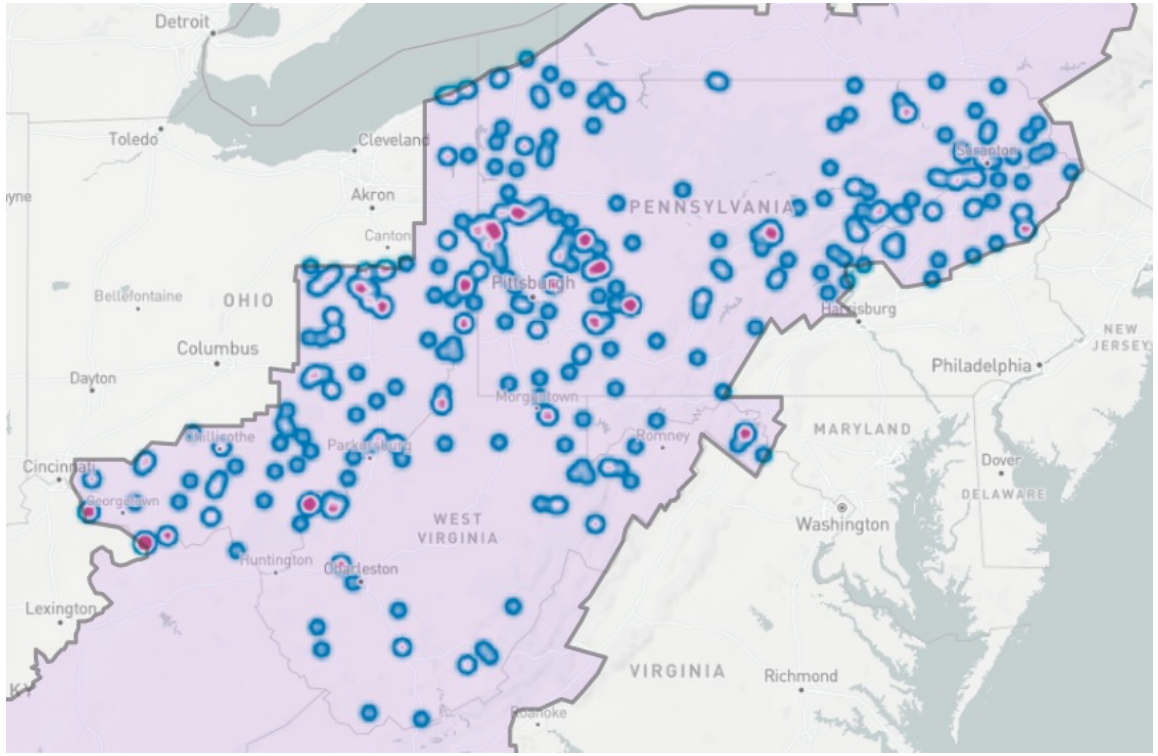
Selective adsorption of REE/CM from leachate using reusable filter columns can recover $5 M in REE/CM per year per 10,000 square feet of Bio Factory

Key Milestones

- FPD Pro Operational (Completed)
  - Harvesting 400,000 lbs. FPD per month (Indium)
- Indium Bio Factory Operational
  - Dec 2023: 0.192 kg/day (1 Kiloliters)
  - Jul 2024: 1.0 kg/day (5 Kiloliters)
  - Dec 2024: 9.6 kg/day (40 Kiloliters)
- REE Bio Factor Operational
  - Ruthenium, Dysprosium, Neodymium, Europium, Erbium, Terbium
  - Dec 2024: (5 Kiloliter / REE)

FPD Pro Robot can process 10M kg of FPD/year containing up to 3500 kg of Indium

SCORE: Economic Value Proposition for a New Economic Opportunity



As an example:
Out of the 300+ bulk waste sites within OH-WV-PA, plus the 1000+ mining sites, if we start with:

61 major sites in coal ash = 570 million cubic yards
Material Value = $579 billion
Critical Minerals = $29 – 38 billion
Rare Earths = $14 billion

Jobs and local economic development for 30+ years

Direct jobs **25,650 from Technology Process**
Total jobs **123,500 from Manufacturing to Transport**

More than 6 waste streams and 19 high value target minerals. SCORE Consortium is capable:

- **Team** with other waste stream beneficiation groups, existing contractors and target waste stream options for commercial viability

– **Maximize the waste value** with existing waste providers in carbons, cements, concrete, aggregate and other building materials, and a host of other targets in the waste – and waste streams that can be reclaimed and reused to gain the maximum value.

Future funding provides the commercial value in minerals by expanding the number of target minerals into commercialization and determines where SCORE will commence its work.

SCORE

SCORE ARISE: Billion Dollar Industry Birthed from Waste

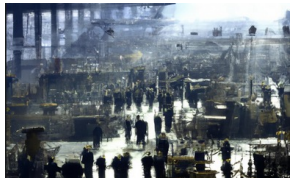
Material Separation

Rare Earths will be separated by local firm for sale and use

Refinement

Target Minerals require refineries to expand for market

Source Materials



Rare materials build or expand firms to trade, manufacture, and transport.

Expanding Employment

Entirely new industry starts in Appalachian States

Economic Gains

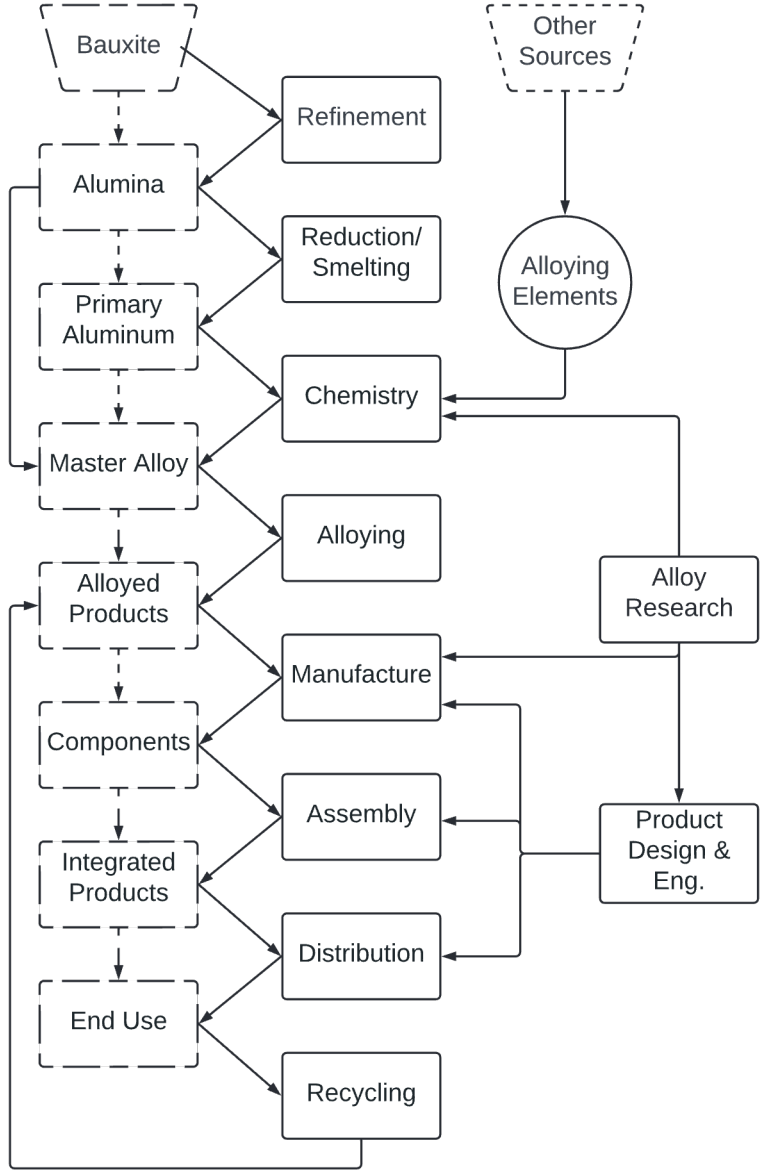
Entire regions will participate in a sustainable recycling effort worth billions in economic spin-off

Expanding tax base

Employment, business, transportation and logistics increase and expand revenues

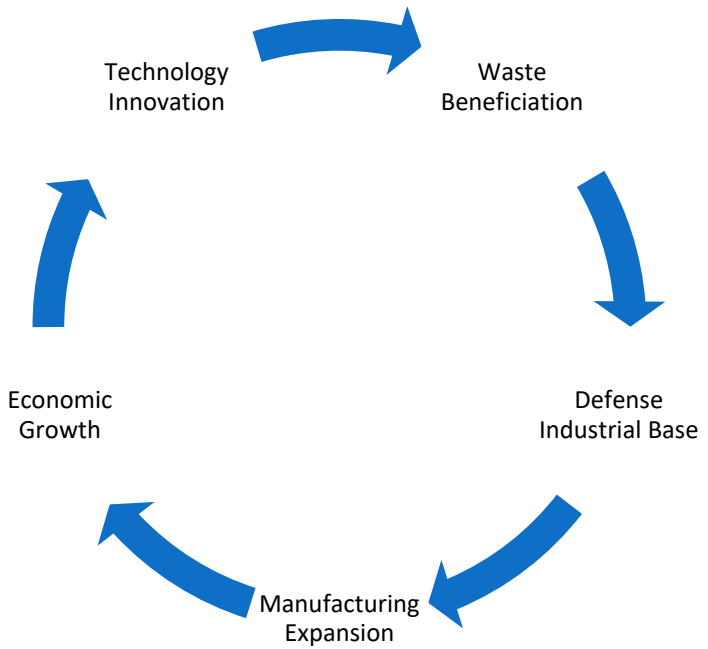
The Critical Minerals Problem: Building Complex New Supply Chains

- SCORE Consortium to develops supply chains shown in the 5-state region OH-WV-PA-MI-WI
- Each state can play a role in the supply chain of 30 target minerals/elements not in the U.S. currently
- Building a new framework for a new economy becomes a combined effort with all states working together.
- With a plan to work connectedly, and in a small footprint, the 5-states can serve US needs in national security and national defense for decades.



SCORE

The Sustainable Opportunity in the Billions



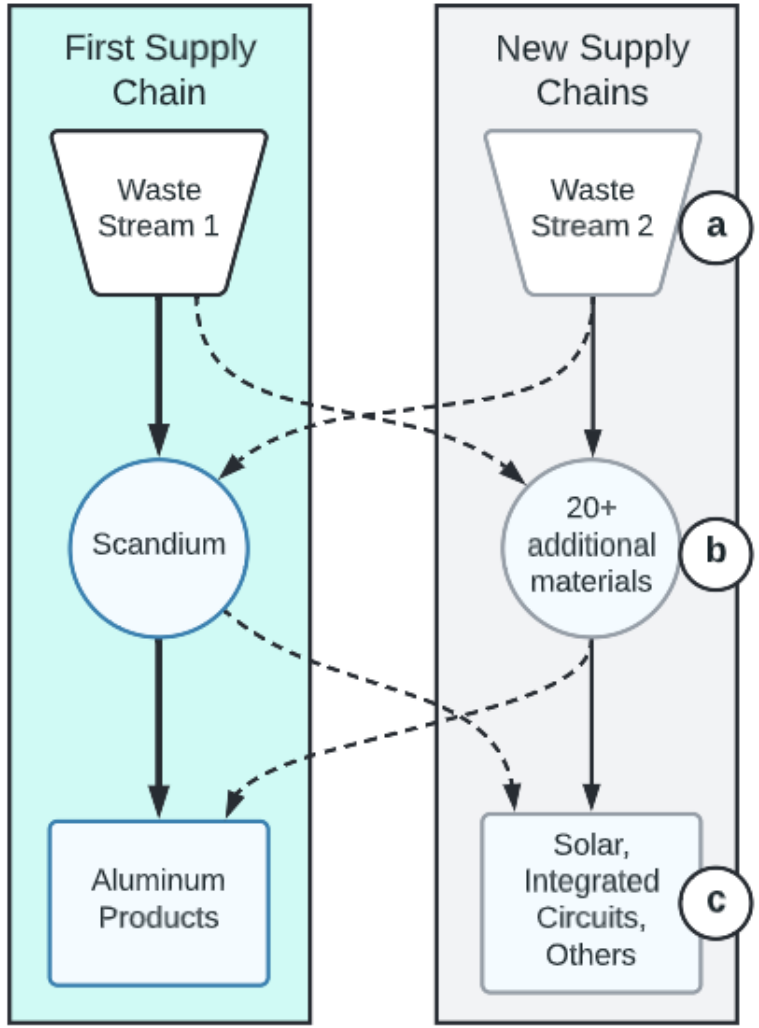
Circular economy waste extraction vs mine extraction

- Reward, Invest and Incentivize
  - government supply purchase requirements
  - tax credit incentives
  - cooperative supply chain agreements within state
- Policy Development
  - Regulatory support for advancement
  - Protections against foreign dumping
  - Domestic sourcing purchase preferences
  - Tax credit/price advantages for domestic sourcing
  - Requirements for 100% waste beneficiation
- Defense and Commercial Industrial Base
  - De-risk with supply chain coop agreements
  - New industry growth in waste beneficiation
  - Critical mineral/REE investments valley of death

Multi-state and multi-federal agency agreements for sector end use applications

SCORE

Next Steps for SCORE



New supply chains

SCORE to Target 20+ Minerals SCORE is commercializing processes that can be quickly adapted to various materials, waste streams, and locations, enabling rapid development of domestic supply chains.

New waste streams

The US has ample supply of waste stockpiles. Marginal additional development can expand capabilities to processing of **coal ash** and byproducts, **bauxite residue**, **phosphogypsum**, and various sources of **mine tailings**, transforming costly liabilities into a powerful economic drivers.

New materials

R&D Funding Sought:

Multiple materials can be extracted from each waste source, further reducing waste and funding sustainable waste management

New applications

Rare Earth Ores and other REE-Critical Minerals

Initial applications stabilize supply for broader use, fueling the reshoring of US manufacturing capabilities from source to production

SCORE

eLoop

Sustainable IT Lifecycle Management

Introducing AI-Robotics in the Demanufacturing of Electronic Scrap

A better way to handle e-waste

eLoop - Background

- Participating in the electronic equipment recycling industry since 2008
- Headquartered in Export PA 20 miles east of Pittsburgh
- Opened a second operating facility in State College PA in 2013
- First certified BAN e-Steward in PA in 2011
- Supports 7 County residential collection programs in PA
- First in the industry to install robotics with the FPD Pro in April 2023
- Entering the Flat Panel Display Business
- Labor pool insufficient to staff manual teardown operations

Next Robotic Application

- FPD Pro - Screen removal and depolluting of LCD screens (mercury)
- Working directly with CMU to build out a series of robots with specific applications
  - Fastener removal scheduled for deployment in August
  - Flat Panel Displays (FPDs) all makes and models
  - Laptops, PCs, and servers
  - Tablets, phones, and communication equipment
  - Major focus on flat panel TVs as they are the fastest growing electronic waste stream in the world.

Benefits of Robotics

- Increased Production Capacity – Speed
- Completing tedious disassembly tasks that are formerly done manually.
- Allows for more efficient use of personnel.
- Improves production planning due to the steady flow of materials
- Creates a complete database of all makes and models processed
- Gold Standard Certification for Carbon Credits

Benefits of Robotics

- Separates plastics and removes metal contamination
  - Looking to produce clean streams and sell into better recycling markets.
  - ABS plastic represents 20% of the weight of a TV.
  - In discussions with Covestro to supply a blend of ABS that meets their specifications for recycled content.

Benefits of Robotics

- We are looking at applications to liberate rare earth and critical materials from electronic devices for further material recovery.
  - The thin film transistor (TFT) in each TV screen contains Indium in the substrate.
  - Successfully recovered Indium at the bench level and we are working with a commercial partner, Indium Corp.
  - Collaboration ongoing samples to be delivered by end of July
  - Developing plans for commercial scale.

Innovation & Sustainability

- Innovative and sustainable operations in State College, PA.
- Central location to work with recyclers in the 7 contiguous states to PA.
  - Reduced transportation costs
  - Reduced energy consumption compared to large scale shredding operations.
  - Diversion of 98% of the material we process from disposal in landfills.
  - Circularity at its finest!