ENGINEERING SOLUTIONS FOR SUSTAINABILITY: MATERIALS AND RESOURCES 3

Toward a Circular Economy

February 18–19, 2017 | Denver, Colorado

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Session 8: Environmental/Waste

Value Creation Through Enabling Technologies to Up-Cycle Aluminum Scrap

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WPI

CR³ Center for Resource Recovery & Recycling

Agenda

- Introduction the Center for Resource Recovery & Recycling
- Background Information: Secondary Al Production
- Enabling Technologies: Optoelectronic Automated Systems
  - XRT
  - XRF
  - LIBS
- Conclusions/Future work

Center for Resource Recovery and Recycling (CR3)

- **<u>Mission</u>**: to develop and maintain sustainable materials and recovery/recycling processes
- This university-industrial partnership consists of a consortium of 20 corporate partners and 4 universities around the world

Academic Partners

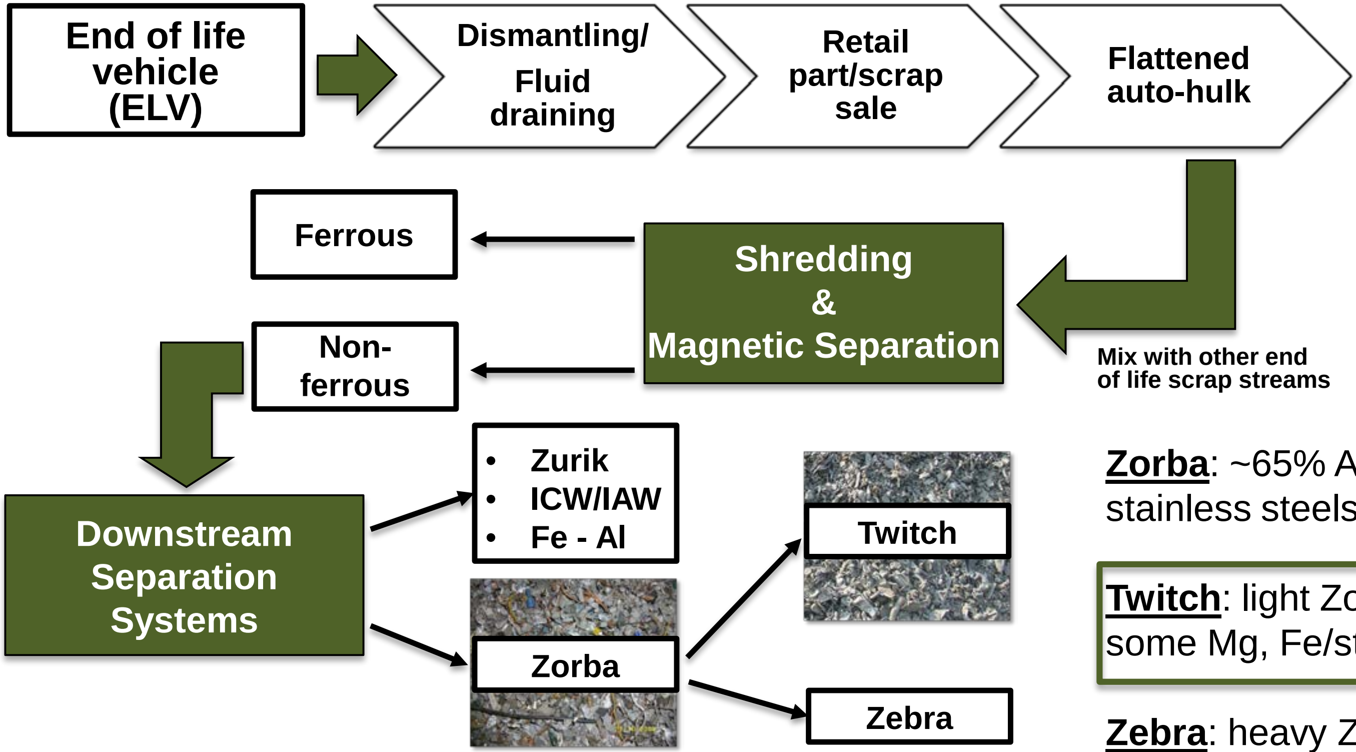
Worcester Polytechnic Institute

Colorado School of Mines

KU Leuven

University of Tokyo

Background: Auto-Al Recovery Process



Separation systems:

-Air separation

-Eddy-current

-Induction sorters

-Density (media-based)

-Optoelectronic (automated sorting systems – XRT, XRF, LIBS)

Zorba: ~65% Al alloys, Cu alloys, Mg, Zn, stainless steels, brass, organics, etc.

Twitch: light Zorba fraction, 90-98% Al alloys, some Mg, Fe/steel (screws, bolts), organics

Zebra: heavy Zorba fractions, Cu, Zn, brass, SS

Why Up-Cycle Twitch?

Twitch

vs.

Bauxite

-Above ground ore
-Energy investment already made
-Currently, very few Al alloy types produced from ore (380)

-Significant energy required to extract aluminum
-Significant waste
-Pure, all Al alloy types produced from ore

Post-consumer Al waste

↓

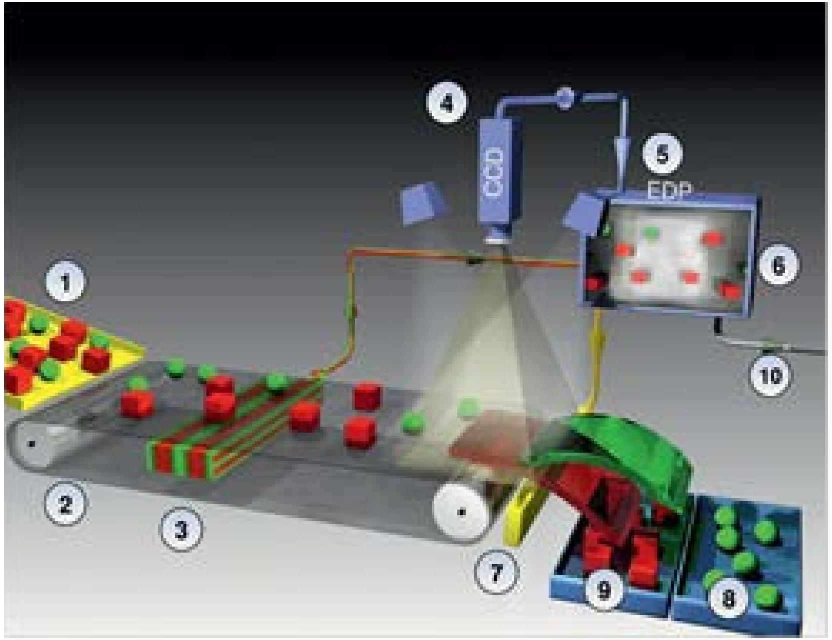
New Al product

↑

Innovation/process upgrading potential → **Sorting systems**

Enabling Technologies: Optoelectronic Automated Systems

Automated sorting process: separation of mixed materials based on measured and detected differences in material property



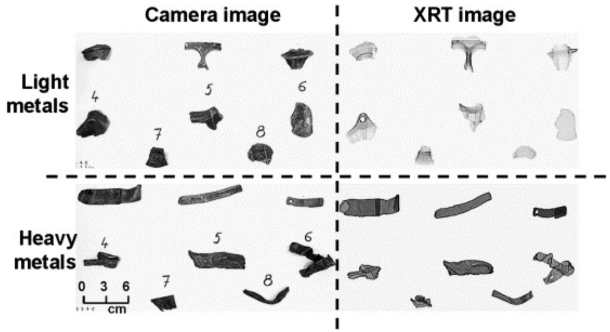
1) Scrap feeding mechanism
2) Belt distribution
3) Sensing system to alert the computational system of the location of the incoming samples
4) Optoelectronic analysis
5-6)Shows the transfer of the electronic signal to the monitor display
7) Air ejection system
8) Ejected (of interest) fraction
9) Dropped fraction
10) Data collection

[1] H. Wotruba, Harbeck, H., "Sensor-based Sorting," Ullmann's Encyclopedia of Industrial Chemistry, vol. 32, pp. 395-404, 2010.

Enabling Technologies: Optoelectronic Automated Systems

X-ray Transmission (XRT)

- Dual-energy XRT capable of sorting metallic particulates based on **atomic density differences**
- Zorba→ Zebra (heavy – Cu, Zn, brass) + Twitch (light – Al alloy, Mg)
- Twitch→ Heavy + Light fraction



Camera image vs. XRT image [2]

STEINERT XSS T

2400lbs. Twitch

~1600 lbs. Heavy fraction (cast)*

*Some "heavy" wrought (2000/7000)

~800 lbs. Light fraction (wrought)**

**Some "light" cast (356/360/413)

Bulk composition difference?

[2] Mesina, M.B., de Jong, T.P.R., and Dalmijn, W.L. 2007. Automatic soring of scrap metals with a combined electromagnetic and dual energy X-ray transmission sensor. *Int. J. Miner. Process.* 82:222-232.

Enabling Technologies: Optoelectronic Automated Systems

X-ray Transmission (XRT)

Cone & Quartering Sampling Method

Melting → Casting OES Pucks

CAST EJECTION	Ti	Cr	Mn	**Fe**	Ni	**Cu**	**Zn**	Zr	Cd	Sn	Pb	LE	Al	**Si**	Mg
	0.07	0.08	0.23	**0.80**	0.12	**3.32**	**1.82**	0.02	0.001	0.03	0.06	93.45	84.44	**8.80**	0.21

WROUGHT DROP w/ Mg impurity	Ti	V	Cr	Mn	**Fe**	Ni	**Cu**	**Zn**	Sn	Pb	LE	**Al**	**Si**	**Mg**
	0.03	0.01	0.04	0.28	**0.44**	0.02	**0.40**	**0.16**	0.01	0.01	98.59	**94.54**	**2.47**	**1.58**

Enabling Technologies: Optoelectronic Automated Systems

X-ray Transmission (XRT)

Cone & Quartering Sampling Method

Melting → Casting OES Pucks

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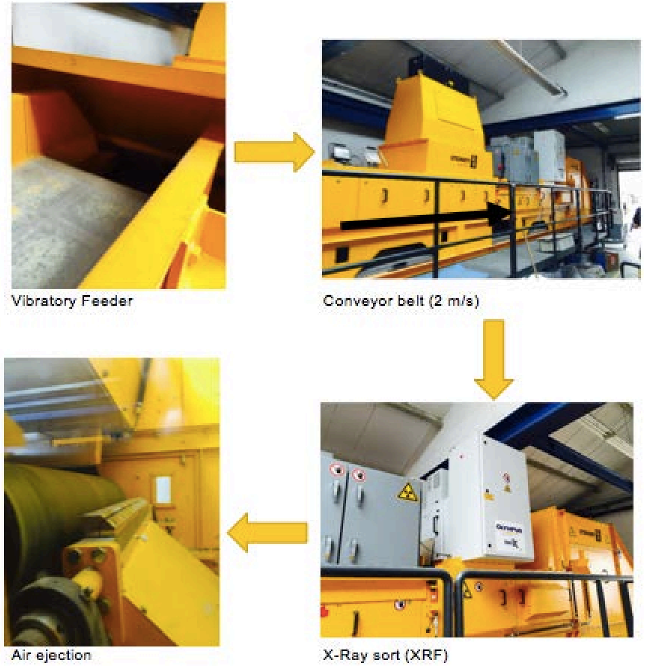
WROUGHT DROP w/o Mg Impurity	Ti	V	Cr	Mn	**Fe**	Ni	**Cu**	**Zn**	Sn	Pb	LE	**Al**	**Si**	**Mg**
	0.03	0.01	0.04	0.27	**0.46**	0.02	**0.45**	**0.18**	0.01	0.01	98.50	**94.76**	**2.65**	**1.10**

Enabling Technologies: Optoelectronic Automated Systems

X-ray Fluorescence (XRF)



STEINERT

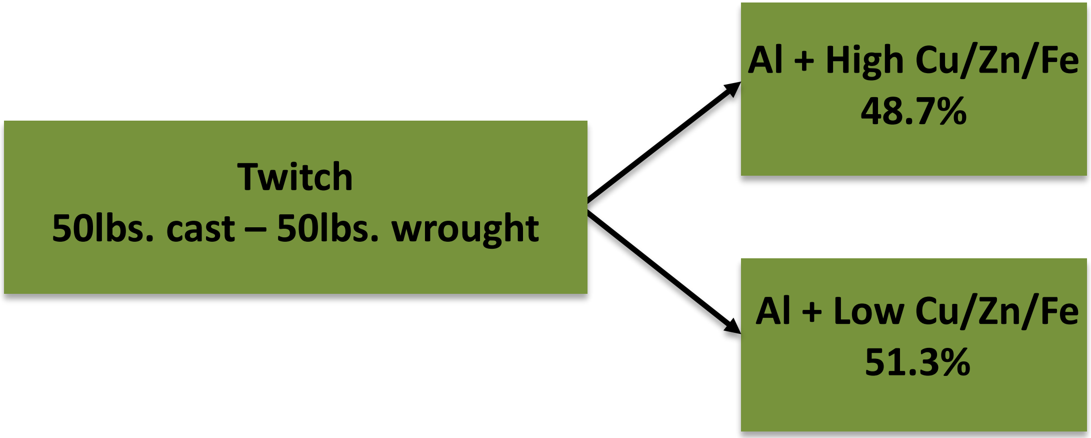
XSS F

XRF Technology:

- X-ray radiation ejects electron from inner shell of metallic element
- High-energy electron fills lower energy vacancy
- Elemental characteristic fluorescence is released due to this jump and is detected
- Compositional-based automated sorting system
- Pre-set sorting criteria based on heavy alloying elements (Cu/Zn/Fe)

Enabling Technologies: Optoelectronic Automated Systems

X-ray Fluorescence (XRF)

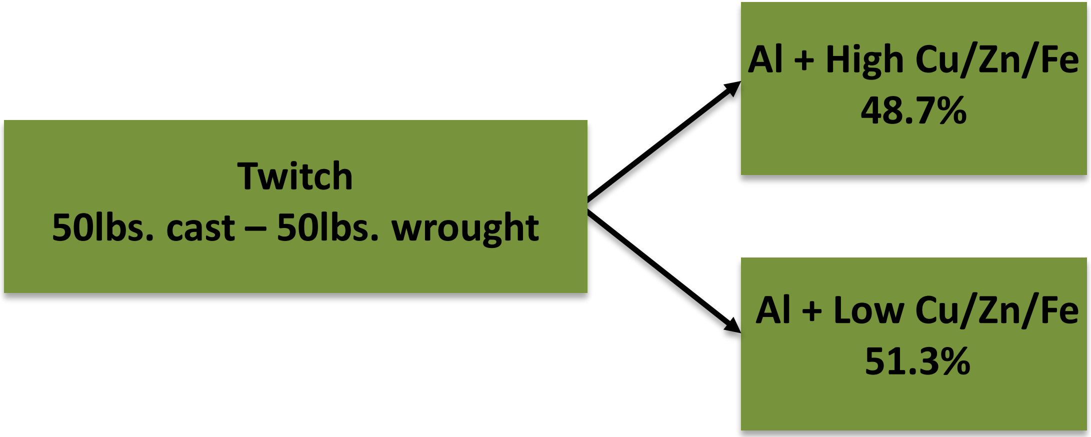


- If alloying concentration met the lowest possible threshold for any of the target elements that particulate was ejected
- Sampled each fraction, melted and casted OES pucks
- Clear distinction between sorting criteria elements (Zn/Cu/Fe)

Sorting Criteria	Wt. % Cast	Wt. % Wrought	OES Zn composition	OES Cu composition	OES Fe composition
Al + Cu/Zn/Fe	72%	28%	0.88%	1.7%	0.55%
Al + No Cu/Zn/Fe	26%	74%	0.027%	0.051%	0.30%

Enabling Technologies: Optoelectronic Automated Systems

X-ray Fluorescence (XRF)



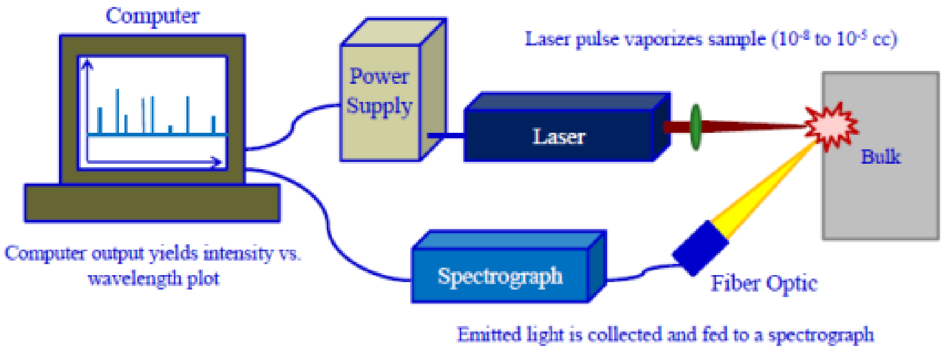
- If alloying concentration met the lowest possible threshold for any of the target elements that particulate was ejected
- Sampled each fraction, melted and casted OES pucks
- Clear distinction between sorting criteria elements (Zn/Cu/Fe)

Light elements?

Sample	Zn	Cu	Fe	**Si**	Mn	**Mg**	Cr	Ni	Ti	Pb	Sn	Other	**Al**
Al + High Cu/Zn/Fe	0.88	1.69	0.55	**7.2**	0.14	**0.29**	0.040	0.040	0.070	0.020	0.010	0.050	**89**
Al + Low Cu/Zn/Fe	0.030	0.050	0.30	**2.9**	0.19	**0.55**	0.030	0.040	0.060	--	--	0.030	**96**

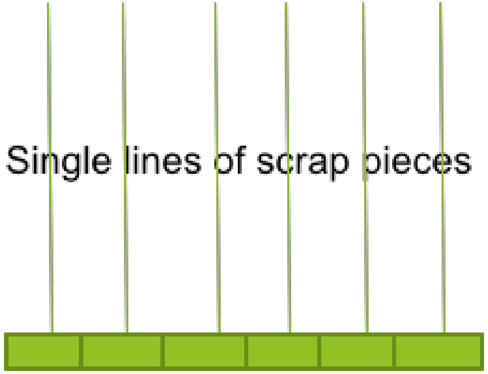
Enabling Technologies: Optoelectronic Automated Systems
Laser-induced Breakdown Spectroscopy (LIBS)

- Capable of analyzing complete aluminum alloy compositions in real-time (advantage over XRF)
- Throughput? – lower than XRF



From Shaymus Hudson

Feeding mechanism???

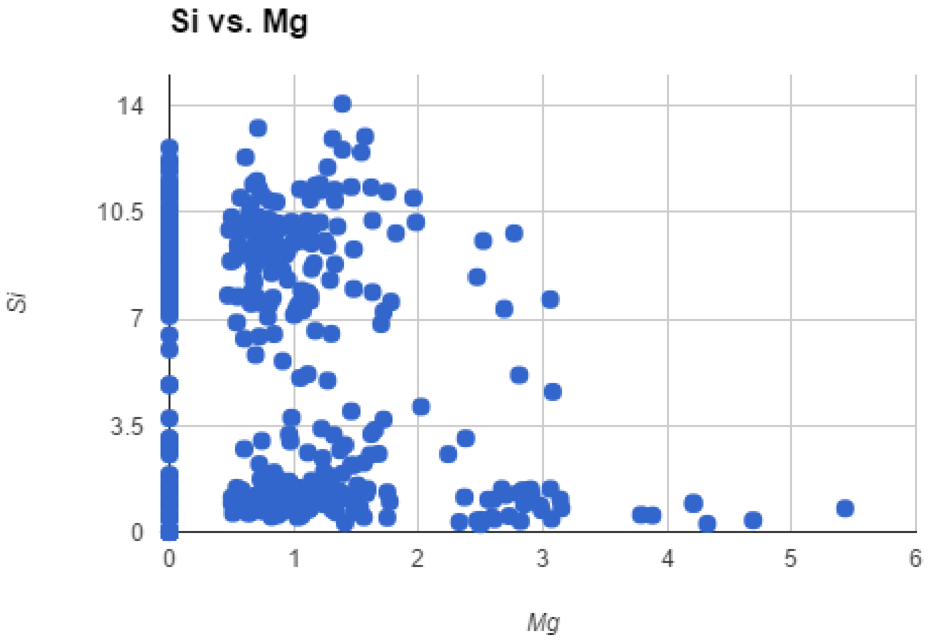


Single line? Multiple lines?
→ Effect on throughput

Enabling Technologies: Optoelectronic Automated Systems
Laser-induced Breakdown Spectroscopy (LIBS)

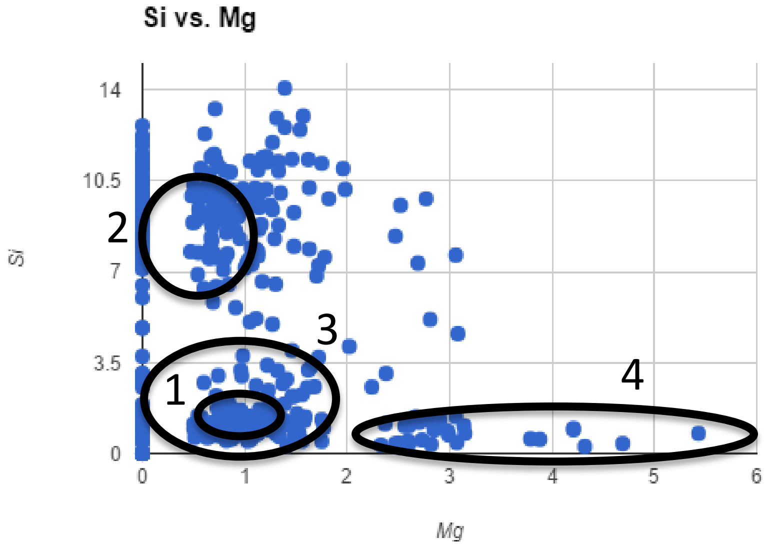
- ~30lbs of Twitch compositionally analyzed with XRF gun
- Si, Mg, Cu, Zn, Fe and Al content recorded
- 2D scatter plots constructed – Why?
    - To look for clusters and opportunity for **up-cycling**

Example:



Enabling Technologies: Optoelectronic Automated Systems

Laser-induced Breakdown Spectroscopy (LIBS)



Sort number	Target composition	Wt. % in Twitch used to attain target comp.	Si	Cu	Fe	Zn	Mg	Al
1	Mg: 0.8 – 1.2 Si: 0.4 – 0.8	5%	0.62	0.06	0.31	0.016	0.96	98

1) *Secondary 6061*

2) Secondary 319

3) *Secondary 6000 series*

4) *Secondary 5000 series*

Conclusions/Future Work

- XRT can upcycle fractions of Twitch based on density differences but further sorting or processing is required

- XRF can upcycle Twitch based on heavy alloying content but further dilution or alloying addition will be required

- Early 2D scatter plots show promise for LIBS system
  - Expansion to 5-6 preset elemental criteria
  - Efficiency testing