ENGINEERING SOLUTIONS FOR SUSTAINABILITY: MATERIALS AND RESOURCES 3

Toward a Circular Economy

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Session #8: Environment / Waste

Metals Recovery and Recycling

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Outline

- **Introduction**
- **Scope and Size of the Problem**
- **Recycling:**
  - Gathering up the stuff – Economically!
  - Limits?
  - Feasibility
  - Complexity of the metals problem
  - Metals sorting → separations and products
  - 4 specific up and coming recycling technologies
- **Review/Conclusions**
- **Acknowledgements**

Introduction

What Does Recycling Really Mean?

Recycling is the diversion or “steering away” of materials from the waste stream.

Materials or resources can be processed into new materials and/or manufactured into new products, instead of being buried in landfills as trash.

Introduction

What Does Recycling Really Mean?

How many pounds of waste do Americans generate per year (before recycling)?

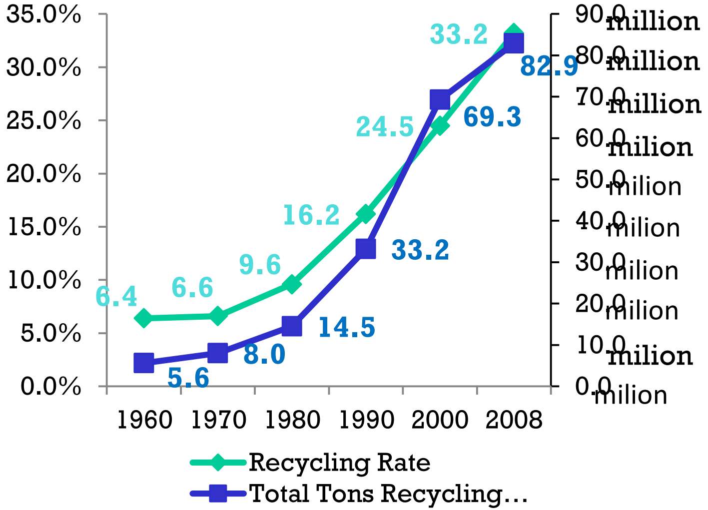
4.4 pounds of municipal solid waste (MSW) per day
x
295,734,134 United States residents
x
365 days a year

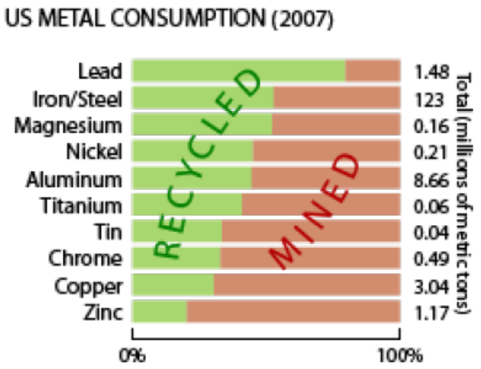
Americans throw away =
474,949,019,204 pounds per year

Introduction

The Good News

Americans are recycling more – and the U.S. EPA hopes this will continue, setting a goal of 35%





Introduction

- **What do/can we recycle? Can we really recycle them all?**
  - Fibers - Paper
  - Polymers/Plastics – Multiple types
  - Electronics – Old and new
  - Batteries – Multiple types/hazardous
  - Magnets/Motors – Multiple types with REE content
  - Glass
  - Organics
  - Metals
    - Aluminum
    - Steel
    - Copper
    - Nickel/Zinc/Cobalt
    - Rare Earths
    - PGMs (Platinum/Palladium/Iridium/Osmium/Gold/Silver)

Examples

Aluminum – 44,000 Tons Recycled

- Energy savings equivalent to powering nearly 88,000 houses for one year
- 95% energy savings on the life cycle of the can
- Recycling one aluminum can saves enough energy to run a TV for 3 hours
- Enough aluminum is thrown away to rebuild the nation’s commercial air fleet 4 times every year
- Greenhouse Gas Reduction equivalent to taking nearly 126,000 cars off the road per year

Examples

Mixed Metals – 358,000 Tons Recycled

- Energy savings equivalent to powering 292,000 houses for one year
- 74% energy savings on the life cycle of the can
- Every pound of steel being recycled saves enough energy to light a 60-watt bulb for 24 hours
- Enough iron and steel is discarded in the US to continually supply the nation’s automakers
- Greenhouse Gas Reduction equivalent to taking nearly 390,000 cars off the road per year

Metals Recovered

- Aluminum Cans
- Aluminum Scrap
- Steel Food Cans
- Steel Scrap
- Non-Ferrous Metals (Copper, Zinc, Gold, etc.)

New Materials/Uses

- New Aluminum Cans
- New Steel Cans
- Car Parts
- Airplane Parts
- Bicycle Parts
- Rebar
- New Misc. Non-ferrous Metal Parts

Examples

Plastics – 198,000 Tons Recycled

- If we recycled every plastic bottle we used, we would keep 2 million tons of plastic out of landfills
- Energy savings equivalent to powering 86,000 houses for one year
- We use enough plastic wrap to wrap all of Texas every year
- Greenhouse Gas Reduction equivalent to taking 54,000 cars off the road per year

Plastics Recovered

- HDPE Natural (milk jugs)
- HDPE Colored (detergent bottles)
- PET (soda & water bottles)
- PVC (water and shampoo bottles)
- Film plastics
- Other plastics

New Materials/Uses

- New Plastics Bottles
- Clothing
- Toys
- Misc. Plastic products
- Carpet Fiber
- Plastic Lumber/Decking
- Terrazzo Flooring Tile
- Car Parts
- Piping

Examples

Old Newspapers – 2,000,000 Tons Recycled

- Recycling of each ton of paper saves 17 trees and 7,000 gallons of water yearly
- Every year enough paper is thrown away to make a 12 foot wall from New York to California
- Energy savings equivalent to powering **317,000 houses** for one year
- Greenhouse Gas Reduction equivalent to taking **773,000 million cars** off the road per year

Paper Recovered

- Old Newspapers
- Corrugated Boxes
- Printing & Writing
- Office Paper
- Specialty Papers
- Cereal-type Boxes

New Materials Made

- Newspaper
- Corrugated Boxes
- Printing & Writing
- Office Paper
- Specialty Papers
- Tissue Paper
- Paper Towels
- Gift Wrap Paper
- Fiber Insulation

Examples

Old Corrugated Containers – 1,900,000 Tons Recycled

- Energy savings equivalent to powering **290,000 houses** for one year
- Greenhouse Gas Reduction equivalent to taking nearly **1,400,000 cars** off the road per year
- Making Corrugated Containers from virgin sources creates sulfur dioxide. Making it from recycled sources cuts the pollution in half
- Corrugated Containers manufactured from recycled products use about 75% of the energy to make them from virgin sources

Idaho National Laboratory

Examples

Glass Containers – 545,000 Tons Recycled

- Recycling of one glass container saves enough energy to light a 100-watt bulb for 4 hours
- 1 ton of glass made from 50% recycled materials saves 250 pounds of mining waste
- Glass can be reused an infinite number of times; more than 41 BILLION glass containers are made each year
- Greenhouse Gas Reduction equivalent to taking **36,000 cars** off the road per year
- Energy savings equivalent to powering **14,000 houses** for one year

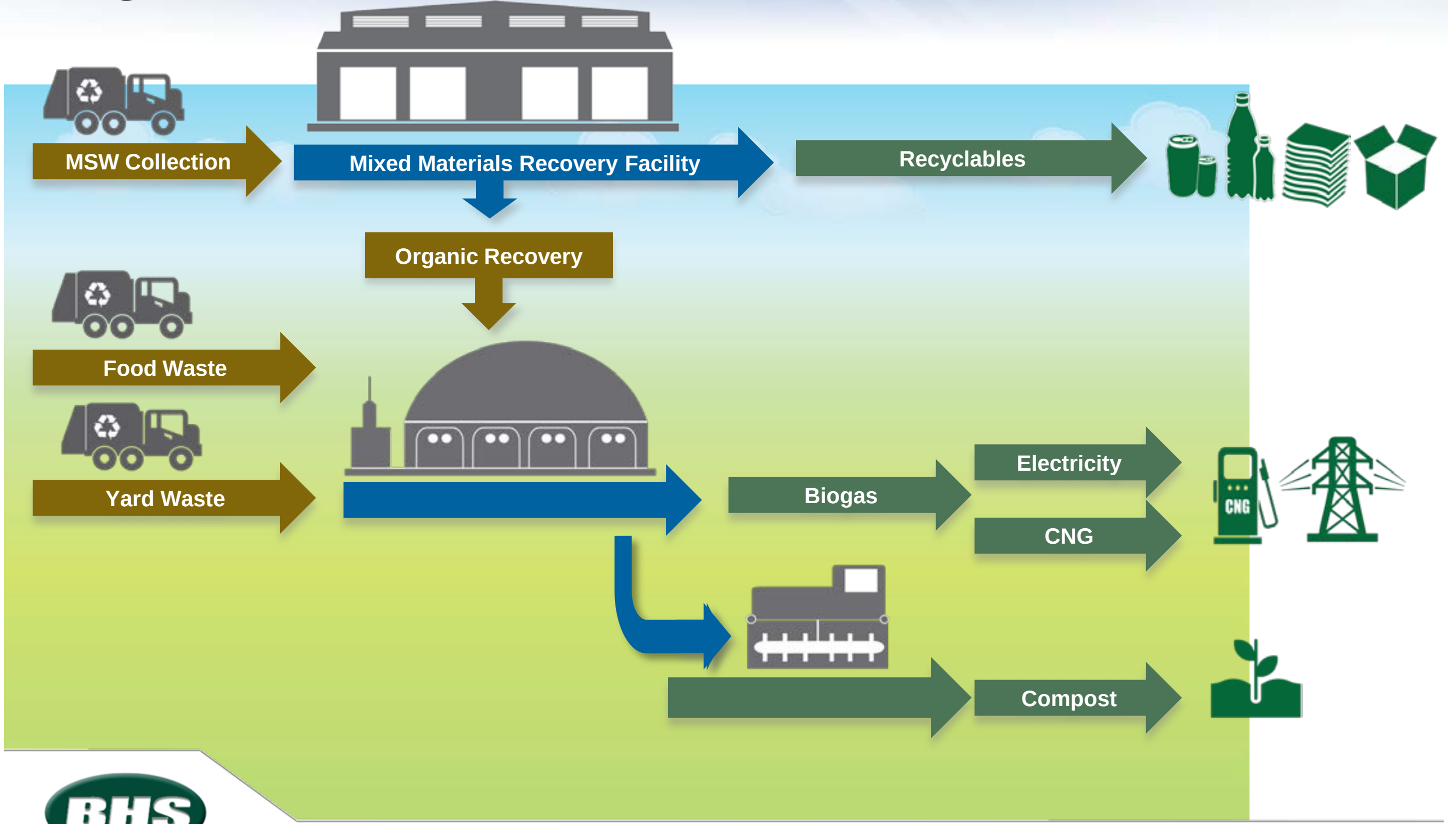
Glass Recovered

- Clear Glass Containers
- Amber Glass Containers
- Green Glass Containers
- Blue Glass Containers
- Flat/Plate Glass

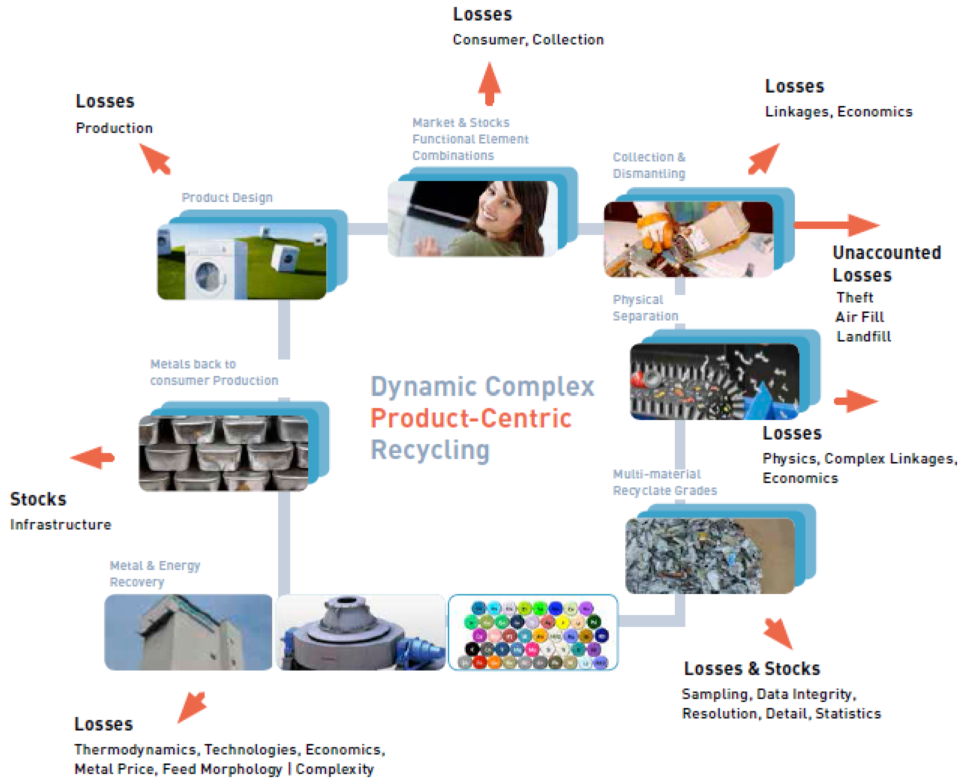
New Materials/Uses

- Glass Containers
- Flat/Plate Glass
- Decorative Landscaping
- Terrazzo Flooring Tile
- Aggregate

Organics – Their Fate (Courtesy of BHS)



Design - Product Centric Recycling
- Losses can be minimized



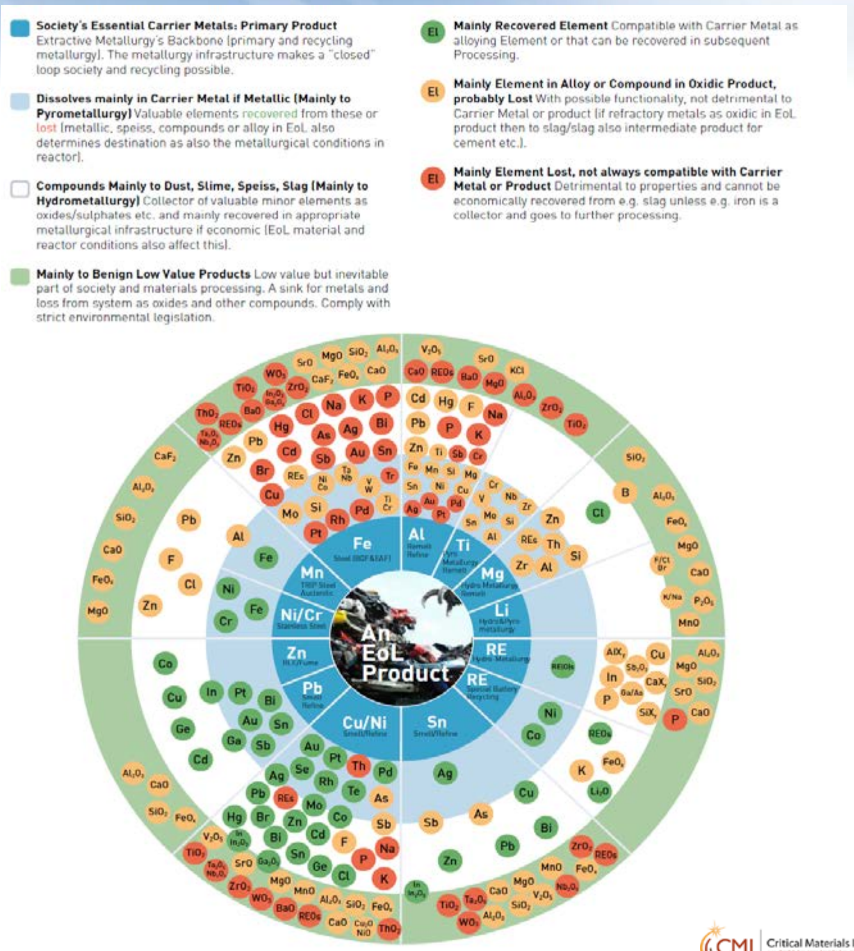
Where do the metals go?
How do we know?

Can they be recovered?
Economics

Can they be reused?
Practicality

Can they be recycled?
Economics

Can they be separated?
If so – How?



Gathering, Identification, Sorting, and Separations

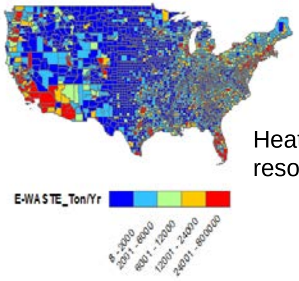
Mind-Set Changes – Recovery

Understanding of the human factors that influence people's decisions to recycle!!

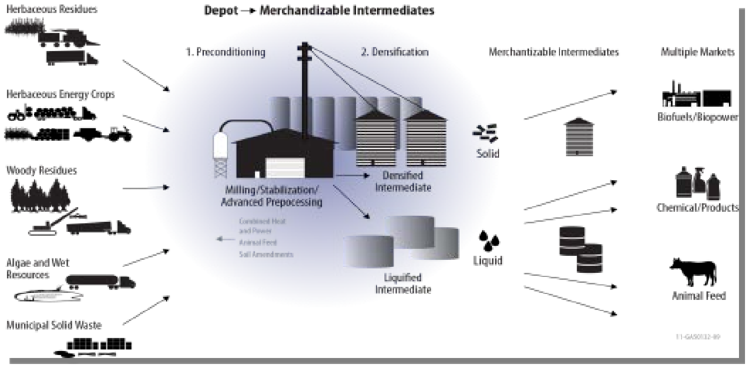
Model basis: Biomass Resource Recovery

Early emphasis - efficient collection methodologies

- Where to collect?
- What to collect?
- How to collect?
- How/where to process?
- Where to refine?

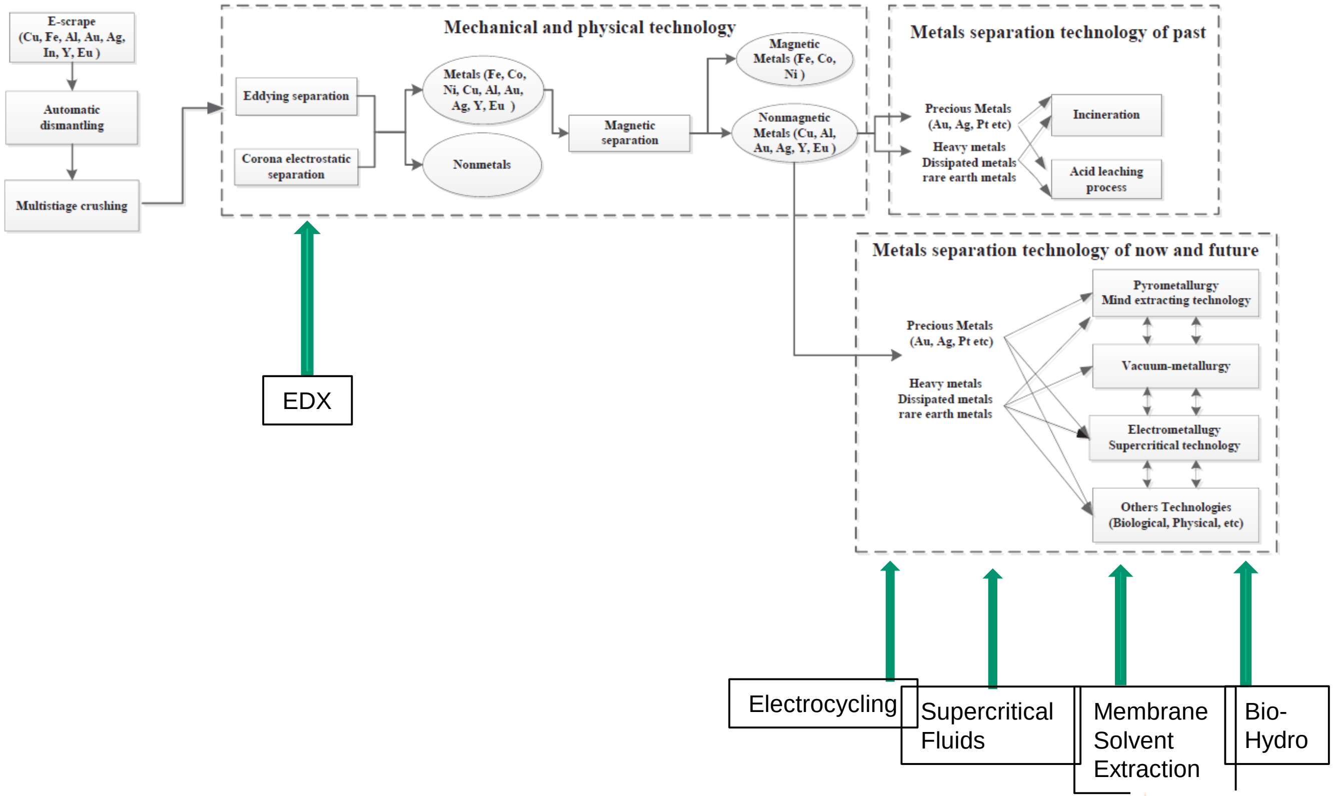


Heat map showing e-scrap resource availability in 2013

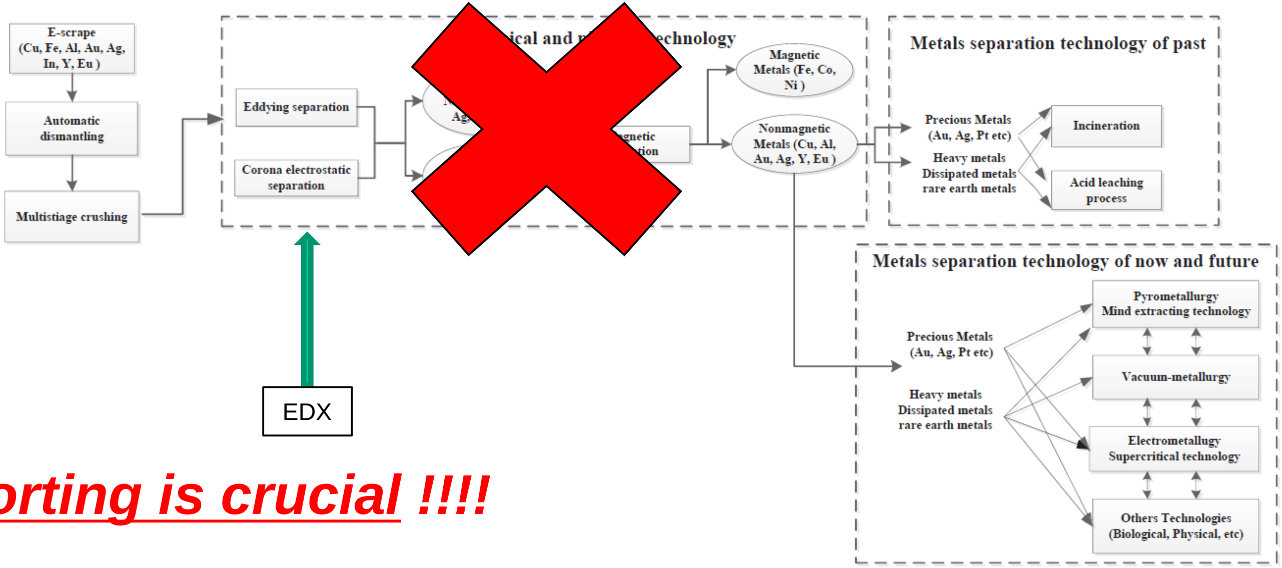


Assume: EPA national average of 4.4 lb/per person per day MSW generation and 1% is electronic waste.
The above resource assessment map can be generalized to show approximate availability for REMADE for 2013.

Metals Separations and the Future!!



Metals Separations and the Future!!



EDX

Electrocycling

Supercritical Fluids

Membrane Solvent Extraction

Bio-Hydro

Sorting is crucial !!!!

No sorting – Recycling HALTS!!!

Automation = Economics

Current Physical Separations

A summary of separating situation for the physical separation technologies (Ruan and Xu, 2016).

Physical separation method	Character of separation	Main advantages and disadvantages
Magnetic separation (MS)	Separation of ferrous metals	MS was most suitable separating steel or iron but not suitable for separating of non-ferrous metals
Eddy current separation (ECS)	Separation of ferrous and non-ferrous materials	ECS was encouraged to recover non-ferrous metallic particles and hard to separate ferrous metals/other metals
Air current separation (ACS)	Separation of light particles from heavy particles	Wind velocity, particle size, particle density, etc. were the critical influences for ACS
Corona electrostatic separation (CES)	Separate metallic particles (size from 0.2 mm to 1 mm) from non-metallic particles	The movement trajectory and collection position of metallic particles in CES were hard to predict and compute

EDX Electrodynamic Sorting Project Team

EDX

Electrodynamic Sorting

Dr. Raj Rajamani - Principal Investigator

Dr. James Nagel - Senior Engineer

Dave Cohrs - Research Associate

Jaclyn Ray - Graduate Research Assistant

Dawn Sweeney - Graduate Research Assistant

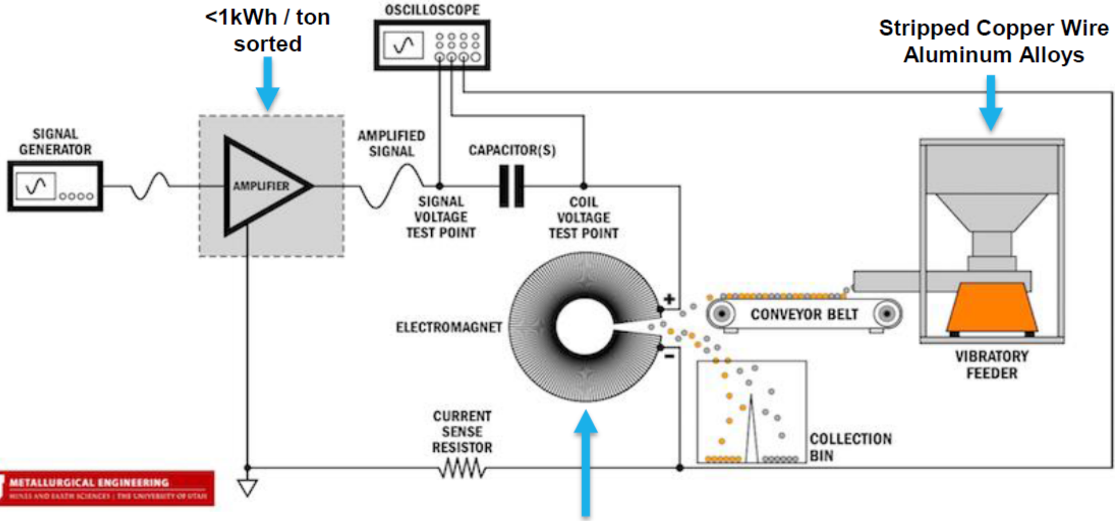
Jake Salgado - Undergraduate Research Assistant

We separate nonferrous metals and alloys from mixed recycled scrap

We save energy by recycling rather than mining

We create value by recovering materials which cannot be sorted using current technologies

EDX Technical Concept



Current ECS technology

Spinning magnets in traditional eddy current sorters can only generate approximately 100-500Hz hence, limited to larger particle sizes (2" and above)

- Variable frequency (1 – 50kHz and beyond)
- Solid state / no moving parts
- Can sort particle sizes below the current practical cutoff of commercially available machines (1-25mm typical)

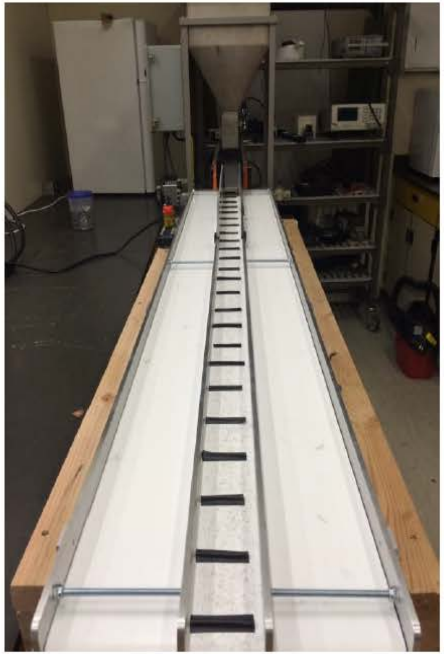
Sorting Results: Cu and Al cylinders (lab)

Throughput = 233 kg / hour

Recovery (Al) = 99.4 %, Recovery (Cu) = 98.5
Grade (Al) = 97.8 %, Grade (Cu) = 99.5%

Mixed Al/Cu
12mm cylinders

Sorting results



Belt fed prototype

TEA Highlights

What are other benefits of your process over a comparable process?

- EDX seeks to capture currently unrealized value in recycled metals products
- EDX sorted products stay domestic, minimizing further carbon input and import buyback premiums
- EDX can sort particles 1-25mm with high grade and recovery
- Only comparable tech is Xray combined with optical methods. Xray machines are upwards of $1-2M whereas EDX would be ~10% of that.

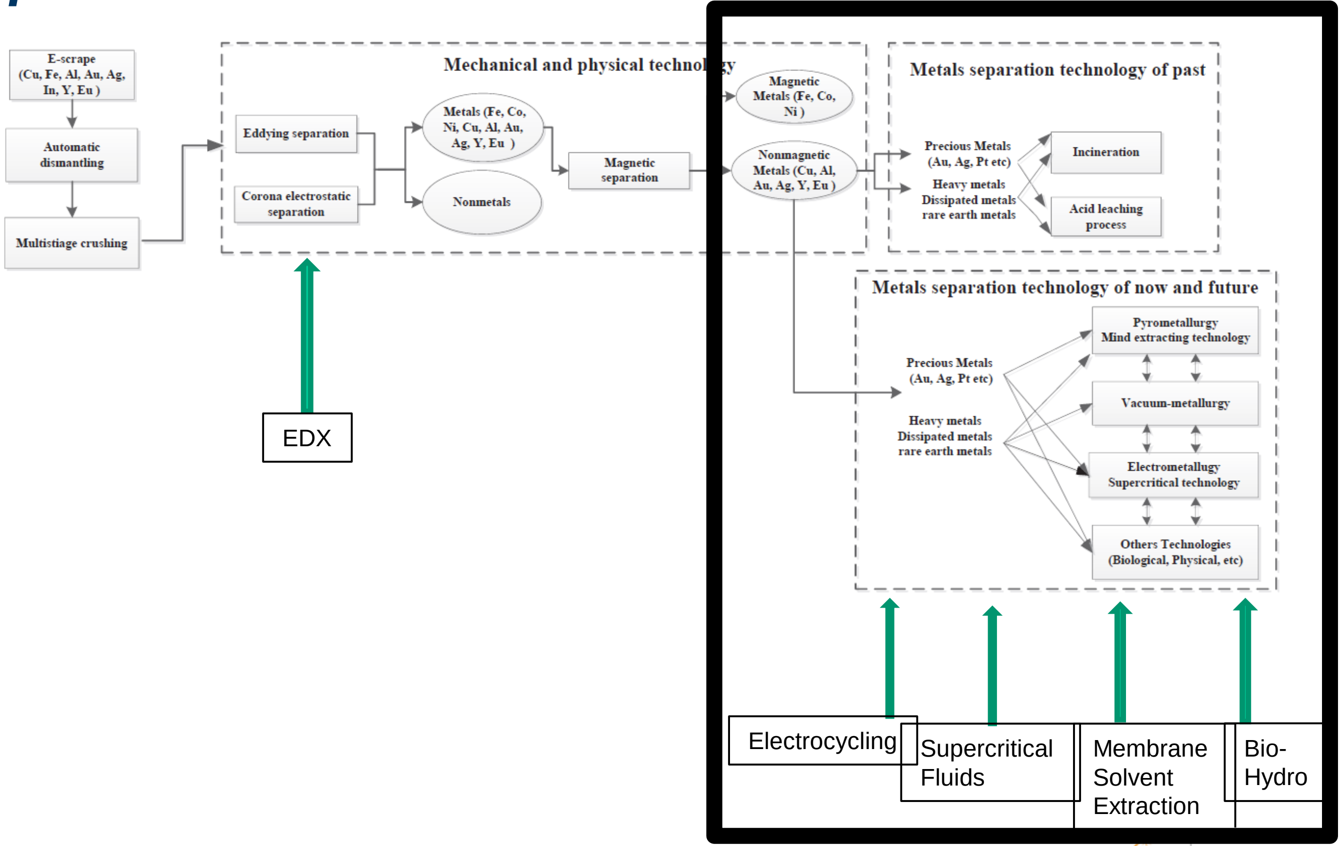
The U.S. Aluminum Industry

YEAR	ALUMINUM RECOVERED FROM SCRAP (MT)	TOTAL ALUMINUM USAGE (MT)	ALUMINUM SCRAP EXPORTS*(MT)
2010	2,700,000	5,053,000	1,913,000
2011	3,110,000	5,099,000	2,125,000
2012	3,430,000	5,768,000	2,034,000
2013	3,480,000	6,196,000	1,869,000
2014	3,640,000	6,240,000	1,718,000

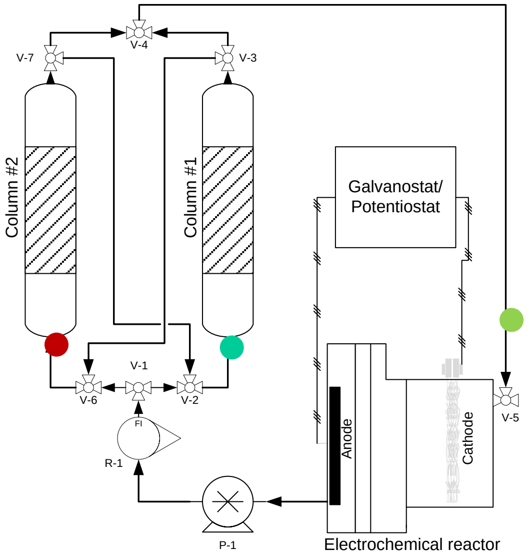
** Includes UBC's and Remelt Secondary Ingot.*

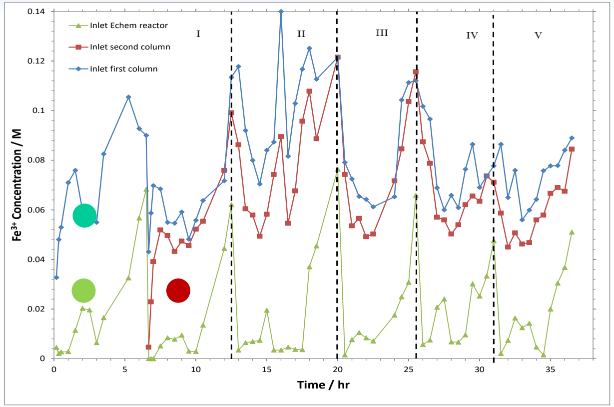
Source: ISRI 2015

Metals Separations and the Future!!

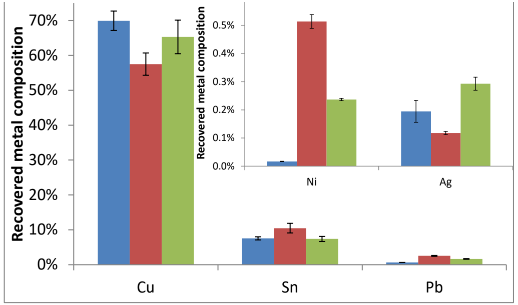


Electro-Recycling Process Optimization





Optimized process: high oxidizer utilization

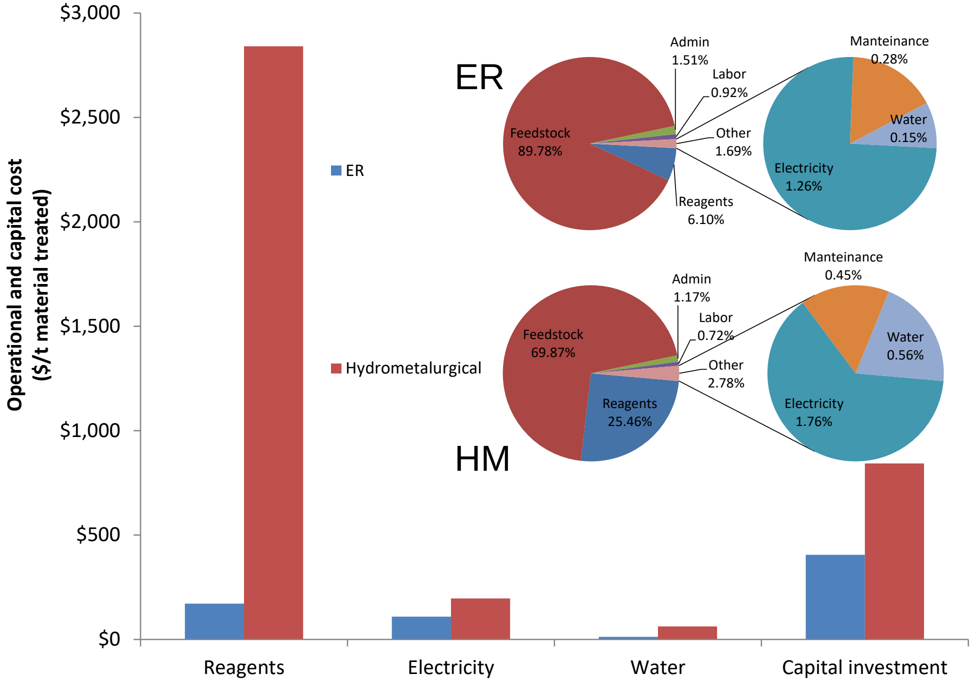


Cu rich deposit obtained

	Predicted value	Observed value	Relative error
Energy consumption kWhr kg^{-1}	1.809	1.94 ±0.09	6.97%
Faraday Efficiency	0.817	0.80 ± 0.04	1.97%
Recovery rate g min^{-1}	0.0104	0.0081 ± 0.0004	22.5%

Lower than electrowinning value

Electro-Cycling vs. Conventional Acid Leach



- ER process easily best due to smaller footprint through combination of unit operations and lower use of chemicals. Feedstock cost dominates cost.

Supercritical Fluid Recovery of REEs

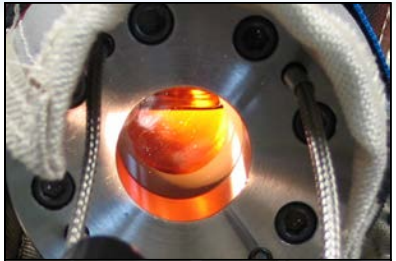
- **Objective:** Supercritical fluid process for recovery of lanthanides.
  - -Demonstrate the process for recovery of lanthanides from phosphors.
  - -Expand the process and demonstrate recovery of lanthanides from magnets and other selected solid matrices.

- **Impact:** Diversion of CFL waste from landfills, recovery from magnets, etc.

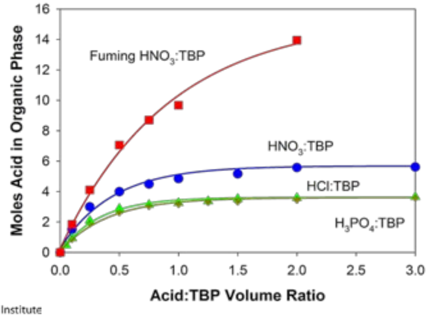
- **Progress:** >95% recovery of selected lanthanides from oxides. >70% recovery of lanthanides from commercial lamp phosphors; Pursuing patent applications for IP that has been filed; finalizing a CRADA with an industrial partner.

- **Next steps:** Phosphor processing chemistries allowing for >90% recovery of lanthanides. Finalize CRADA; execute remainder of project tasks to ensure successful deployment and application of the technology.

- 1 CRADA signed, 1 license signed
- Shift emphasis to FCCs, magnets
- Finalize CRADA/license commercialization work on phosphors for stockpiling oxides – State desired result
- Increase budget to enhance commercial activities – 1 yr limit, $200K



Acid:TBP Adduct Properties

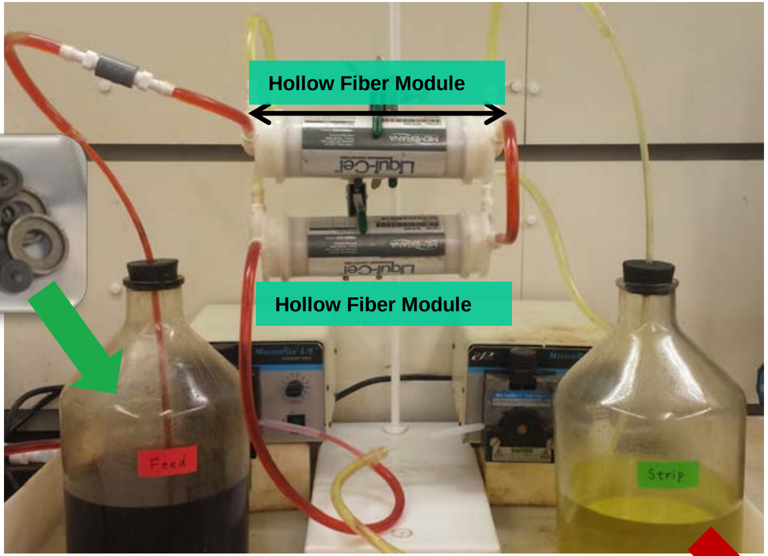


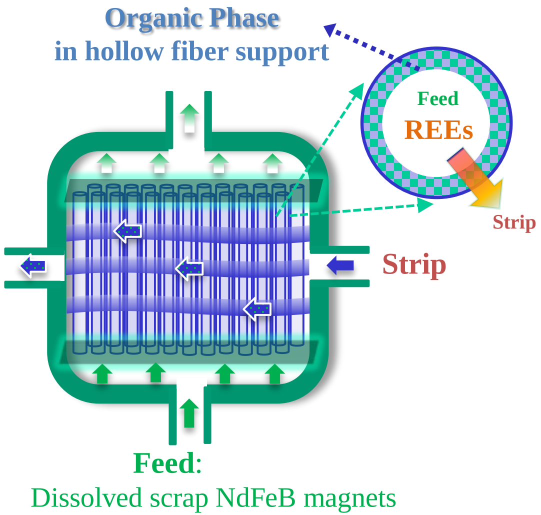
MSX Technology

- **Objective**: Recover high purity REEs suitable for reuse and recycle from scrap/swarf magnets dissolved in strong acids with highly selective extractants.
- **Impact**: 1) REEs can be directly recycled without additional chemical/physical processing. 2) minimizes hazardous waste compared to traditional technologies.
- **Progress**: 1) Demonstrated the recovery of high purity REEs from a wide range of scrap/swarf magnet samples provided by industrial partners. 2) achieved higher extraction rates and REE recovery (>98%) with larger area modules (>1 m^2). **3) Technology Licensed to US Rare Earths.**
- **Next steps**: 1) Process optimization and economic analysis for scale-up including system configuration for continuous operation to maximize throughout and REE recovery. 2) engage licensee and other potential industry partners for technology commercialization, 3) prepare for pilot-scale demonstration by December 2017.

- **Process optimization for magnets/e-scrap**
- **Scale-up testing at 1Kg, extended term tests**
- **Flow sheet development**
- **End product – demonstrate efficient >99% recovery**

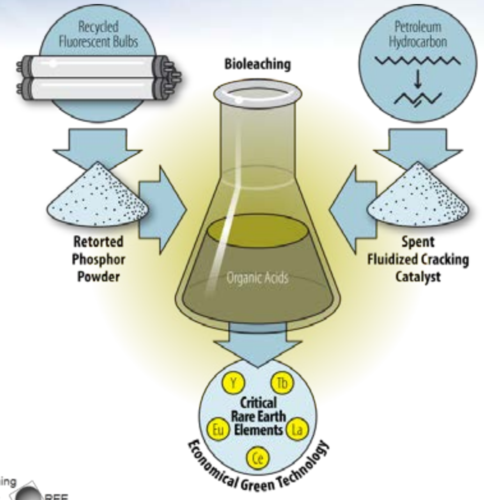
Membrane Solvent Extraction System: Bench Scale



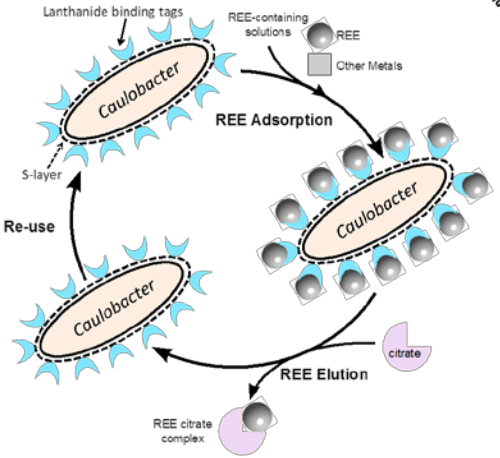


Bioleaching and Bio-adsorption

- **Objective:** Develop microbially mediated leaching and adsorption strategies to recover REE from low-grade REE source materials
- **Impact:** Lower costs; accesses lower grade ores
- **Progress:** 1) Developed strategy using biologically produced organic acids (predominantly gluconic acid) that leach REE from EOL products, 2) Genetically engineered bacterium for high-density cell surface-display of lanthanide binding (LBT) that are selective for REEs.



- **Next steps:** 1) Develop bench-scale leaching/adsorption processes, 2) Evaluate the capacity of a cell-free LBT system, 3) Increase organic acid production to enhance leaching efficiency.
- Considering different commercial configurations, do economic analysis, compare cell-free with cell containing.



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Acknowledgements

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