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Energy & Environmental Research Center (EERC)

CRITICAL MINERALS FROM LIGNITE: THE PROCESS AND PRODUCTS

May 25, 2023

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Webinar Series Events

Critical Minerals: What, How, Why All the Hype?
September 21, 2022

Today's Critical Mineral Technologies and How to Move Forward
November 30, 2022

Why Do Critical Mineral Business in the Williston Basin?
Our Strengths, Our Assets, Our Needs
January 11, 2023

Critical Minerals from Lignite: The Process and Products
May 25, 2023

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CRITICAL MINERALS FROM LIGNITE: THE PROCESS AND PRODUCTS

May 25, 2023

Nolan Theaker, Senior Research Manager

Critical Minerals, Institute for Energy Studies

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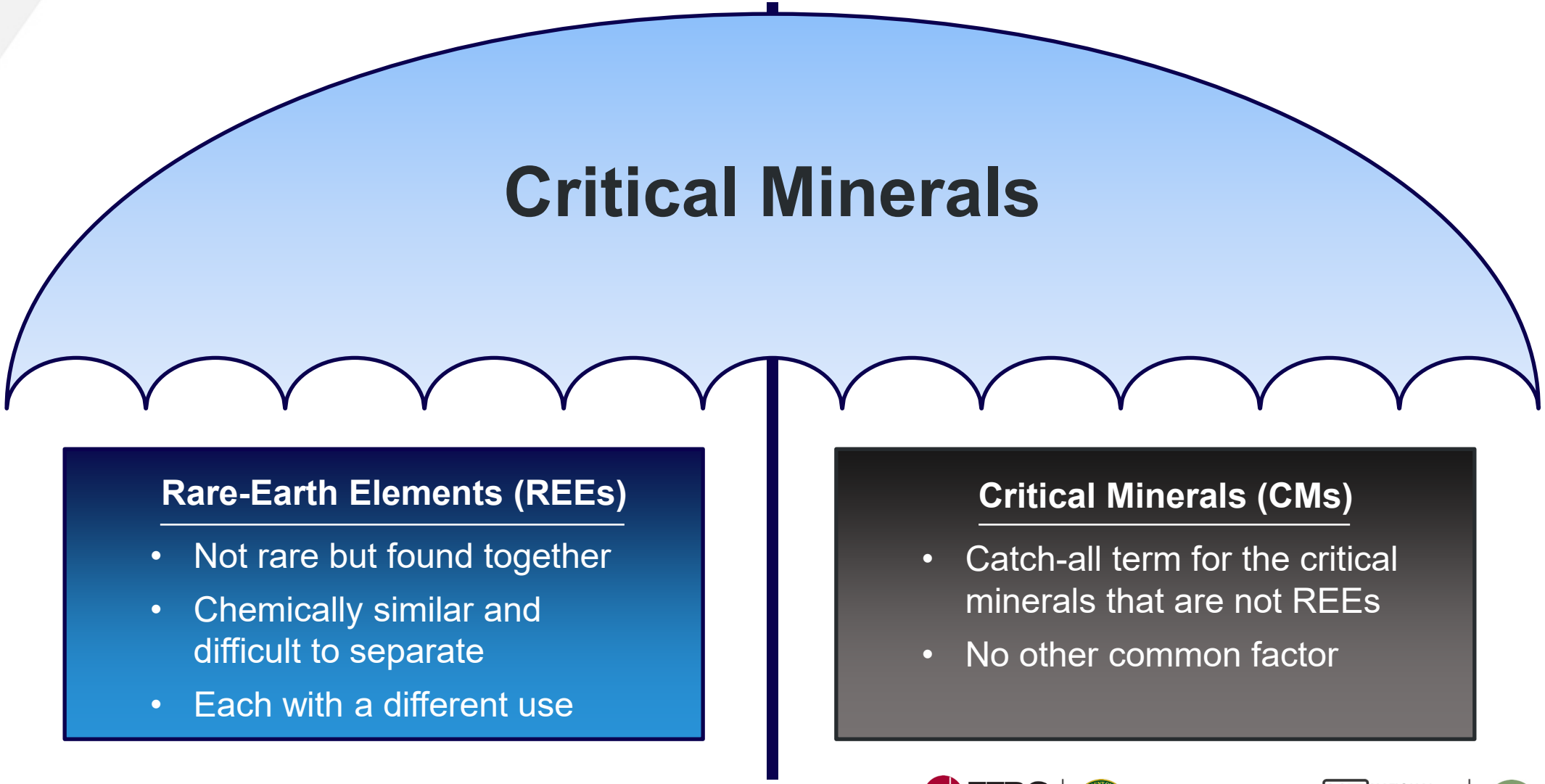
CORE-CM WILLISTON BASIN

Defining Critical Minerals



Critical Minerals Play a Vital Role in Our Modern Economy and National Security

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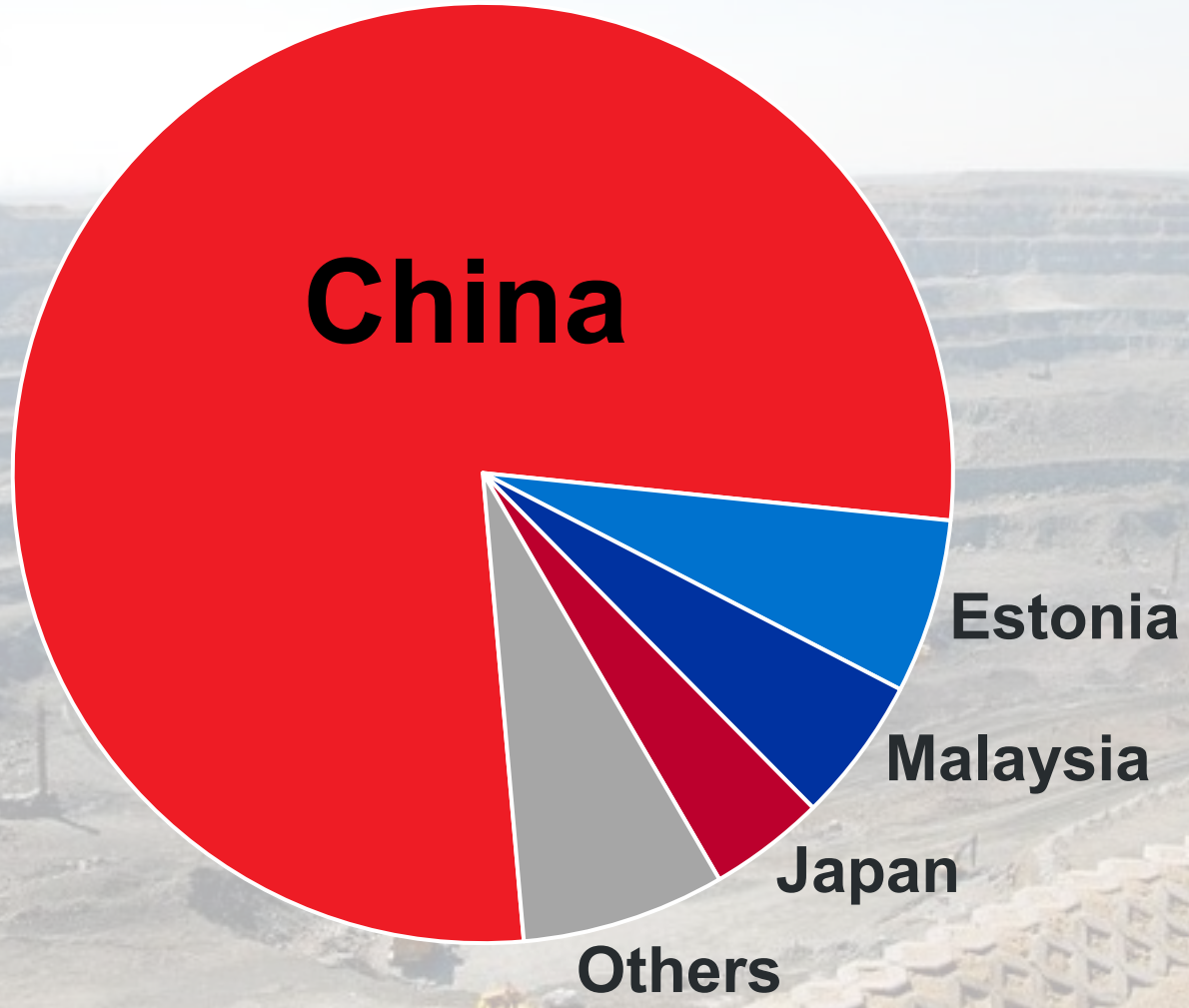
U.S. REE Suppliers

More than 80% of U.S. critical minerals are imported.



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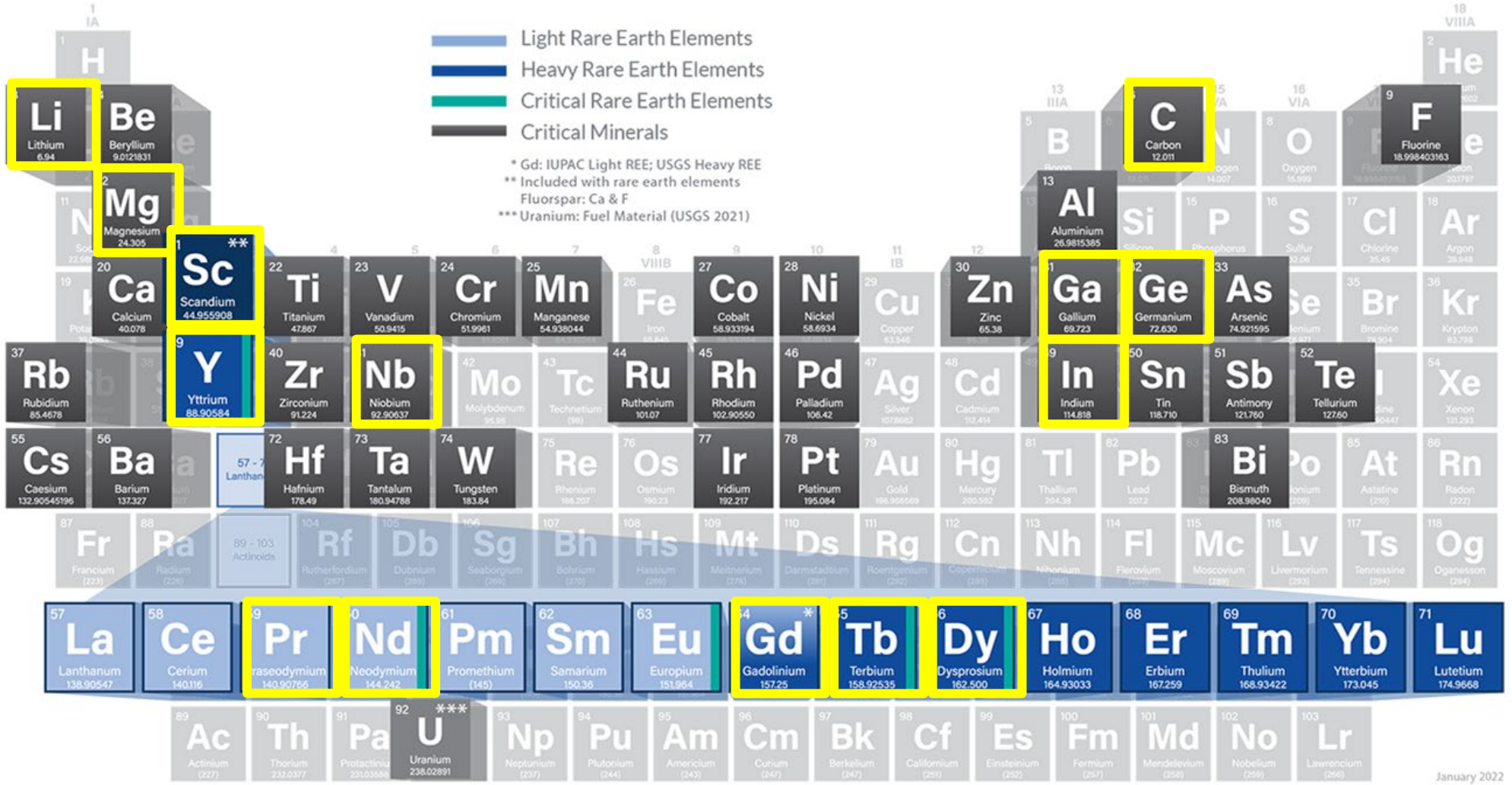
Elements with Greatest Potential to Contribute to the Williston Basin Market



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Developing New Sources and Innovative Ways to Extract CMs and REEs

Existing Lignite Coal Mines

Produced Water

ND Shales: Pierre, Niobrara, Upper and Lower Bakken

Deep Unminable Coal Seams by In Situ Extraction

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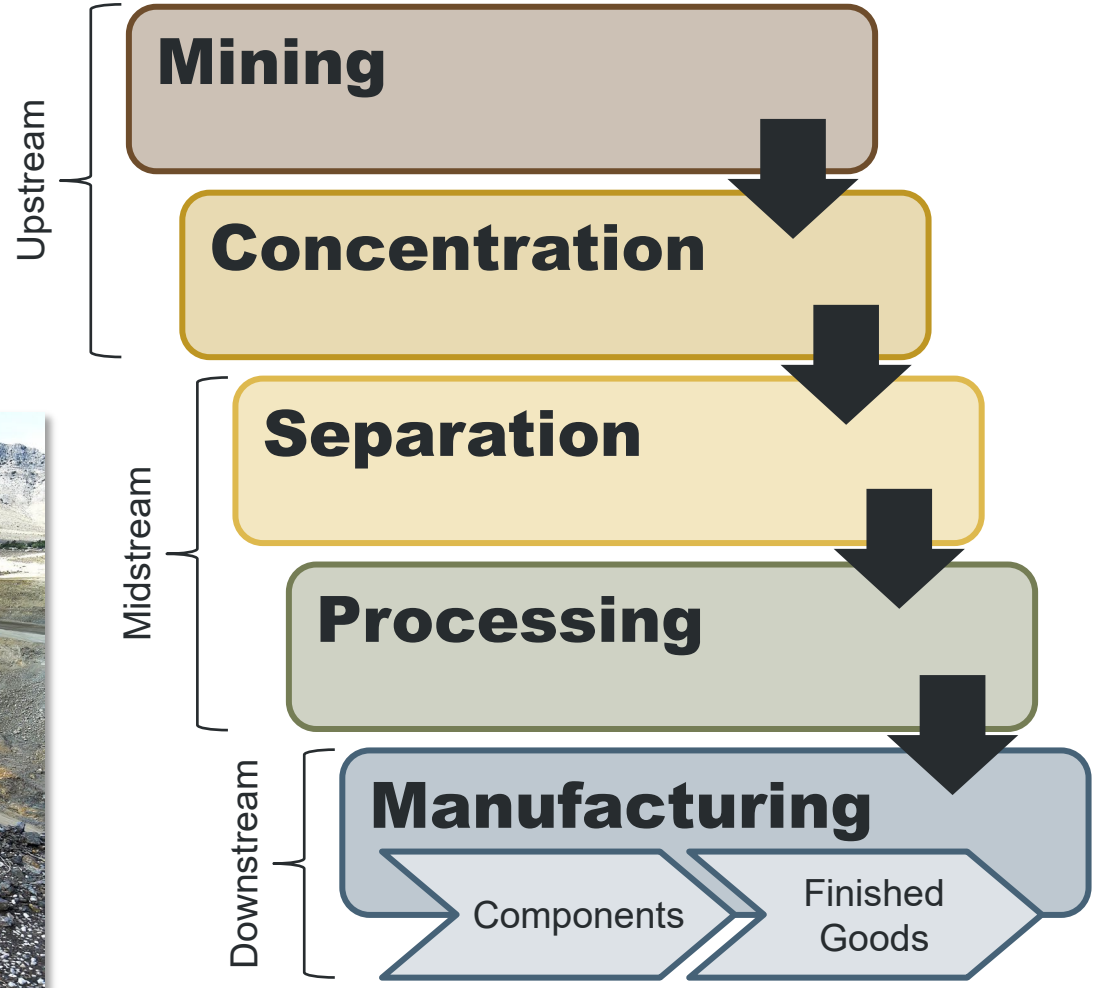
Business Findings and Takeaways

- Regional industries
  - End users of final products
  - Defining business model

Mountain Pass REE Mine, California



Goals of This Webinar

What does it take to process REEs and CMs from lignite?

What methods?

How many steps and involved parties?

Where do handoffs exist?

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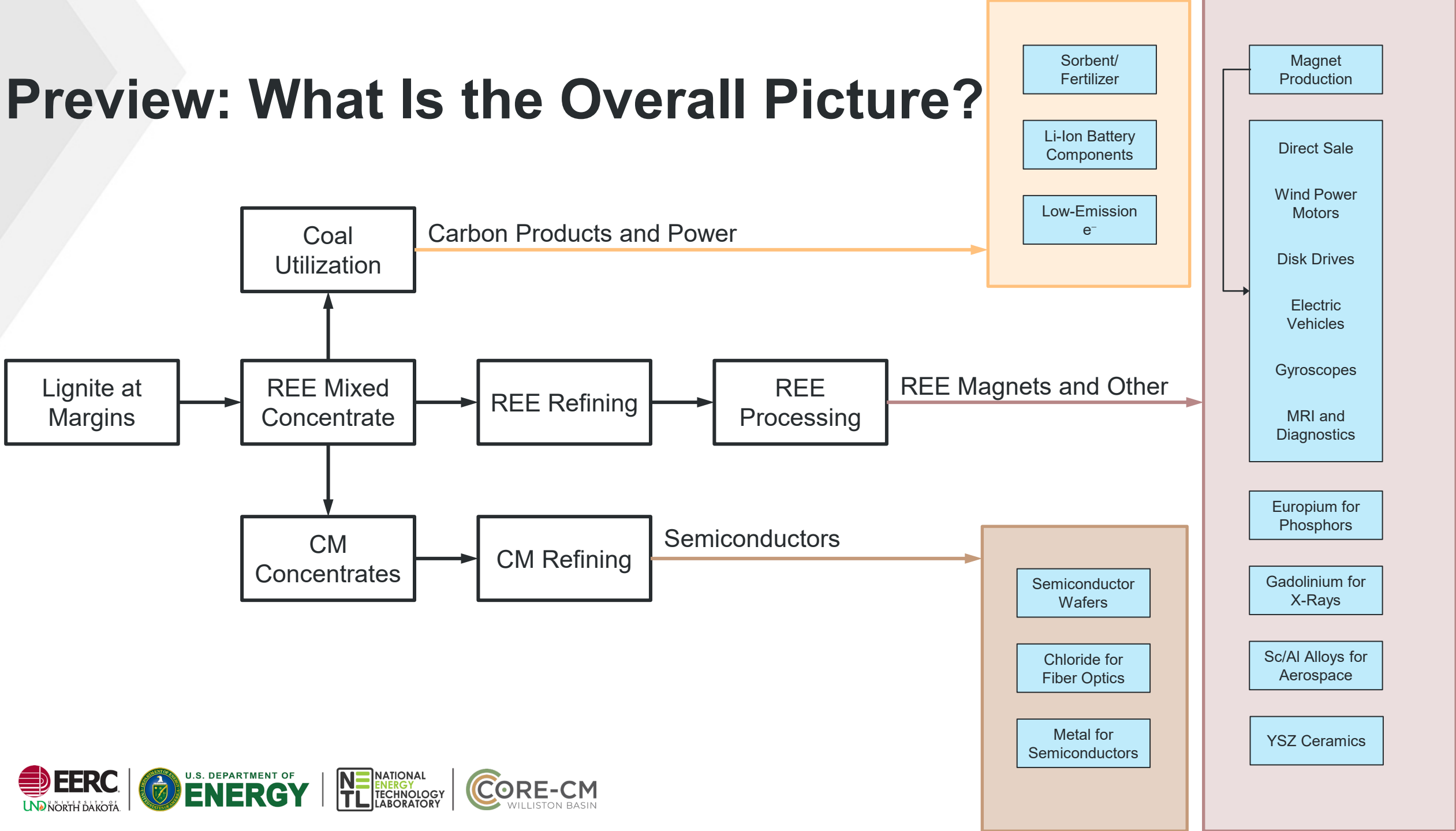
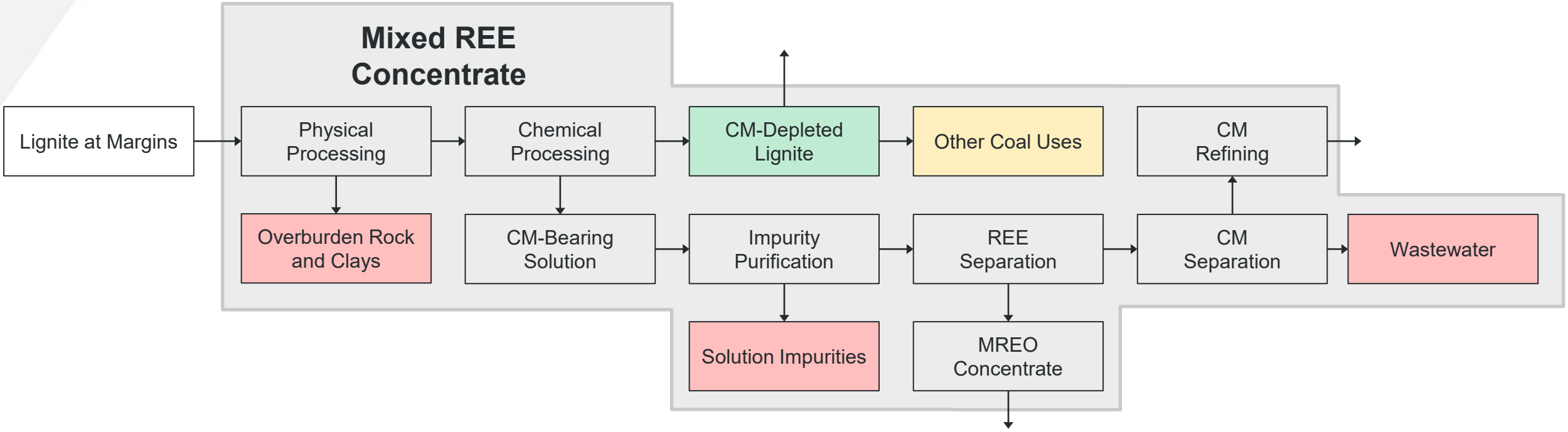
ENTERING THE FLOWCHARTS

Preview: What Is the Overall Picture?



Diving into Mixed REE Concentrate



How Does This Look?

60%–90% Pure Mixed REOs

Image credit: UND Institute for Energy Studies

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REE Refining and Processing

Lignite at Margins

REE Mixed Concentrate

Refining

Magnet REEs → Metallization and Alloying → Magnet Production

HREE Concentrate → Medical/Defense Applications → Europium for Phosphors

SEG Concentrate → SEG Purification → Europium for Phosphors, Gadolinium for X-Rays

LREE Concentrate → La/Ce Disposal or Sale

Scandium/ Yttrium → Separation and Processing → Scandium Metal for Alloying → Sc/Al Alloys for Aerospace

Separation and Processing → Yttrium Oxide for Ceramics → YSZ Ceramics

Direct Sale

Wind Power Motors

Disk Drives

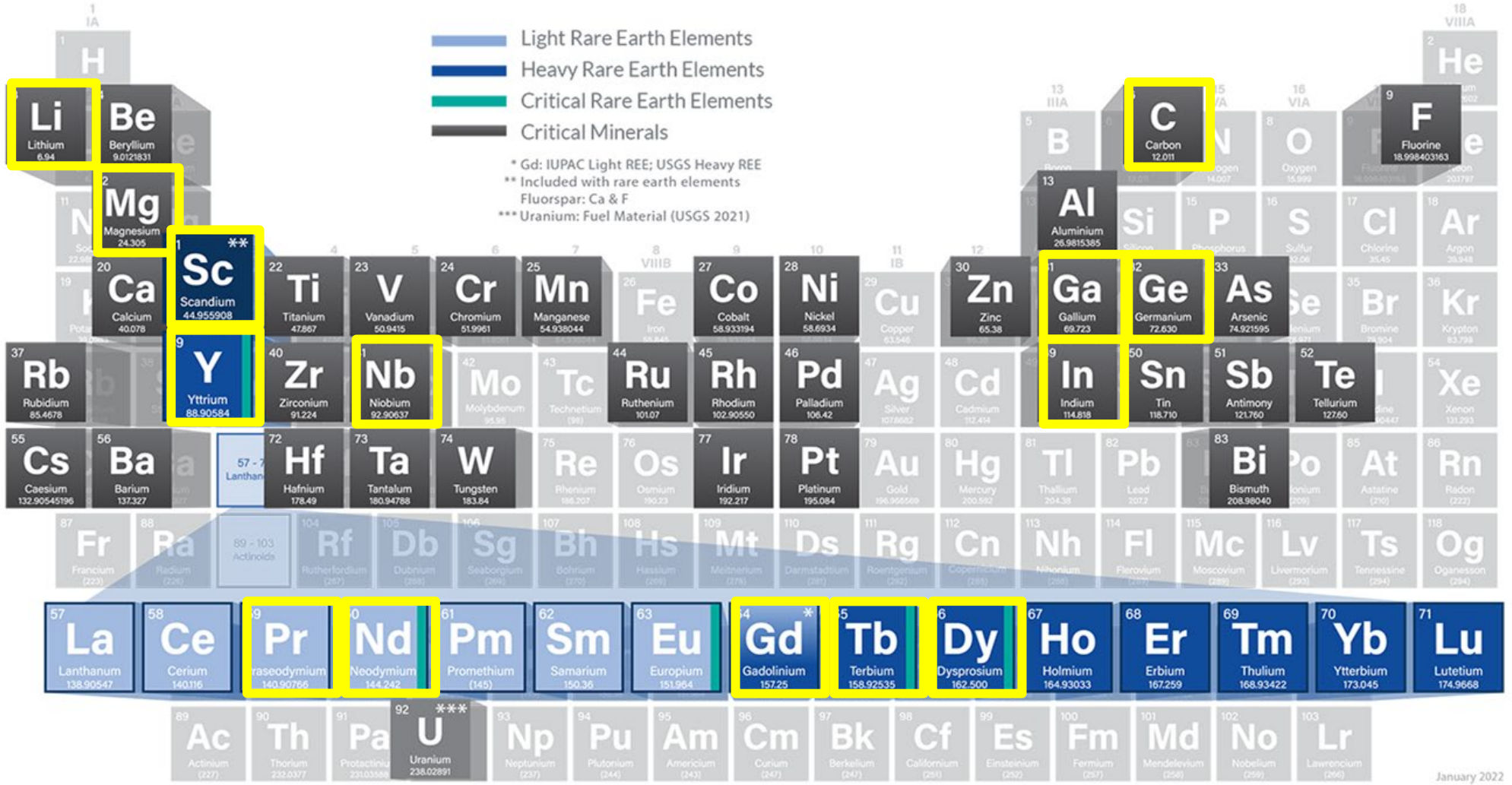
Electric Vehicles

Gyroscopes

MRI and Diagnostics

REE Refining and Processing

Elements with Greatest Potential to Contribute to the Williston Basin Market



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REE Refining and Processing

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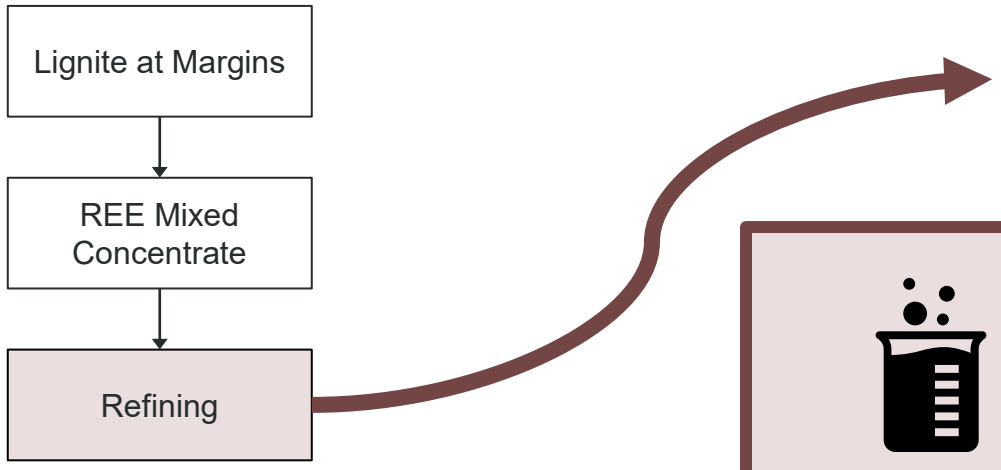
Magnet Production; Europium for Phosphors; Gadolinium for X-Rays → Direct Sale; Wind Power Motors; Disk Drives; Electric Vehicles; Gyroscopes; MRI and Diagnostics

REE Refining and Processing

What Does the Refining Box Entail?



Three Paths of Refining

(that have been materially researched)

- Chemical
- Electrical
- Physical

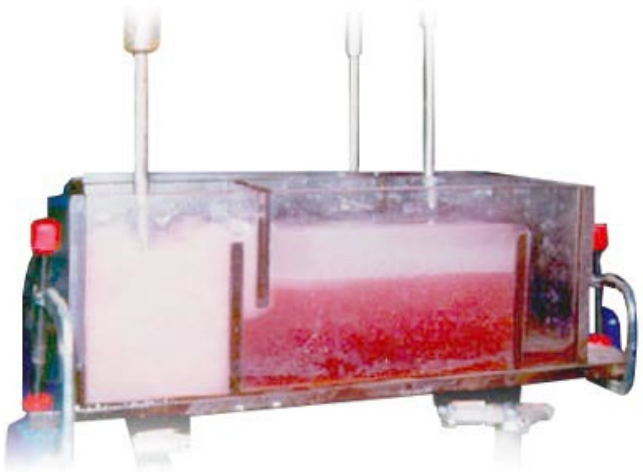


Image credit: Elettronica Veneta Mixer-Settler

Chemical refining is the dominant path to date.

This is typically solvent extraction.

What Isn't Shown in the *Refining* Box

All rare earths are chemically similar.

Any method for **separating REEs is extremely difficult**.

Breakthroughs are reducing the process **from hundreds or even thousands of steps to tens per element.**

4-STAGE EXTRACTION
4-STAGE SELECTIVE SCRU
8-STAGE SCRUBBING
4-STAGE STRIPPING
26-STAGE EXTRACTIO
3-STAGE STRIPPING
6-STAGE SCRUBBI
26-STAGE EXTRA
6-STAGE SCRUB
8-STAGE STRI

98 STEPS

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Products of Refining

Hundreds to Thousands of Steps

Purity: 99.9%+

Image credit: Metal Tech News

Purity: 99.9%+ and Dropping

Image credit: Corsica LLC

Purity: 26.7%

Image credit: Amazon Neodymium Disk Magnets

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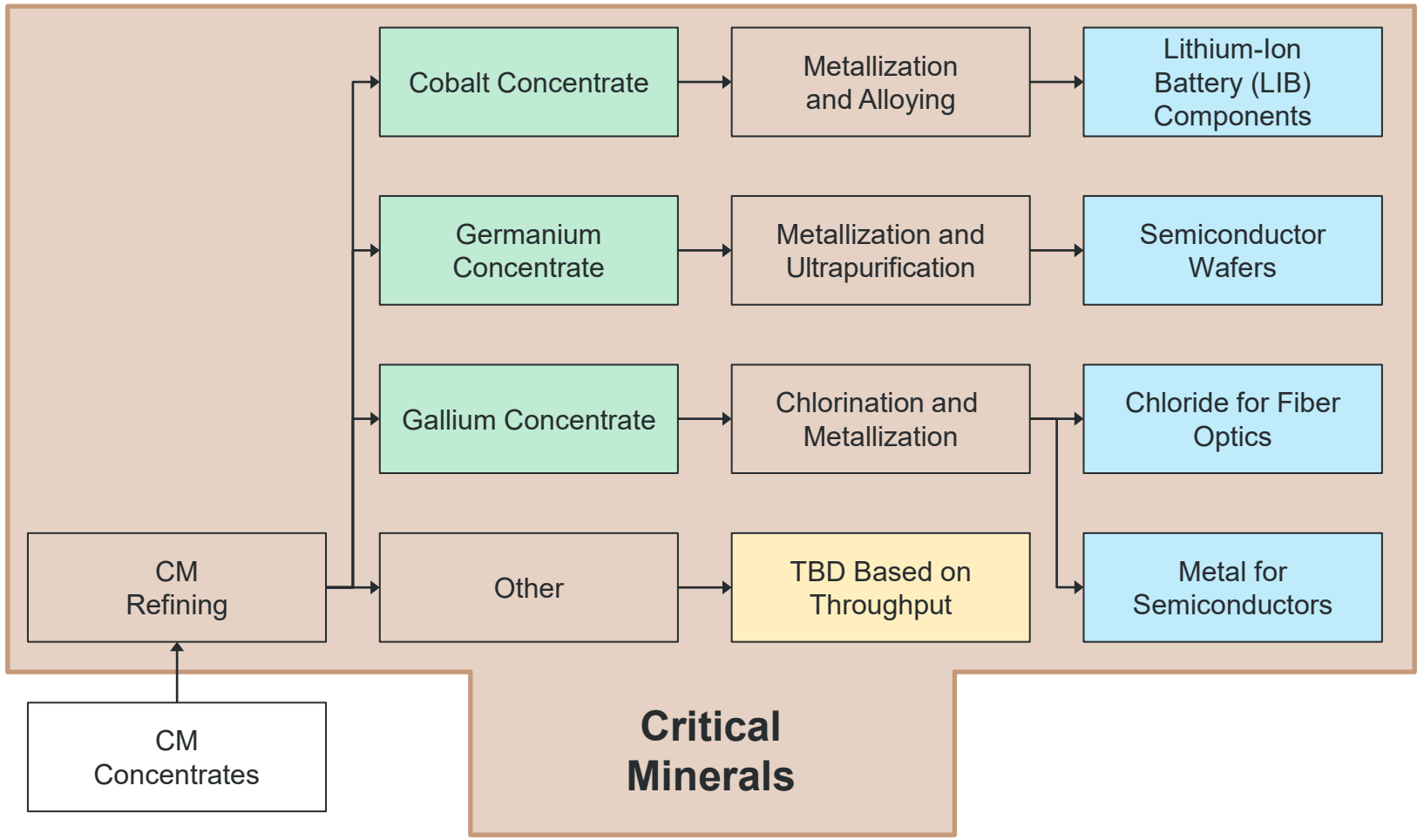
CM Refining

This does not show all CMs that can be produced.

The CMs shown are likely **some of the most valuable**.



A Note on Purity
Semiconductor vs. REE purity

REEs typically need between 3N and 5N.

Semiconductors (Ge and Ga included) need typically 6N–12N, or up to 100,000,000 times more pure than REEs.

Purity Expressed as N

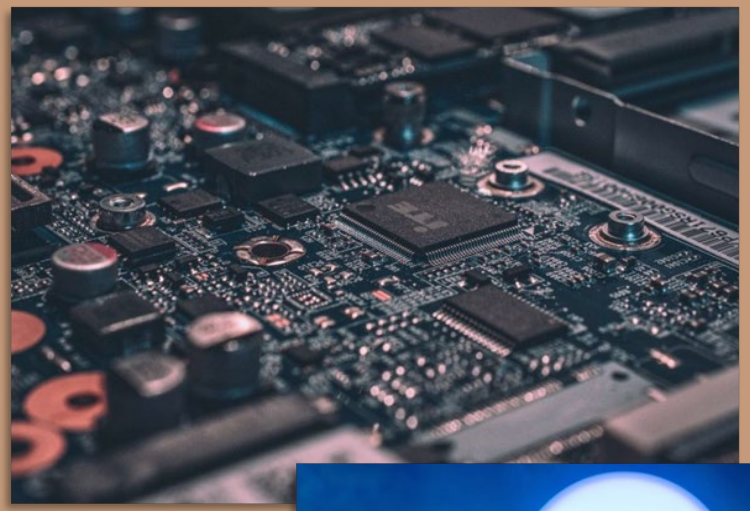
3N = 99.9%
5N = 99.999%
11N = 99.999999999%
12N = 99.9999999999%

To purify from 11N to 12N purity, **remove 1 mg of impurities from a railcar of metal.**

Czochralski Process: Melt Refining

Image Credit: Wikipedia

CM Products



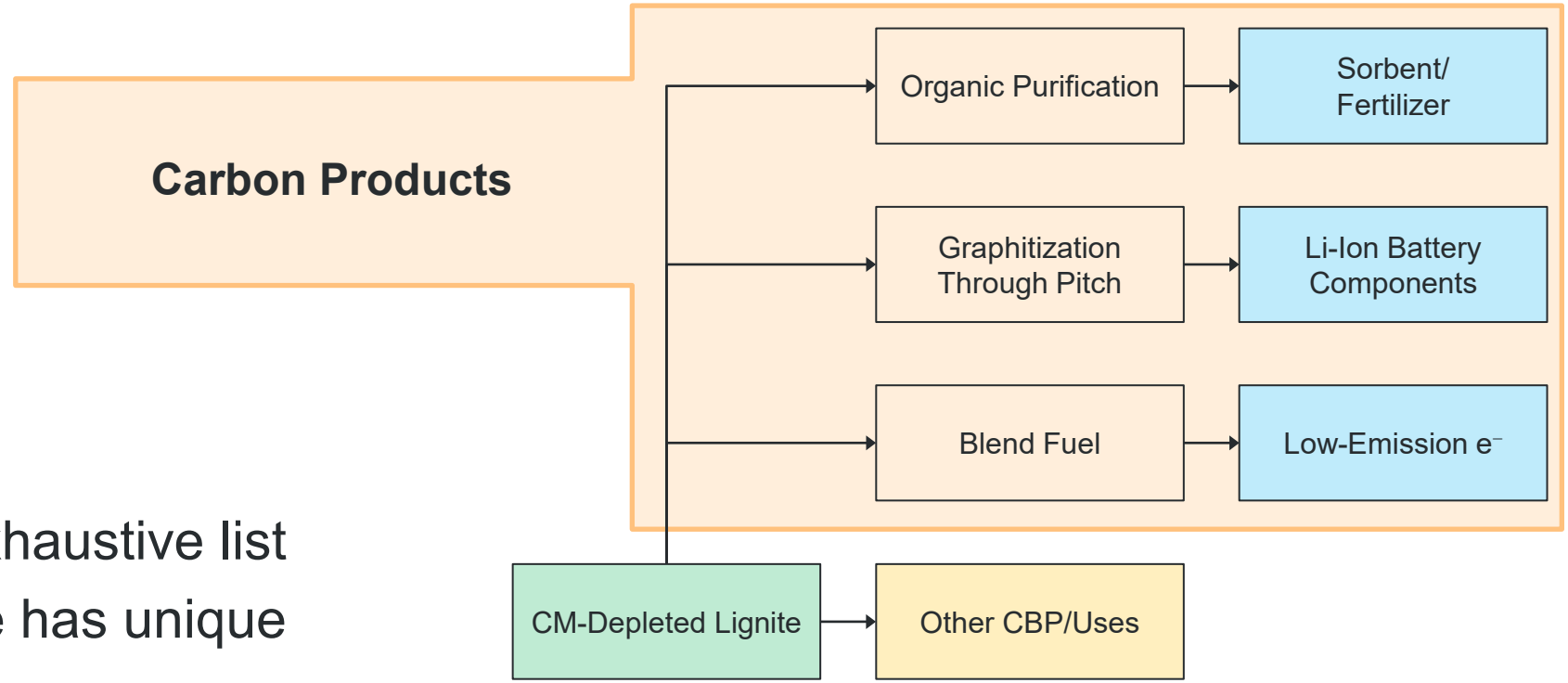
Semiconductor Metals
(Ge and Ga)

- More than 90% import-reliant
- Key weakness identified by DOD suppliers

Battery Components
(cobalt and graphite)

- Primary constituents of both electrodes in lithium-ion battery
- Account for 54% of battery cost

Carbon Products



- By no means an exhaustive list
- CM-depleted lignite has unique properties
- Value vs. market size

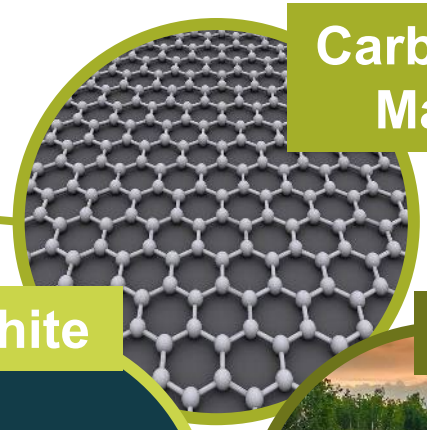
Coal

Extraction Process

Critical Minerals

CM-Depleted Lignite

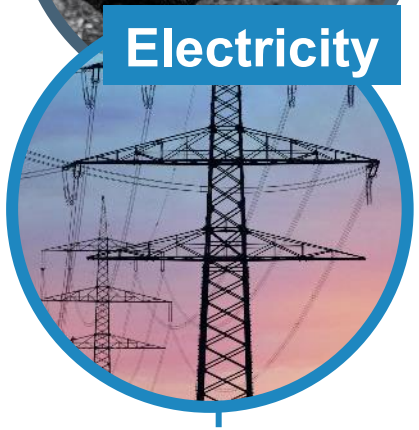
Carbon-Rich Material



REE Products

CM Products

Electricity



Graphite

Graphene

Smart Phones
Military Equipment
Farming

Medical
Equipment
Kitchenware

Power Plants
Power Lines
Homes/Businesses

Phone
Batteries
Car Batteries

Water Filters
Body Armor
Automotive
Equipment

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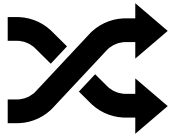
Summary of the Process

Many steps—and handoff points—from mined lignite to products.

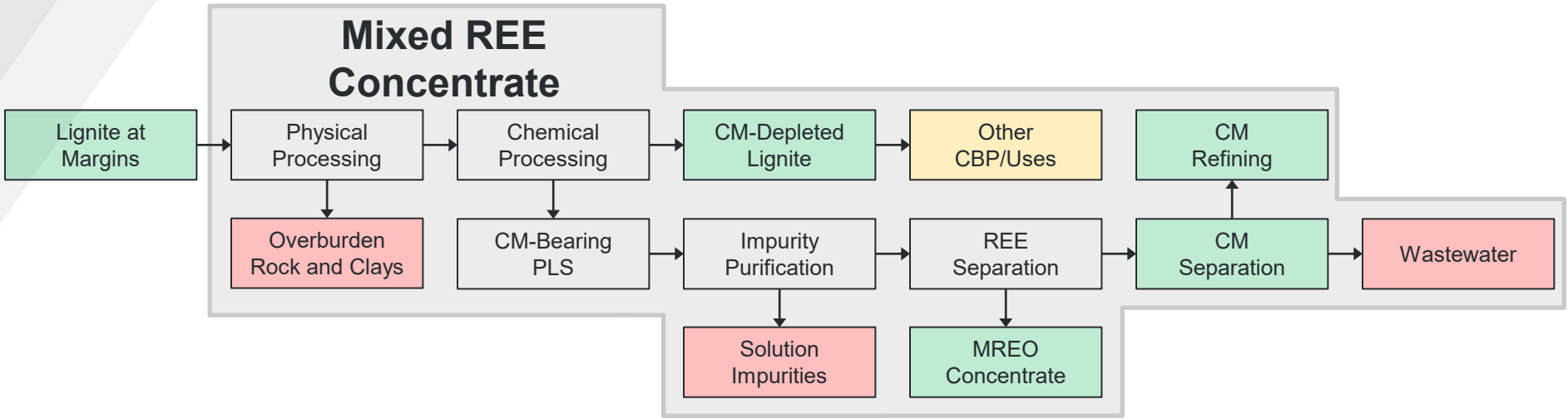


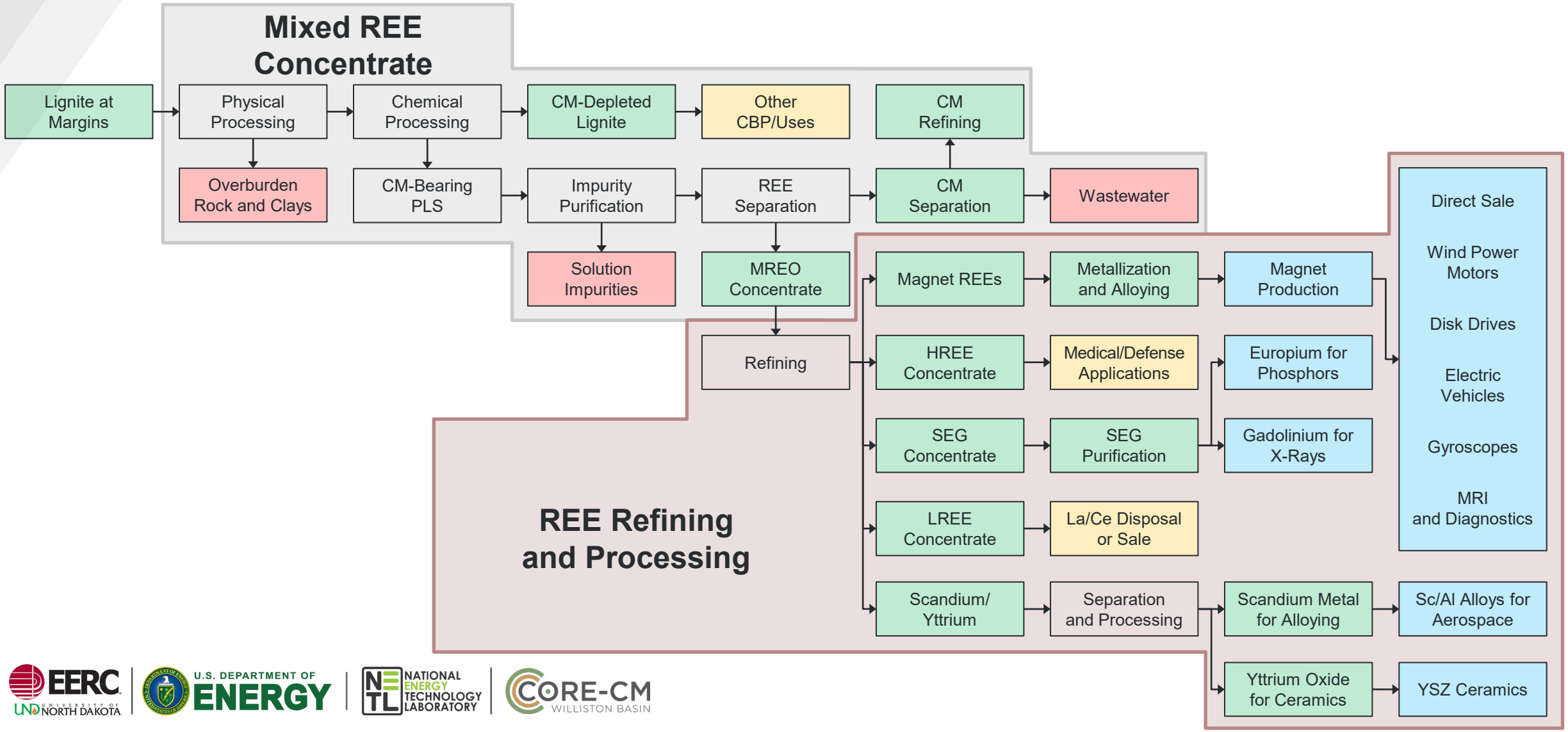
Different purities and processing methods.

Many companies in many locations.

Shipping solids is easy over long distances.

Anytime a solid is produced, this could be another business.


Mixed REE Concentrate
Lignite at Margins
Physical Processing
Chemical Processing
CM-Depleted Lignite
Other CBP/Uses
CM Refining
Overburden Rock and Clays
CM-Bearing PLS
Impurity Purification
REE Separation
CM Separation
Wastewater
Solution Impurities
MREO Concentrate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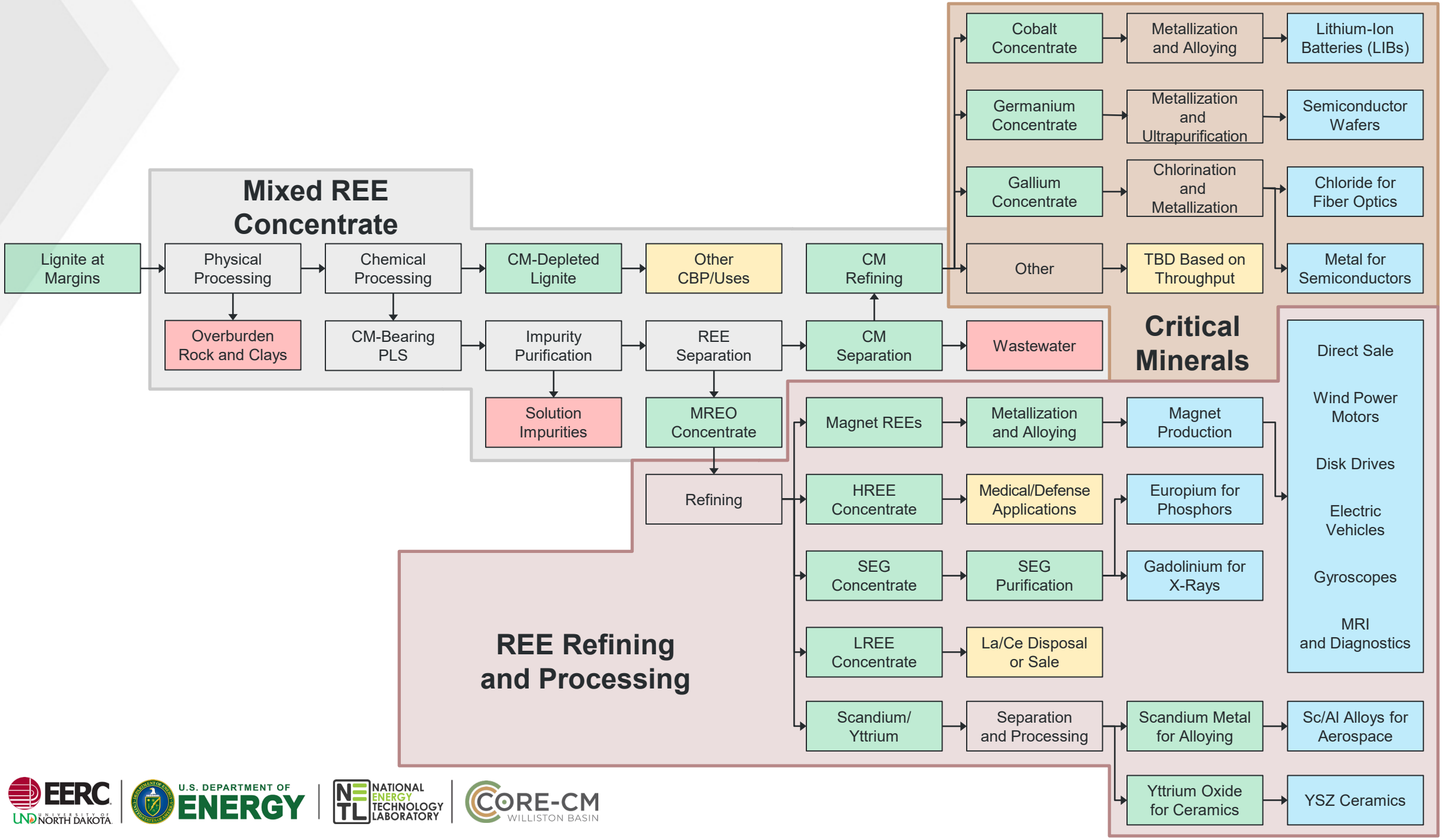

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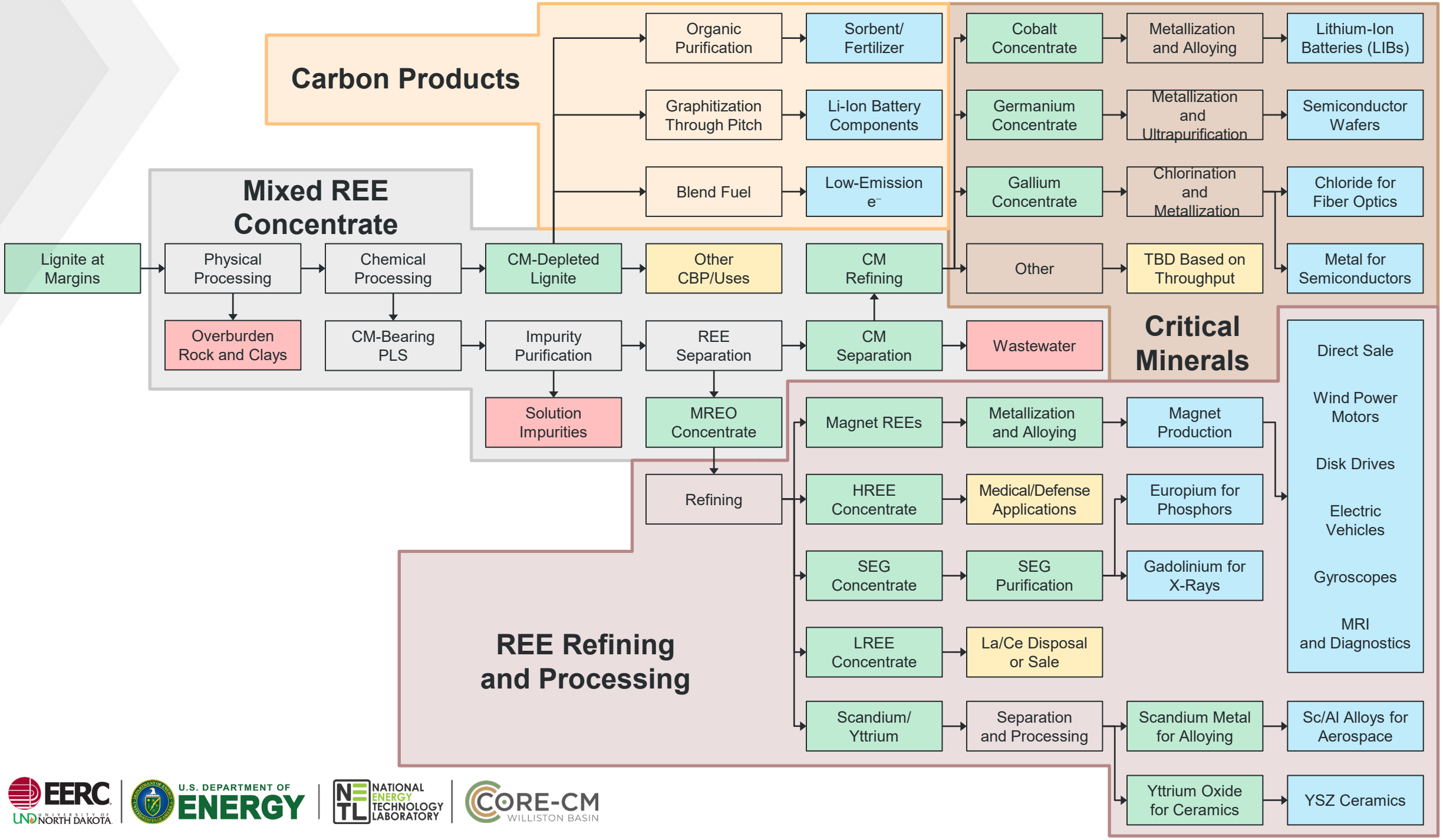

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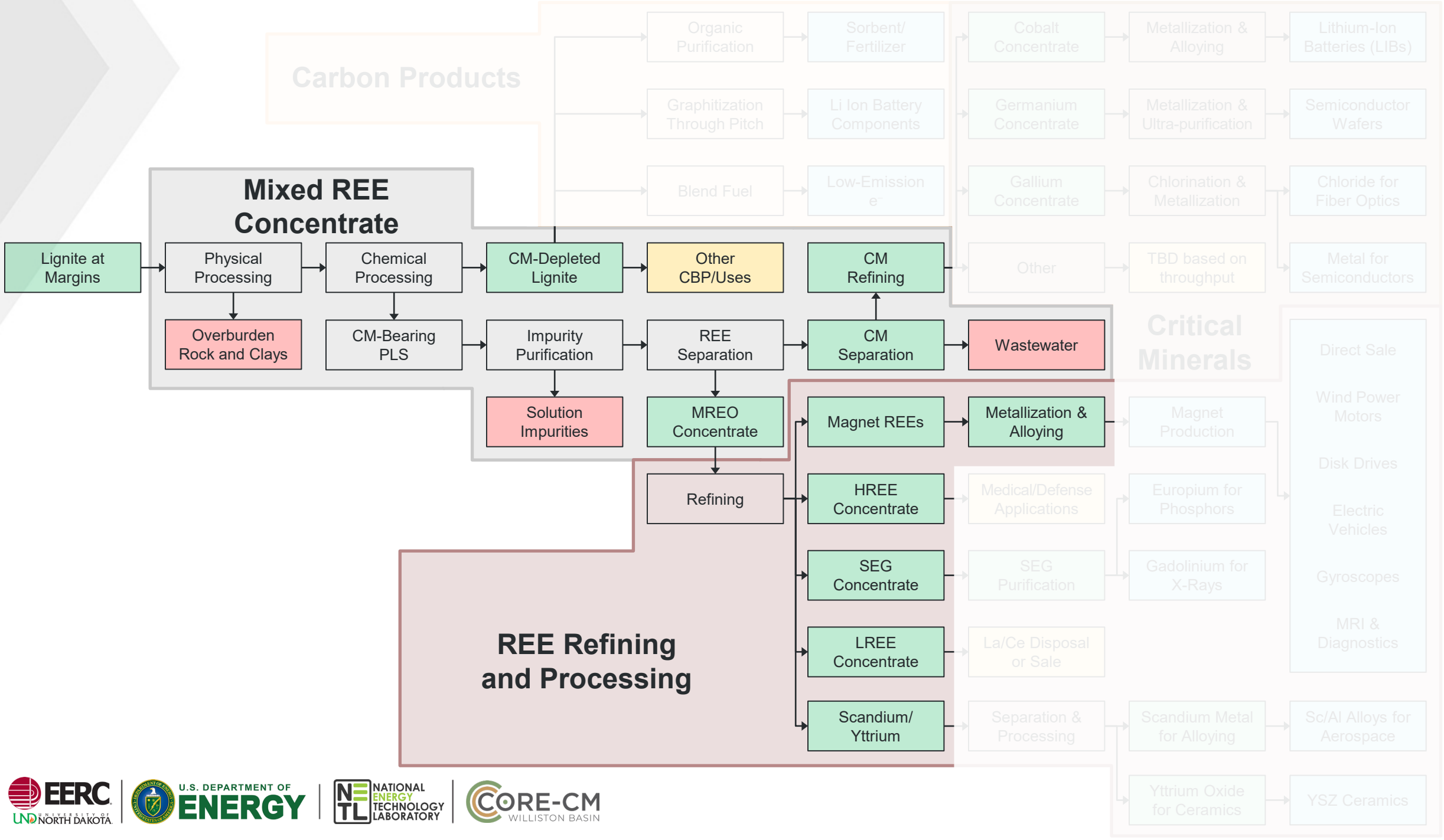

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Nolan Theaker

Senior Research Manager – Critical Minerals

nolan.theaker@und.edu

(701) 777-6298

Institute for Energy Studies

University of North Dakota

2844 Campus Road, Stop 8153

Collaborative Energy Complex, Room 236

Grand Forks, ND 58202-8153

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Carbon Ore, Rare Earth, and Critical Minerals Initiative (CORE-CM)

U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL)-Led Program

- Catalyze economic growth.
- Job creation in energy communities.
- Energy communities not to be left behind.
- Domestic production of REEs and CMs.
- Strengthen our national economy and security.

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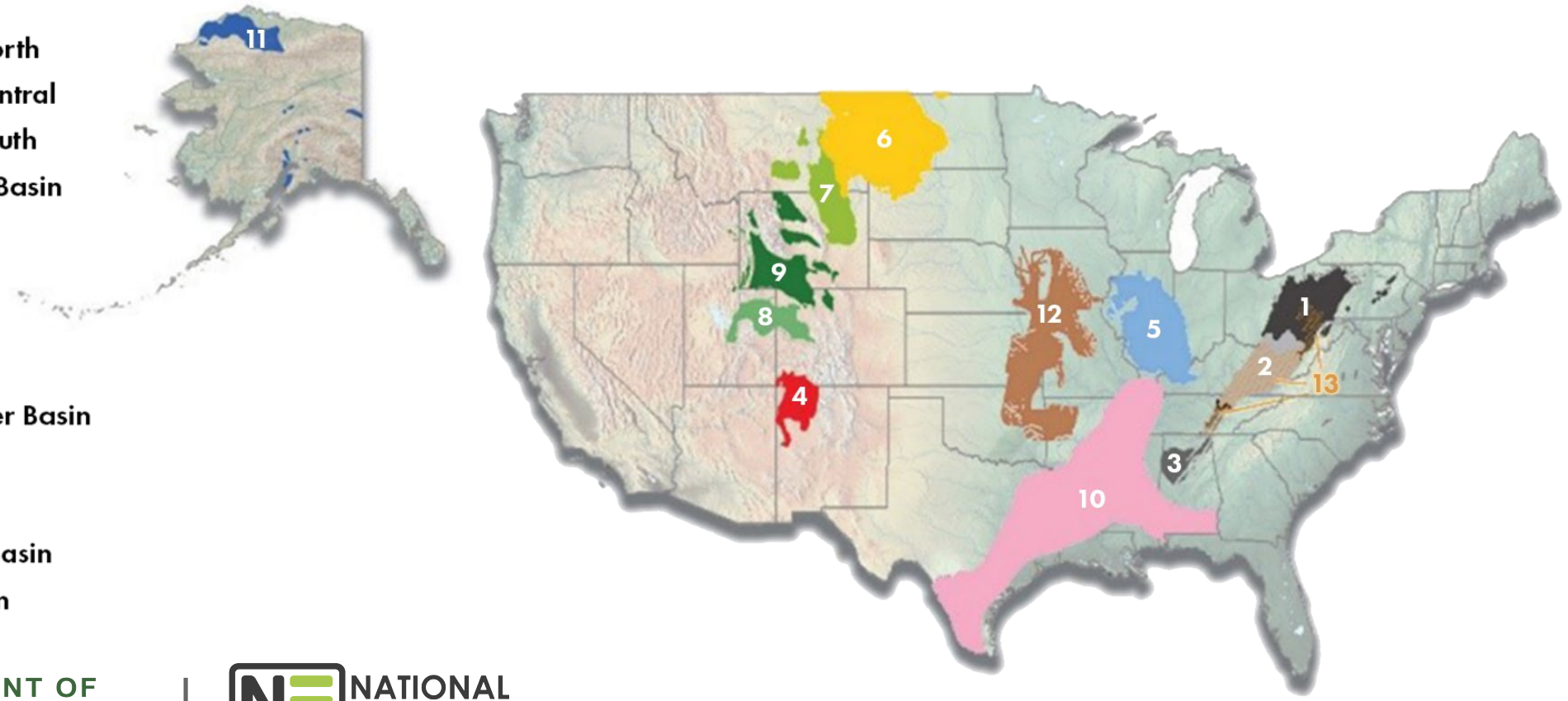
13 CORE-CM Initiative Teams

US BASINS

1. Appalachian Basin, North
2. Appalachian Basin, Central
3. Appalachian Basin, South
4. San Juan River-Raton Basin
5. Illinois Basin
6. Williston Basin
7. Powder River Basin
8. Uinta Basin
9. Green River-Wind River Basin
10. Gulf Coast Basin
11. Alaska Basin
12. Cherokee-Forest City Basin
13. Mid-Appalachian Basin



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Williston Basin CORE-CM Project Team

UND Energy & Environmental Research Center
UND Institute for Energy Studies
UND Nistler College of Business & Public Administration
Pacific Northwest National Laboratory
North Dakota State University
Montana Tech University
Critical Materials Institute (Ames)
Basin Electric Cooperative
BNI Energy
Current Lighting Solutions
General Atomics
Illinois Geological Survey CORE-CM Team
Lignite Energy Council
Minnkota Power Cooperative

NDIC Lignite Research Program
North American Coal
North Dakota Department of Commerce
North Dakota Geological Survey
North Dakota Governor's Office
Northrup Grumman
Semplastics
South Dakota Geological Survey
U.S. Geological Survey
University of Alaska CORE-CM Team
University of Utah CORE-CM Team
Western Dakota Energy Association
Wyoming School of Energy Resources CORE-CM Team

ACKNOWLEDGMENT

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November 2023

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Monday, October 9, 2023

Symposium
Tuesday, October 10, 2023

Details coming soon.

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