RECYCLE COLORADO

Recruiting Cleantech Recyclers to Colorado

Summit for Recycling – Steamboat Springs, Colorado – May 23, 2023

SESSION OVERVIEW (10:45am – 12:15pm)	
Welcome	10:45 – 10:50
Importance of Circular Economies	10:50 – 10:54
Introduction of Cleantech Recycling Panelists	10:54 – 10:57
Panel Presentations:	10:57 – 11:45
❑ *The Problem: Explanation of waste stream & recycling potential now & in future*	
❑ *What's involved? Explain the recycling process of your material steam*	
Panelist Discussion	11:45 – 11:55
❑ *Challenges of establishing a recycling operation in Colorado*	
Q & A	11:55 - 12:15

Image credit: Inter-American Development Bank

IMPORTANCE OF CIRCULAR ECONOMIES IN THE RENEWABLE ENERGY TRANSITION

- ❑ Mitigating climate change
- ❑ Preserving natural resources
- ❑ Innovating for sustainable growth
- ❑ Proactively addressing future needs

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PANEL OF CLEANTECH RECYCLERS

Jeremy Norris
Wind Power Solutions LLC

Wind turbine blade recycling

Aaron Palumbo
REQYRD

EV battery recycling

Kate Collardson
SolarRecycle.org

Solar panel recycling

Image credit: Inter-American Development Bank

PANELIST PRESENTATIONS

The Problem:

- ❑ Explanation of waste stream & recycling potential now & in future
- ❑ What's involved? Explain the recycling process of your material steam

RECYCLE COLORADO

WIND ENERGY

End-Of-Life Explained & A Path Forward

Jeremy R. Norris
CEO/President

05/2023

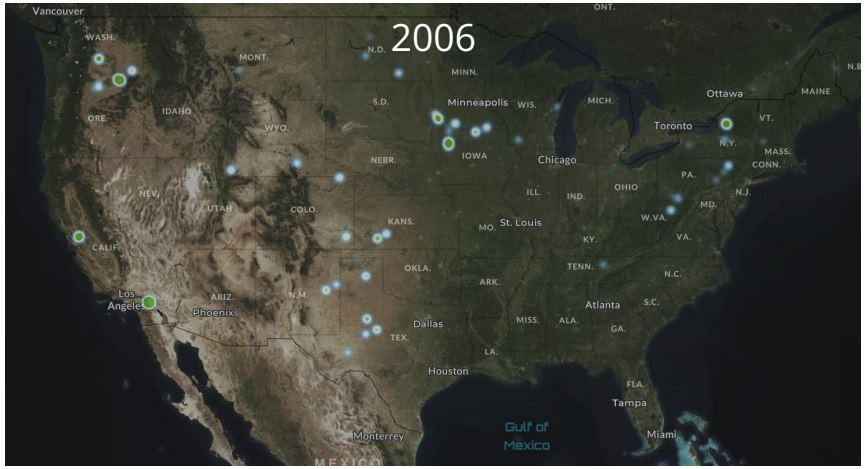
Meet the presenter

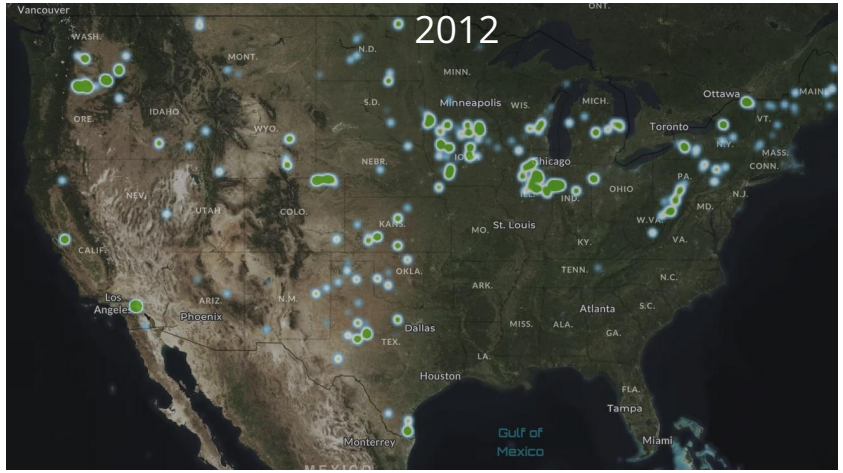
Jeremy R. Norris

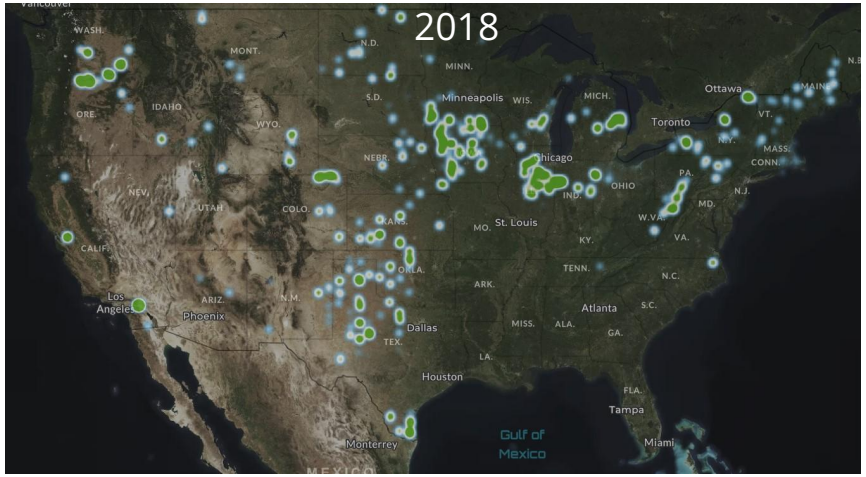
CEO/President of Wind Power Solutions

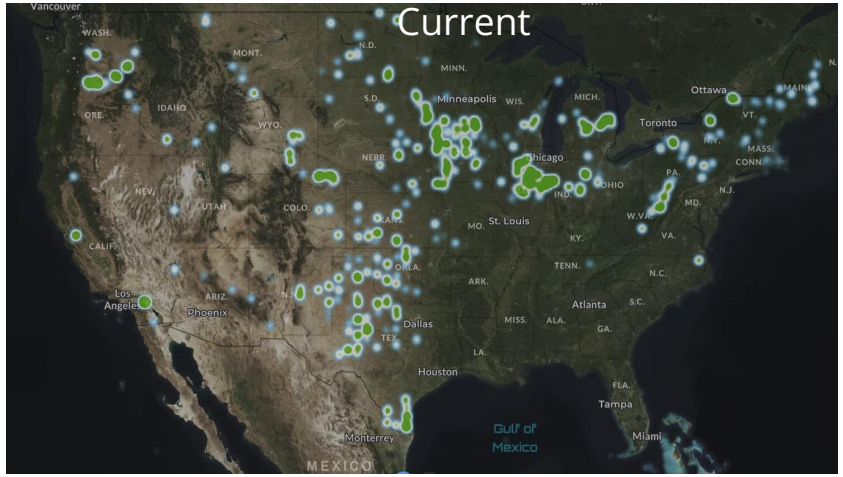
A company focused on providing environmental solutions for Wind Turbine Blade Recycling that are cost-efficient, ESG driven, and scalable.

Wind Energy Deployment at Scale









WIND TURBINE BLADES BY THE NUMBERS

~6%
Percentage of the world's electricity generated by wind energy in 2020

>110 m
Length of today's longest wind turbine blades

10,000–20,000
Number of wind turbine blades to be retired in the US annually from 2030 to 2040

43 million metric tons
Cumulative mass of all blades to be decommissioned by 2050

Sources: International Energy Agency; Siemens Gamesa Renewable Energy; *Waste Manage.* 2017, DOI: 10.1016/j.wasman.2017.02.007; *Resour., Conserv. Recycl. 2021, DOI: 10.1016/j.resconrec.2021.105439*.

Repowering & Decommissioning Wind Farms

When a wind farm has reached its End-of-Life (typically 20-25 years), owners will then decide whether to upgrade full or partial Wind Turbines to increase output, or to decommission site entirely. Either way, waste will be produced in the process. According to U.S. Wind Turbine Database there are approximately 218,700 blades in our 138-Gigawatt U.S. fleet.

Typical Repowering Project includes:

- Removal of blades and replace with new longer blades. (Partial)
- Removal of nacelle, hub, and blades and replace with new OEM equipment. (Partial)
- Replacement of all existing infrastructure with new and larger Wind Turbine Generators. (Full)

Typical Decommissioning Project includes:

- Removal of all underground collection systems, substations, Wind Turbine Generator components, concrete foundations, and ancillary support equipment.

What are the waste streams produced from Repowering and Decommissioning?

FIBERGLASS

Fiberglass material from blades, nacelle, and hub. These materials typically make up 12-16% of total mass.

METAL

Turbine tower sections and frame work are predominately made of steel and cast iron. These materials typically make up 66-79% of total mass.

E-WASTE

Various mineral oils used to keep gearbox, hydraulics, and major components running.

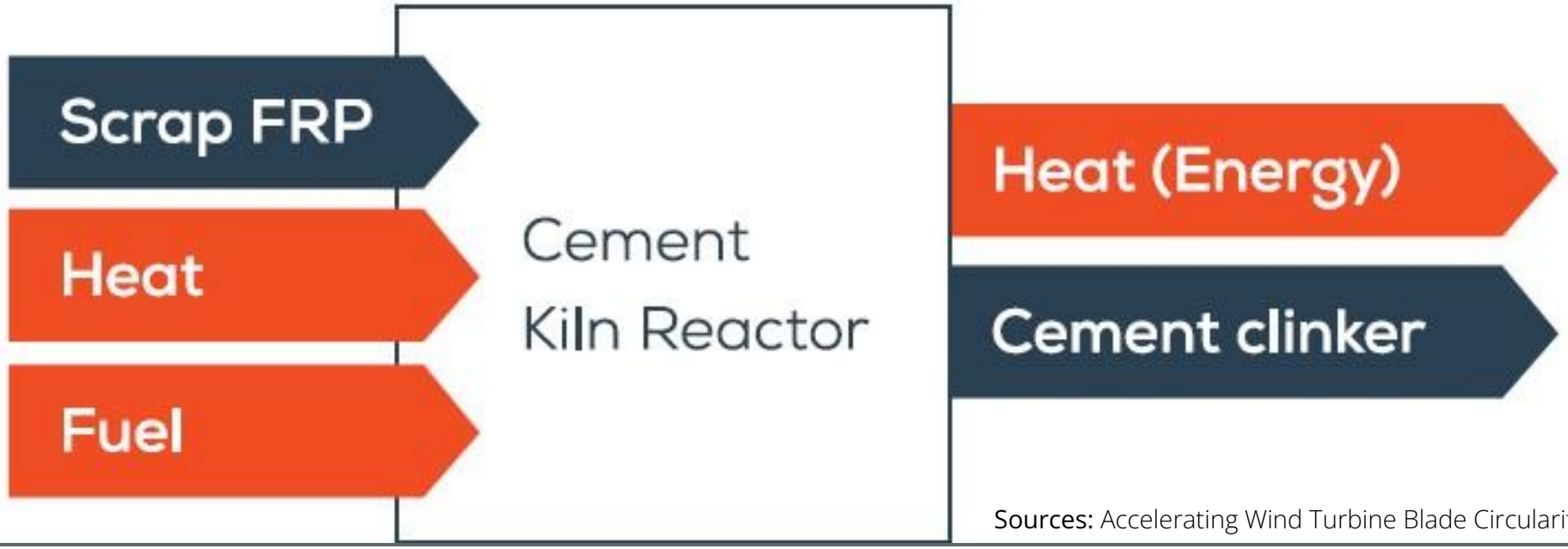
DISPOSAL STRATEGIES FOR FIBERGLASS BLADES

CEMENT CO-PROCESSING

Pros:
Simple supply chain & scalability

Cons:
Singular use due to damaged fibers.

The glass fibers are recycled as a component of cement mixes. The polymer matrix is burned as fuel for the process ,which reduces the carbon footprint of cement production.



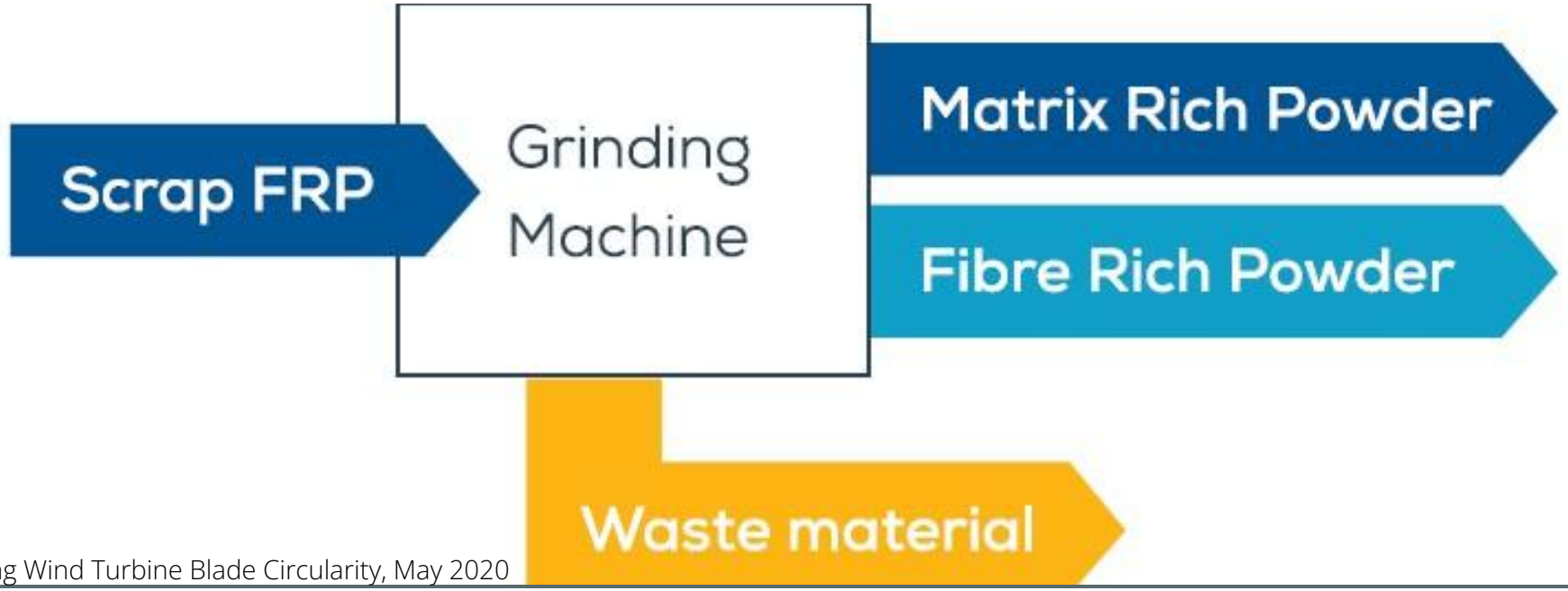
Sources: Accelerating Wind Turbine Blade Circularity, May 2020

MECHANICAL GRINDING

Pros:
Low cost and energy requirement.

Cons:
Deterioration of mechanical properties.

The glass fibers are processed into fine powders to be used in reinforcement, concrete, and filler applications.



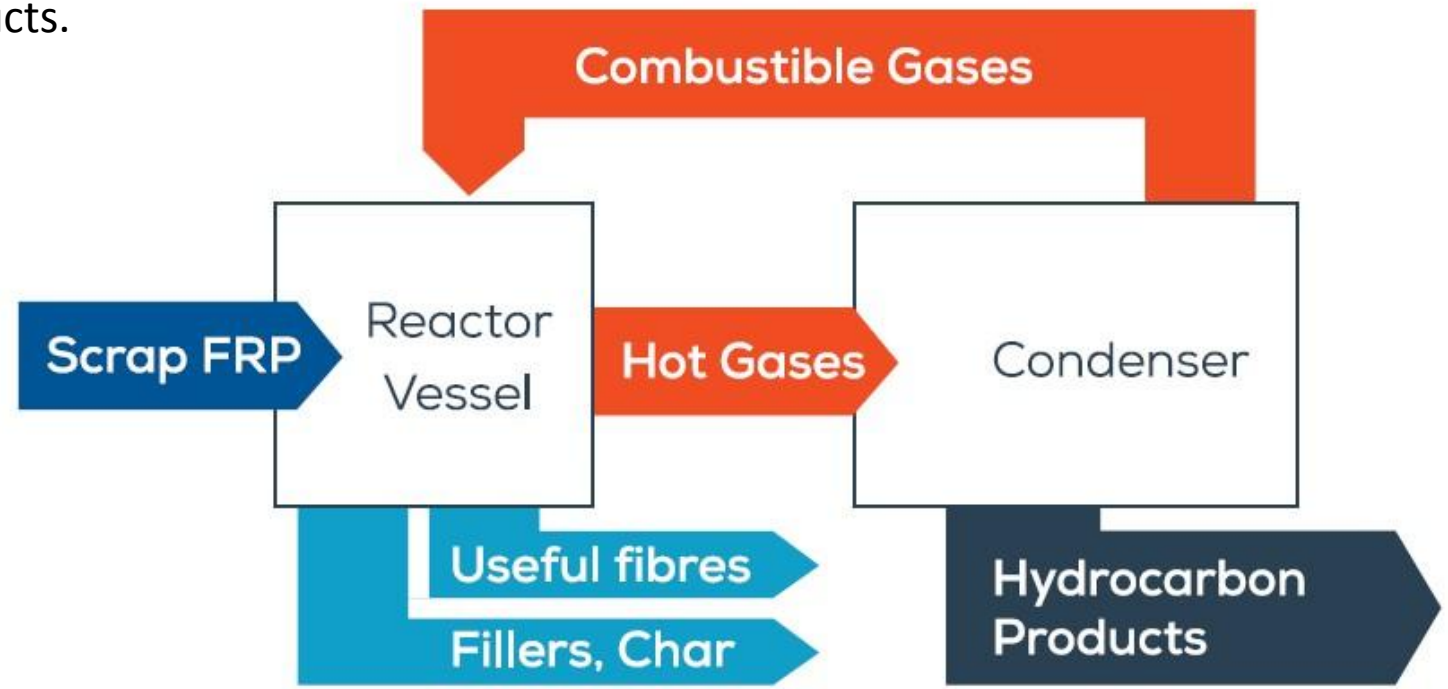
Sources: Accelerating Wind Turbine Blade Circularity, May 2020

PYROLYSIS

Pros:
Lower damage to fiber and used at scale

Cons:
High Investment and OPEX costs.

Thermal recycling process in which a reactor breaks down glass fiber materials into ash and hydrocarbon products.



Sources: Accelerating Wind Turbine Blade Circularity, May 2020

SOLVOLYSIS

Pros:
Lower degradation of fibers

Cons:
High investment and OPEX cost

Chemical treatment where solvents (water, alcohol and/or acid) are used to break the matrix bonds at a specific temperature and pressure. Solvolysis offers many possibilities due to a wide range of solvent, temperature and pressure options.

Sources: Accelerating Wind Turbine Blade Circularity, May 2020

THANK YOU

REQYRD TECHNOLOGIES & MATERIALS

Aaron Palumbo

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recovery of critical materials for batteries, catalysts, and superalloys

NSF

COLORADO
Office of Economic Development & International Trade

CMI
Critical Materials Institute

GARRISON MINERALS

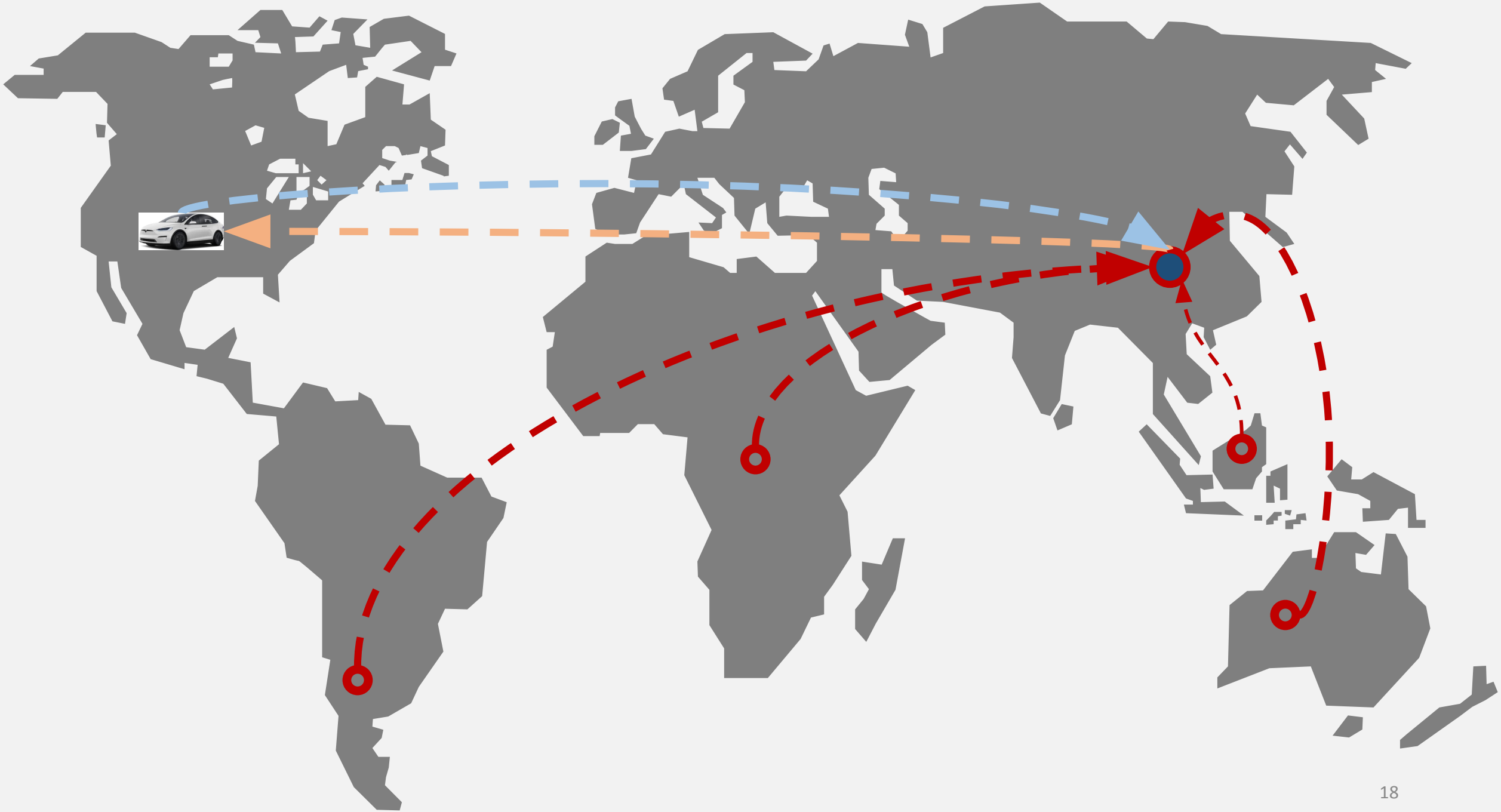
U.S. DEPARTMENT OF ENERGY

AMES LABORATORY

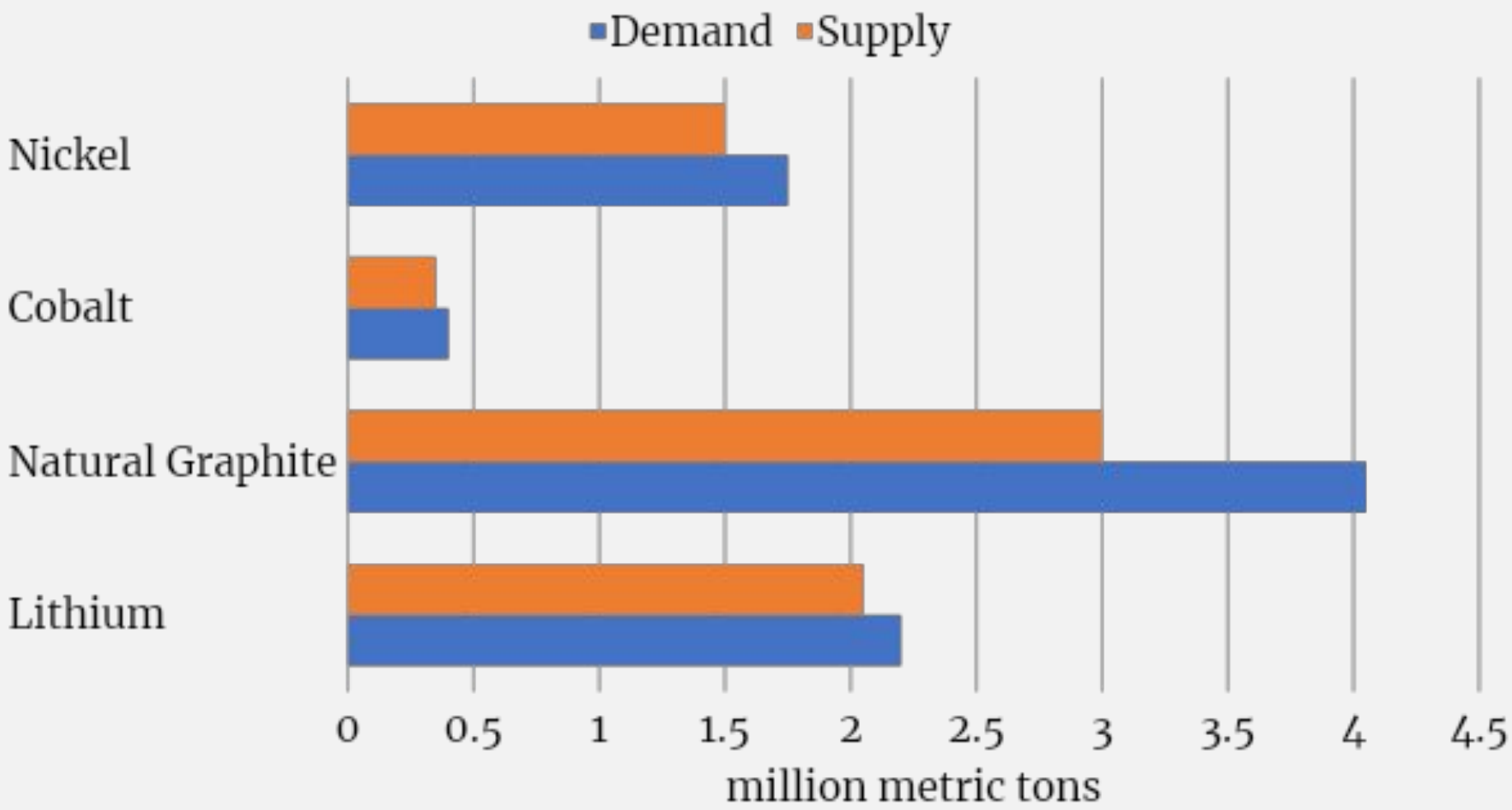
NextCycle Colorado

Big Blue Technologies

Irish Metals



with little to no domestic production



U.S. Share

Nickel	0.5%
Cobalt	0.3%
Natural Graphite	0.0%
Lithium	2%

usgs.gov. 2022 Mineral Yearbook Reports.

LIB recycling is expected to grow annually at 21%

$5B in 2022

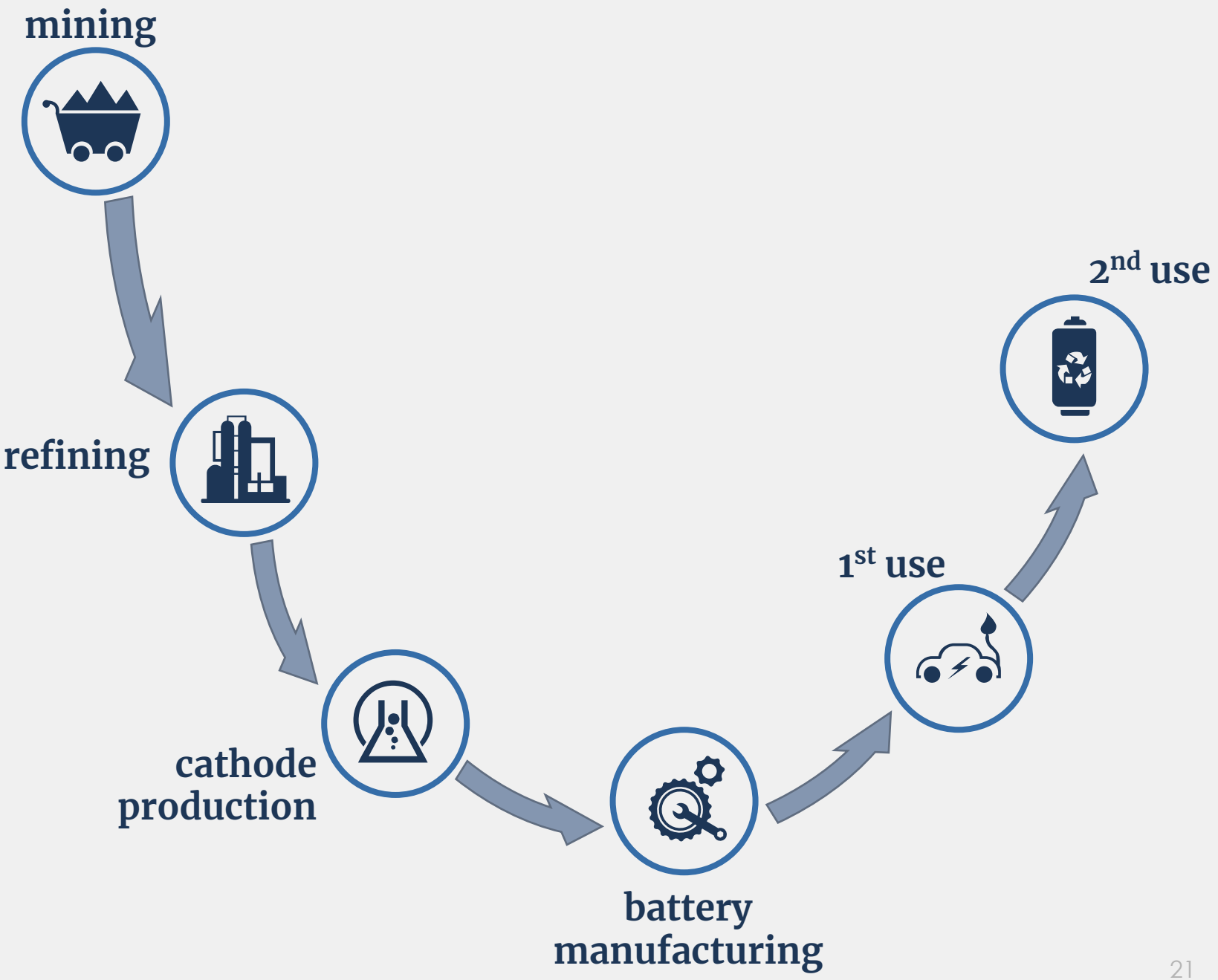
to

$24B by 2030

US DOE & Circular Energy Storage.

what we do

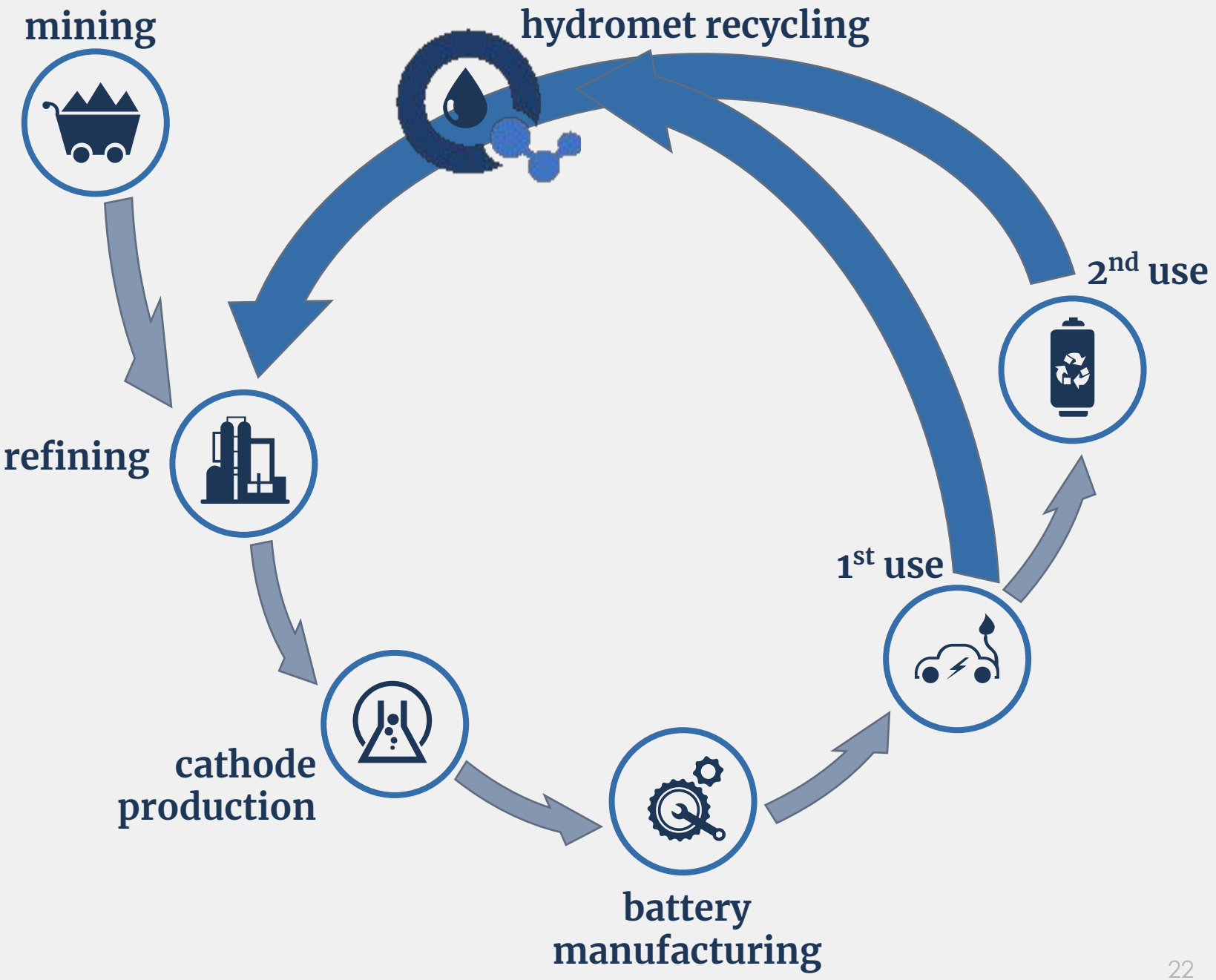
technology development and scale-up for hydrometallurgical recovery of critical materials to support battery, superalloy, and catalyst markets



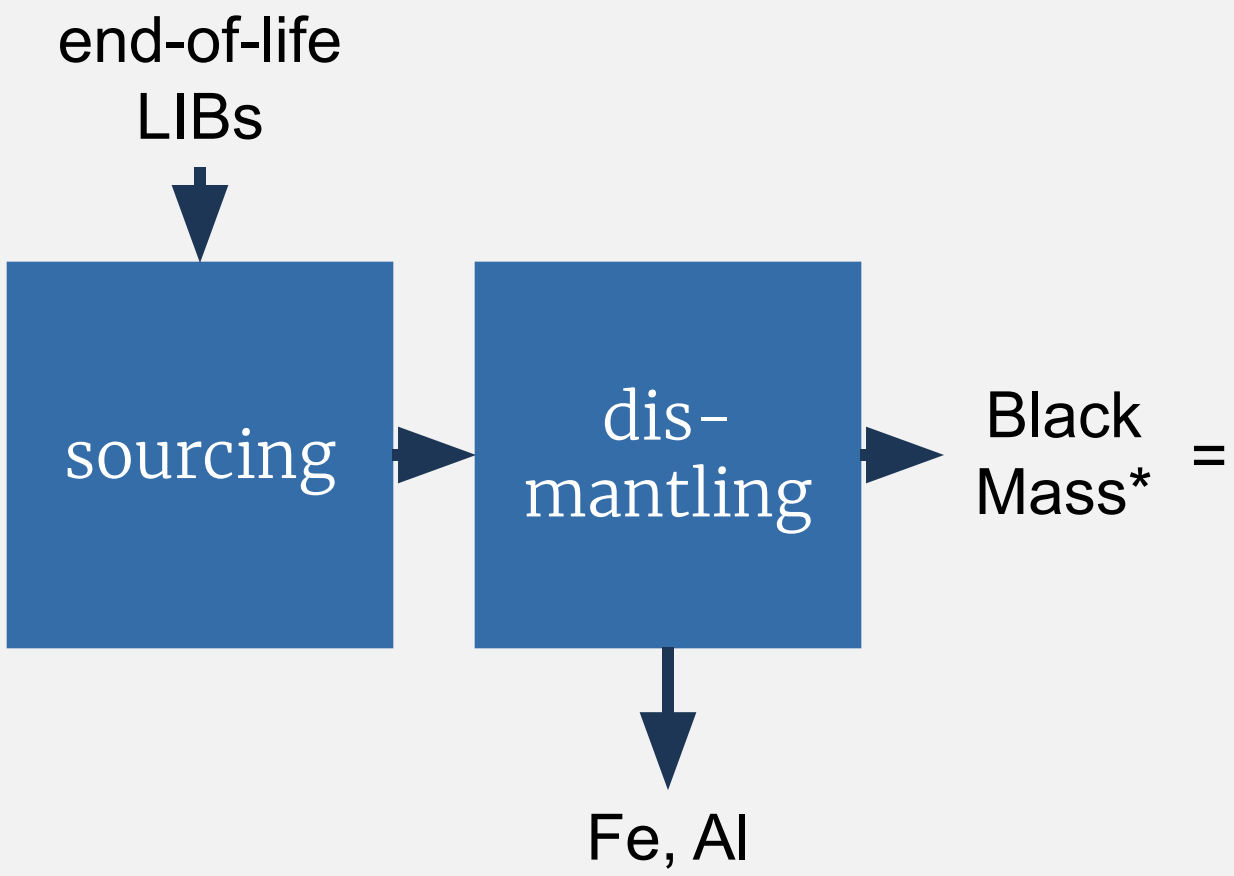
what we do

technology development and scale-up for hydrometallurgical recovery of critical materials to support battery, superalloy, and catalyst markets

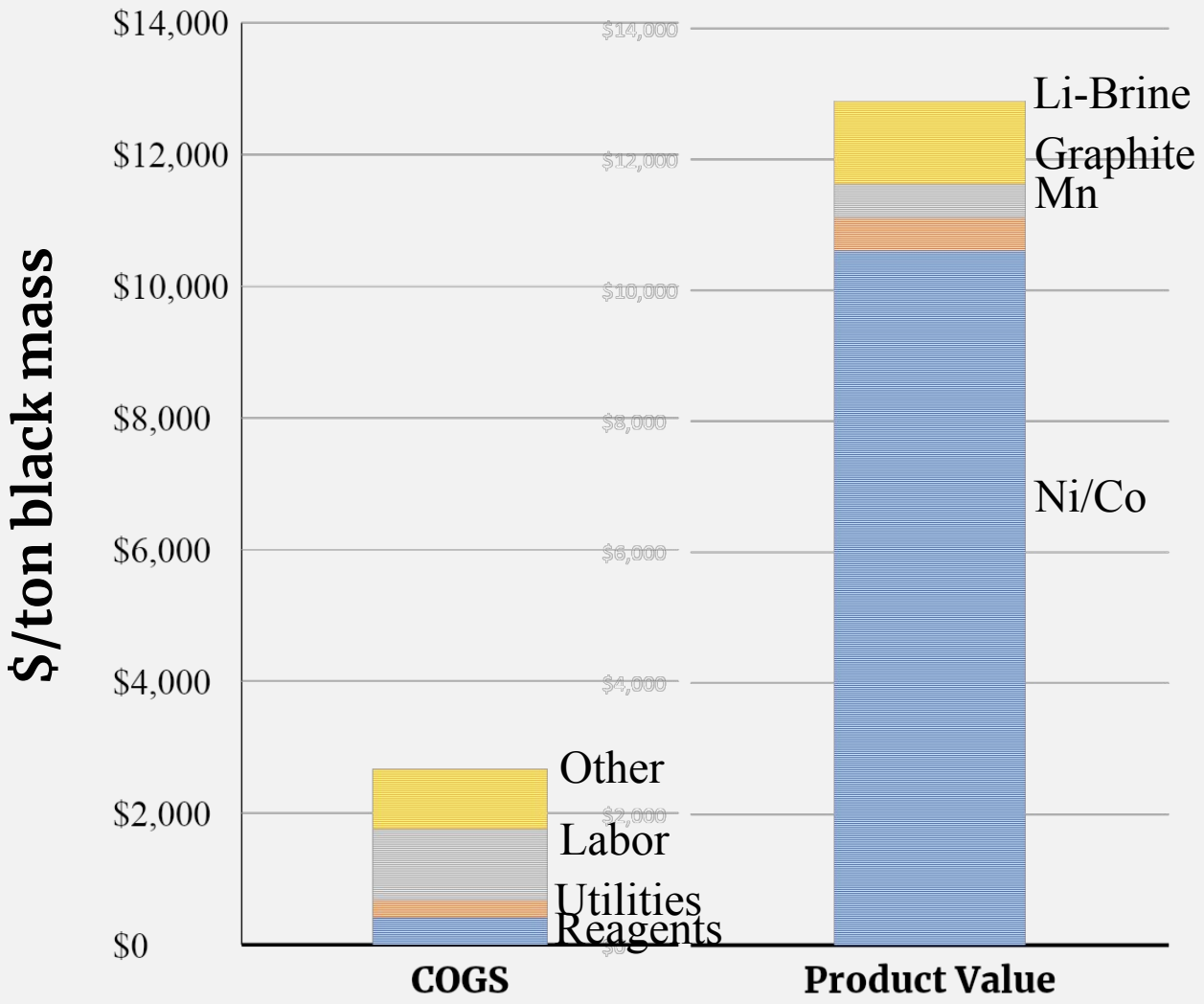
27 Co 58.933	28 Ni 58.693	3 Li 6.941
74 W 183.84	25 Mn 54.938	6 $C_{(gr)}$ 12.011



material flow for LIB recycling



material value for LIB recycling



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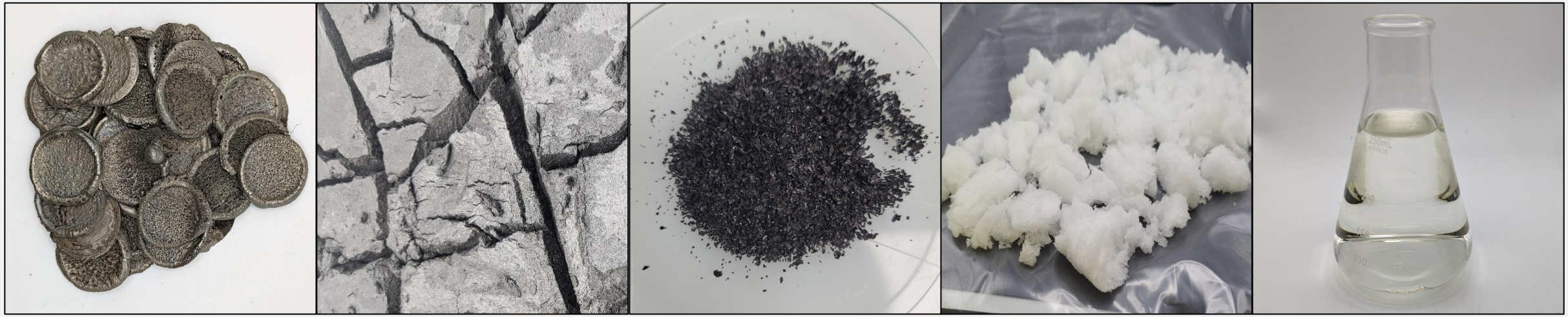
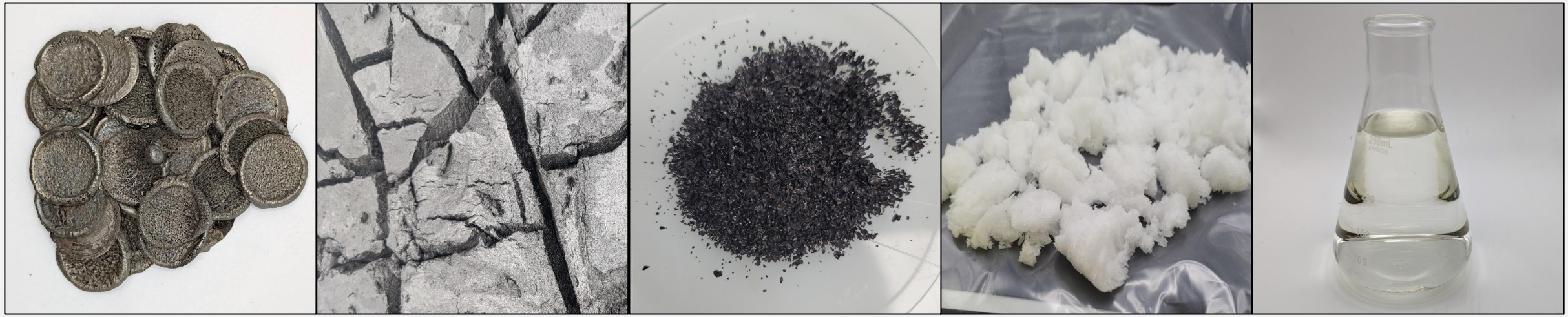
current product lineup



Ni/Co Alloy | Graphite | MnO_2 | $Na_2SO_4 \cdot 10H_2O$ | Li-brine

current product lineup



Ni/Co Alloy | Graphite | MnO_2 | $Na_2SO_4 \cdot 10H_2O$ | Li-brine

Oak Ridge National Laboratory

Non-LIB markets

Argonne National Laboratory

Pouch battery test cells

best in class – impact basis

Cate-gory	Unit		Electrochemical leaching	Peroxide based leaching	SO2 based leaching (Smith &Swoffer)	Xin et al., 2016	Wang et al., 2009	Guzolu et al., 2017	Meshram et al., 2015	Latif and Ahmad, 2017	Cheng and Zhuo, 2014	Musariri et al., 2019	Li et al., 2012	Li et al., 2015	Li et al., 2017	Bioleaching (Alipanah et al.,)
Ozone depletion	kg CFC-11 eq															
Global warming	**kg CO2 eq**															
Smog	kg O3 eq															
Acidification	kg SO2 eq															
Eutrophication	kg N eq															
Carcinogenics	CTUh															
Non carcinogenics	CTUh															
Respiratory effects	kg PM2.5 eq															
Ecotoxicity	CTUe															
Fossil fuel depletion	MJ surplus															

THE UNIVERSITY OF ARIZONA

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Thank You!

OMNIDIAN

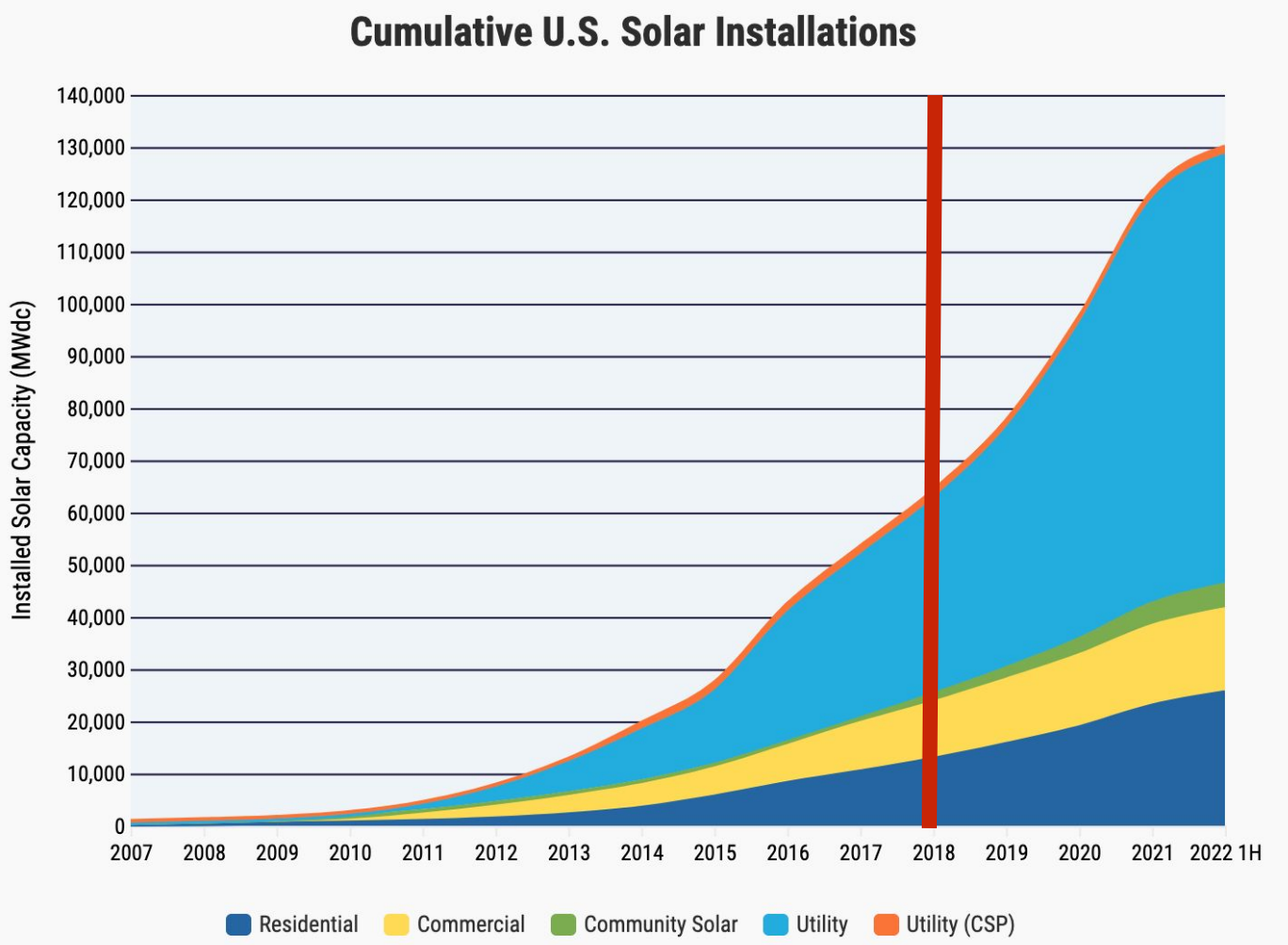
Solar Without Fear

Solar Recycling

Creating a sustainable industry

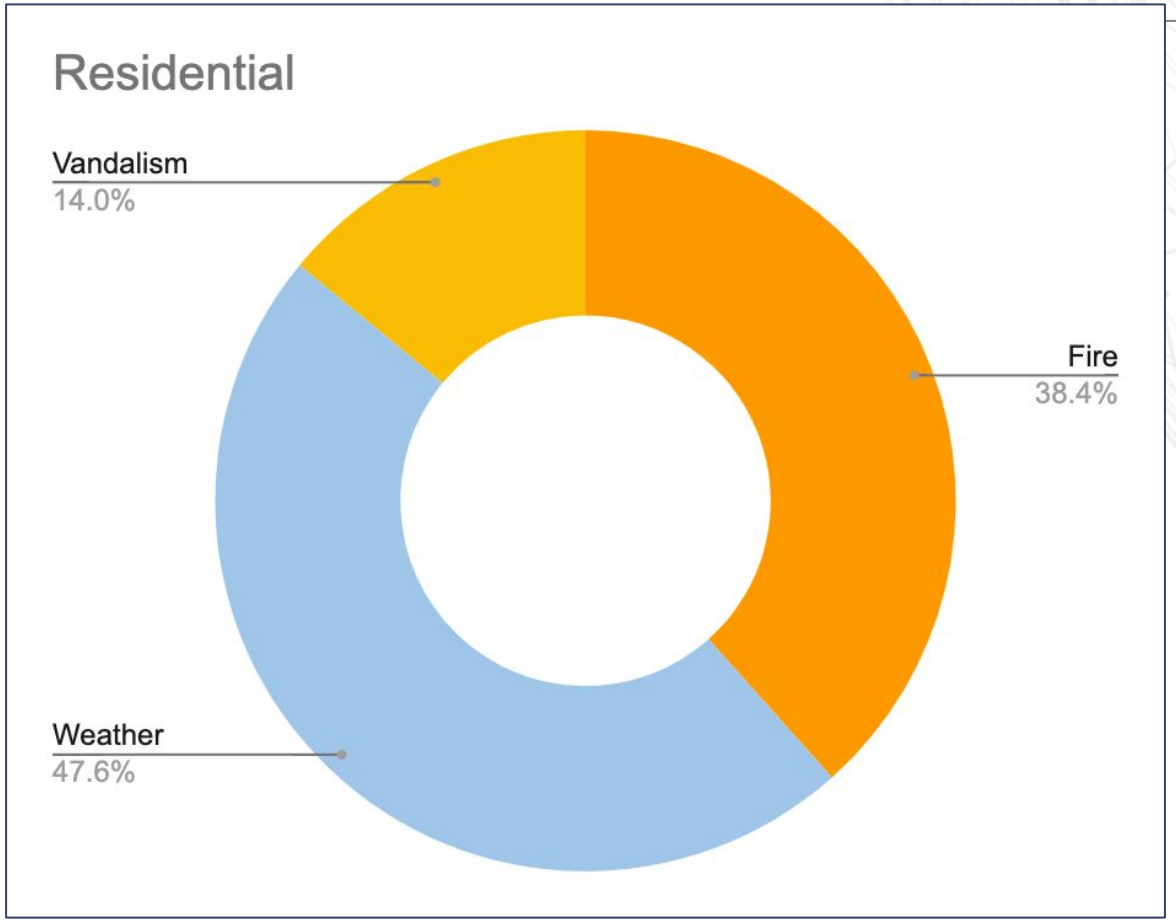
Presentation Date

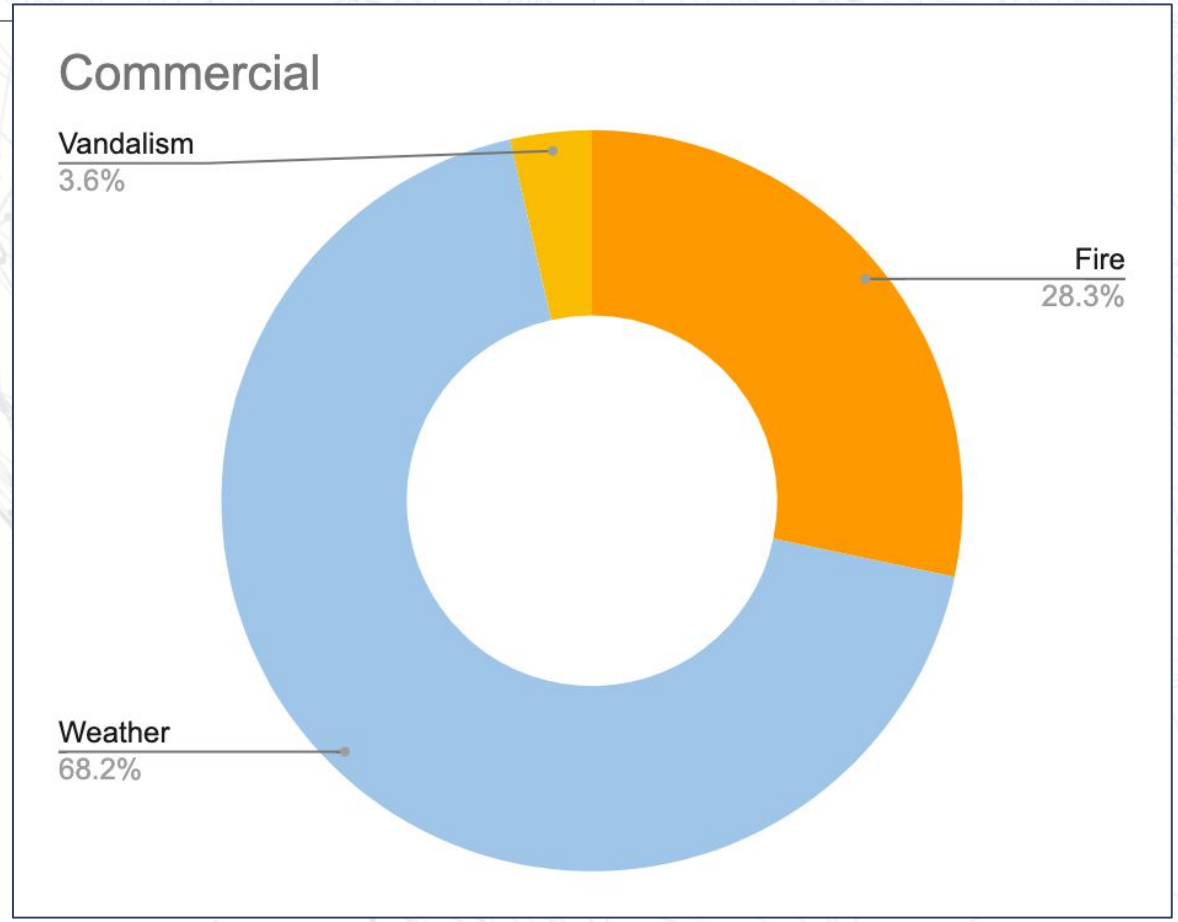
Solar Waste



Source: SEIA/Wood Mackenzie Power & Renewables U.S. Solar Market Insight Q3 2022

Root Causes of Solar PV Claims

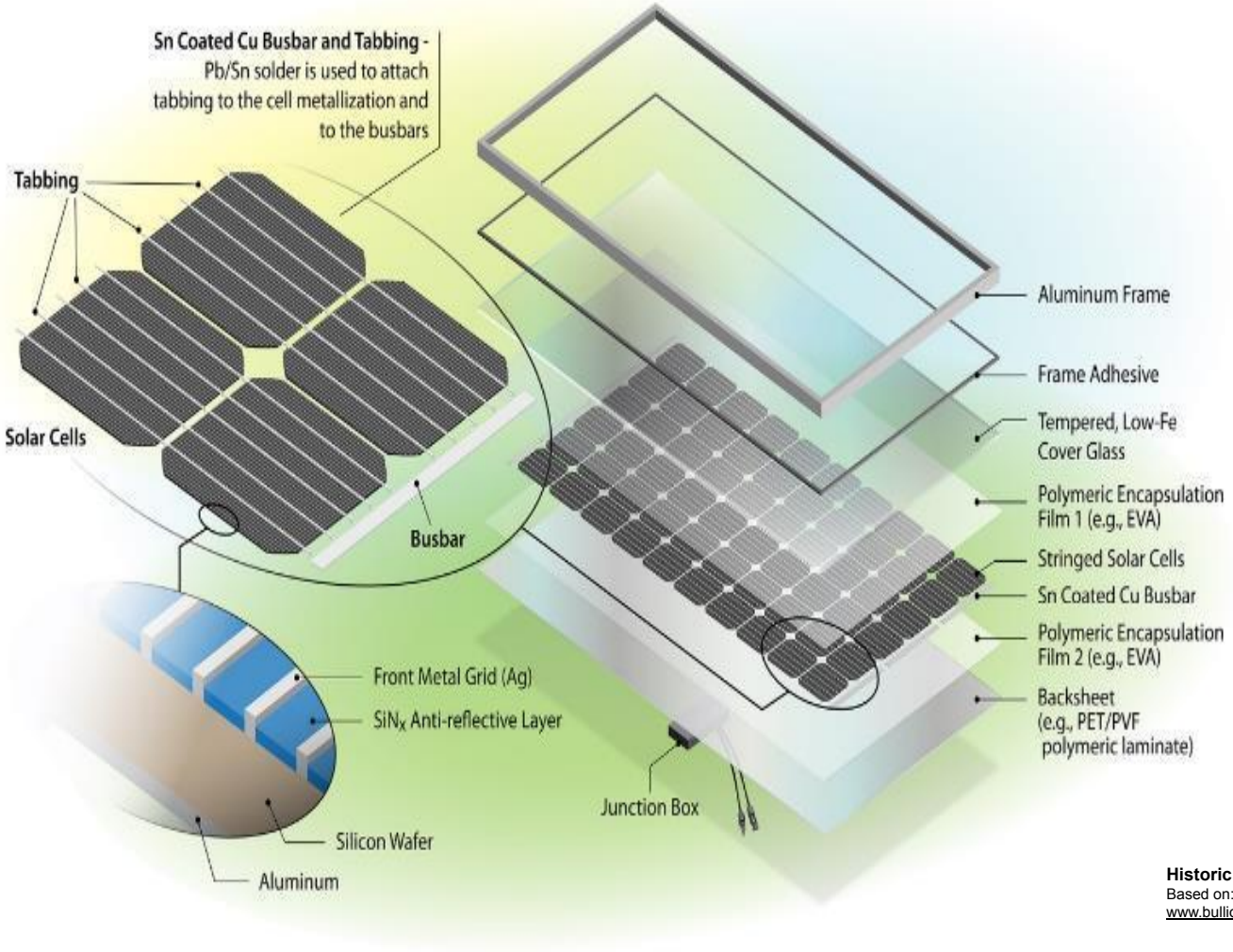


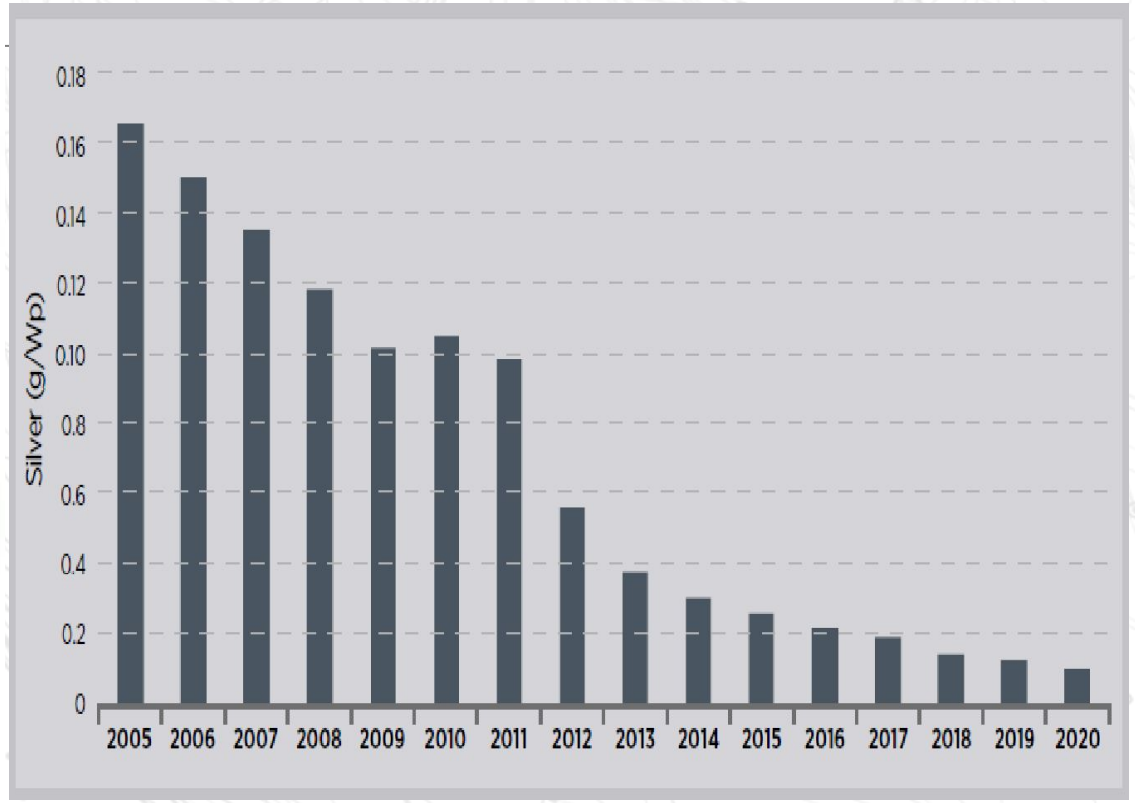


Repowering

Recycling Process

What's in a module?



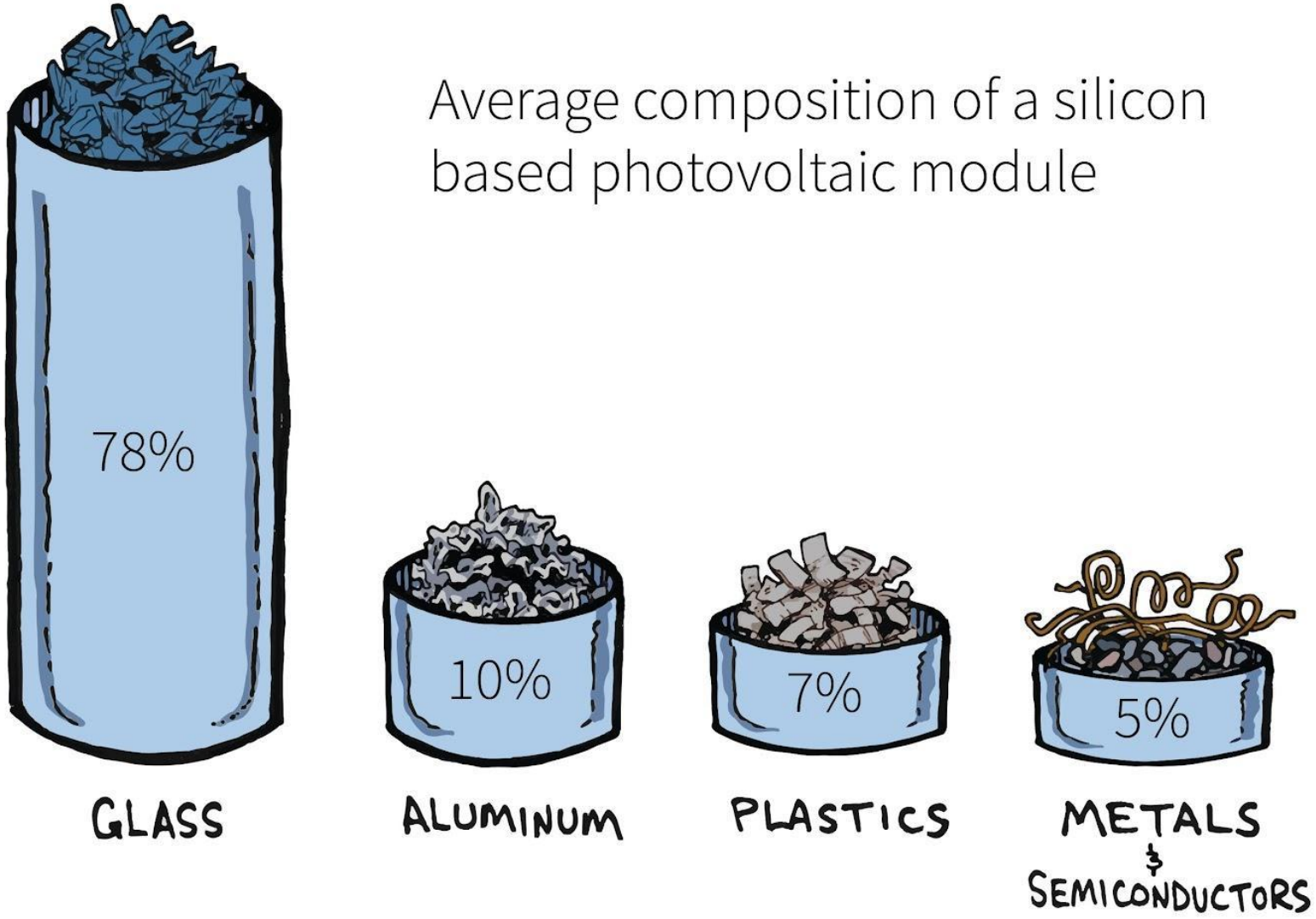


Historic and expected silver consumption per Wp
Based on: Perez-Santalla, M. (2013), Silver Use: Changes & Outlook, www.bullionvault.com/gold-news/silver-use-103020132

Credit: NREL

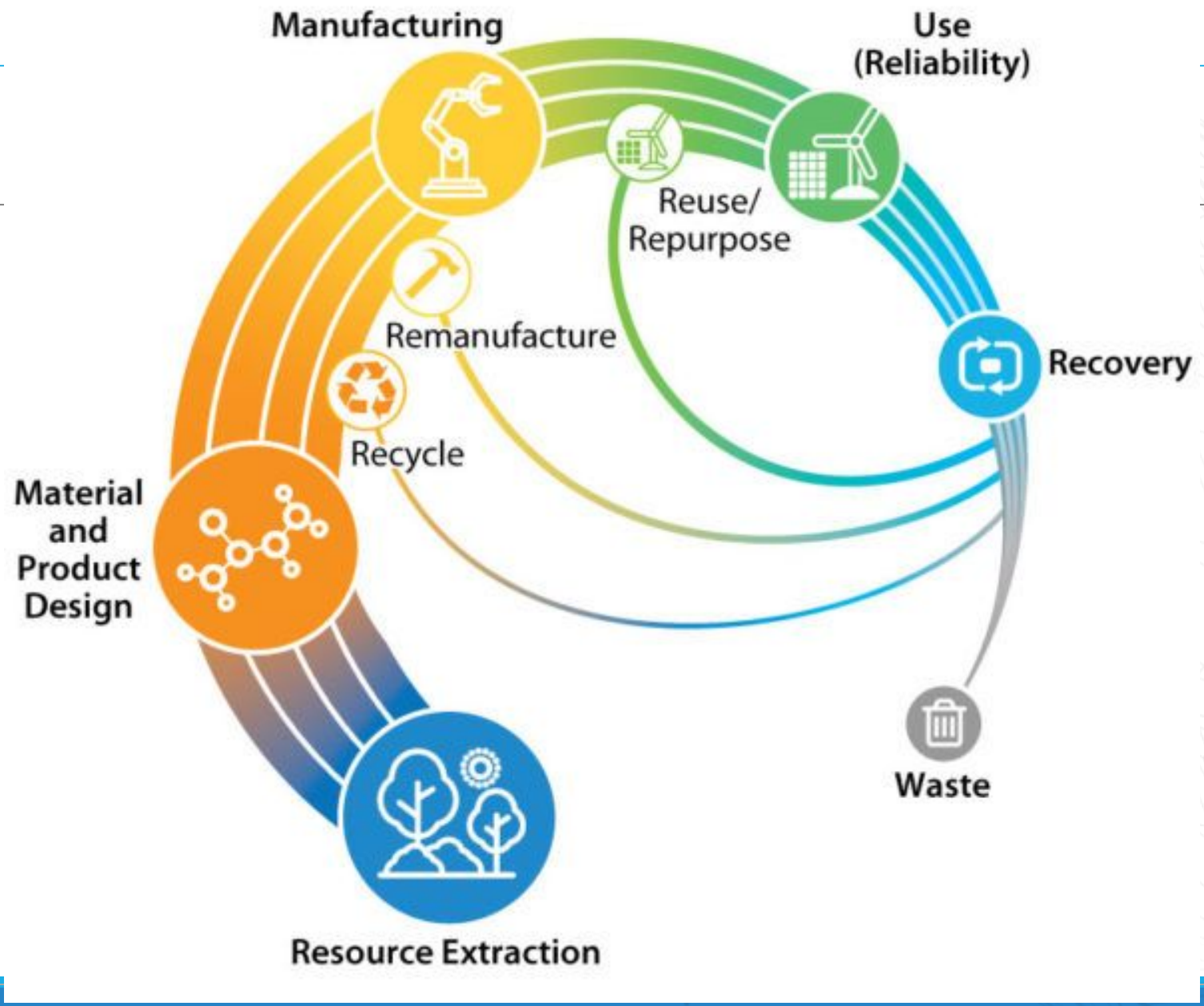

Frame Separator
Glass Separator
J-Box Separator

Average composition of a silicon based photovoltaic module



Looking ahead

SolarRecycle.org


Manufacturing
Use
(Reliability)
Reuse/
Repurpose
Remanufacture
Recycle
Recovery
Material
and
Product
Design
Waste
Resource Extraction

Thank you

Image credit: Inter-American Development Bank

PANEL DISCUSSION

Challenges of establishing a recycling operation in Colorado

What barriers need to be addressed to recruit and retain cleantech recyclers in Colorado.

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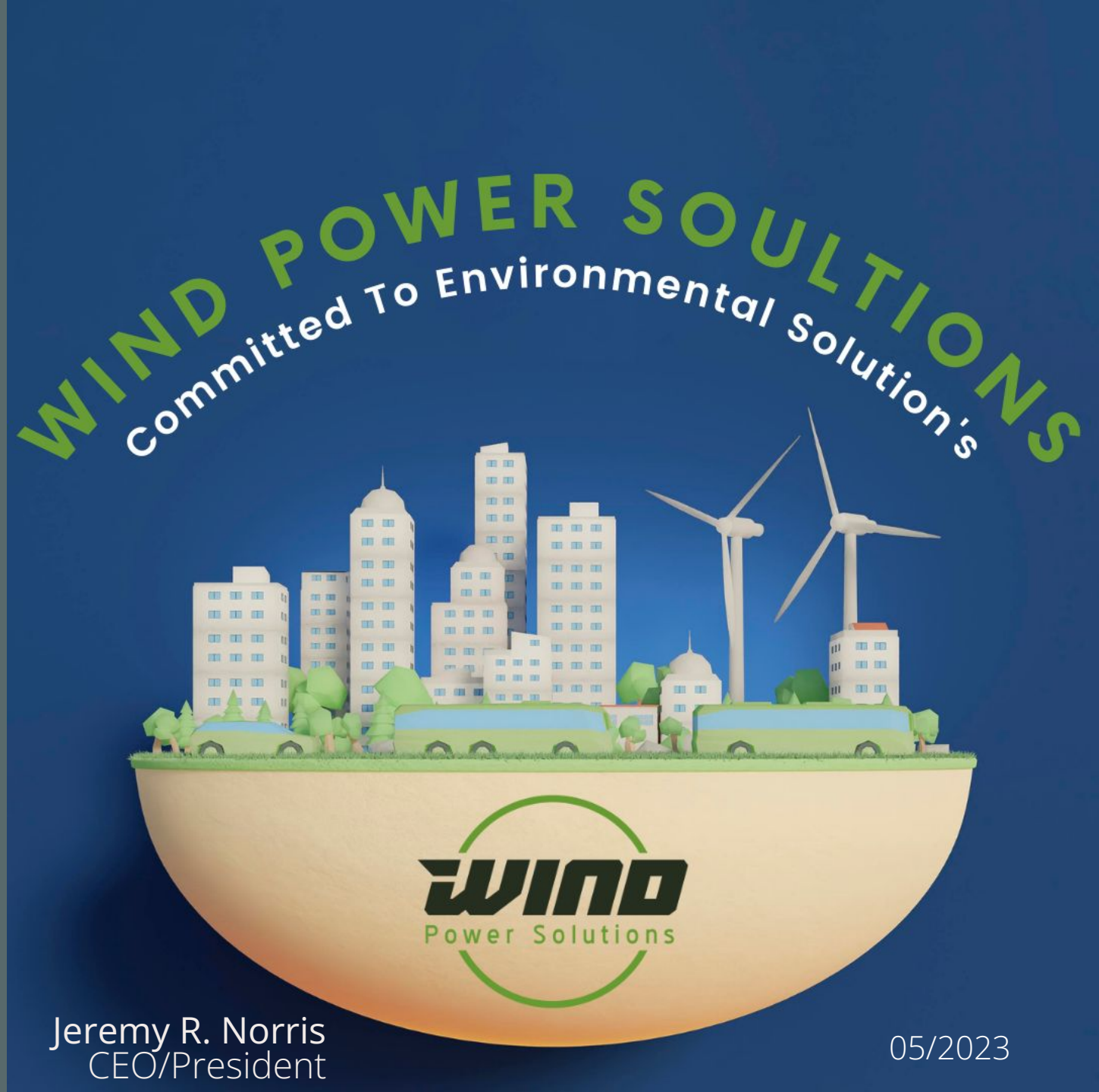
How do we turn waste into resources?



Jeremy R. Norris
CEO/President

05/2023

What is the market value chain for Wind Turbine Blade Recycling?

Material Supplier

- OEM's
- GC's
- Utilities
- Asset Owner's

Material Handlers

- Wind Power Solutions handles logistics, site removal, offtake selection, and environmental remediation.

Material Recycler

- Pyrolysis
- Mechanical Grinding
- Solvolysis
- Cement Co-Processing

KEY DRIVERS OF COST

- Transportation
- Offtake Selection
- Project Variables

1. Project Evaluation & Pre-Planning

- Identify permitting, state, and local regulations.
- Identify a recycling facility that is cost-effective and flexible for the project.
- Develop transportation and logistics plan.
- Choose disassembly method via cross-section or material grinding.

2. Project Execution

- Implementation of Transportation & Logistics Plan
- Disassembly of Wind Turbine blades
- Supply Chain Management
- Handle Material Chain-of-Custody to Offtake (Recycler).

3. Post-Project Analysis & Close-Out

- Full Supply-Chain Close-Out (Certificate of Recycling).
- Remediation and environmental efforts.
- Post-project Analysis (KPIs).
    - *Recycling Rates | Environmental Impact | Transportation Efficiency*

THANK YOU

CLEANTECH RECYCLERS

Q & A

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THANK YOU

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