Challenges and Opportunities of Lithium-Ion Battery Recycling

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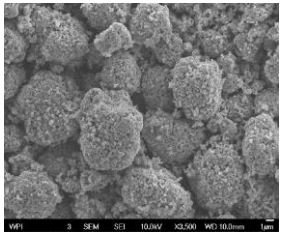
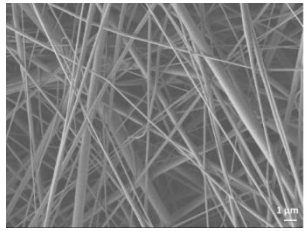
My Research at WPI

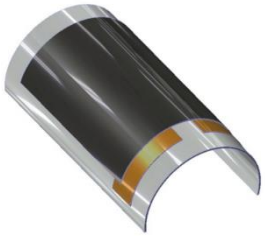
Materials and Structures

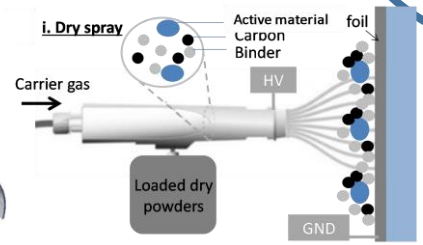




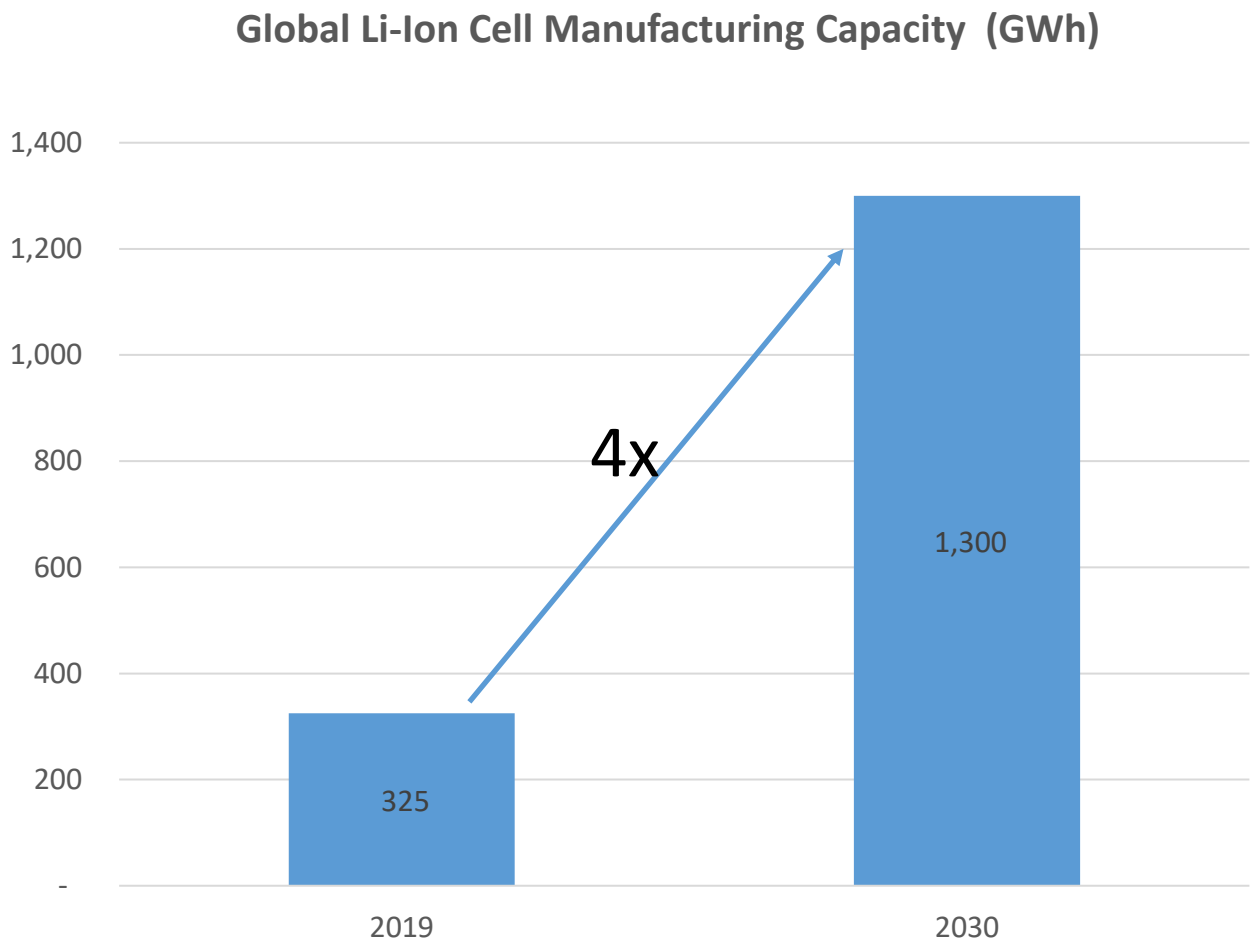
Design and Recycle

Manufacturing



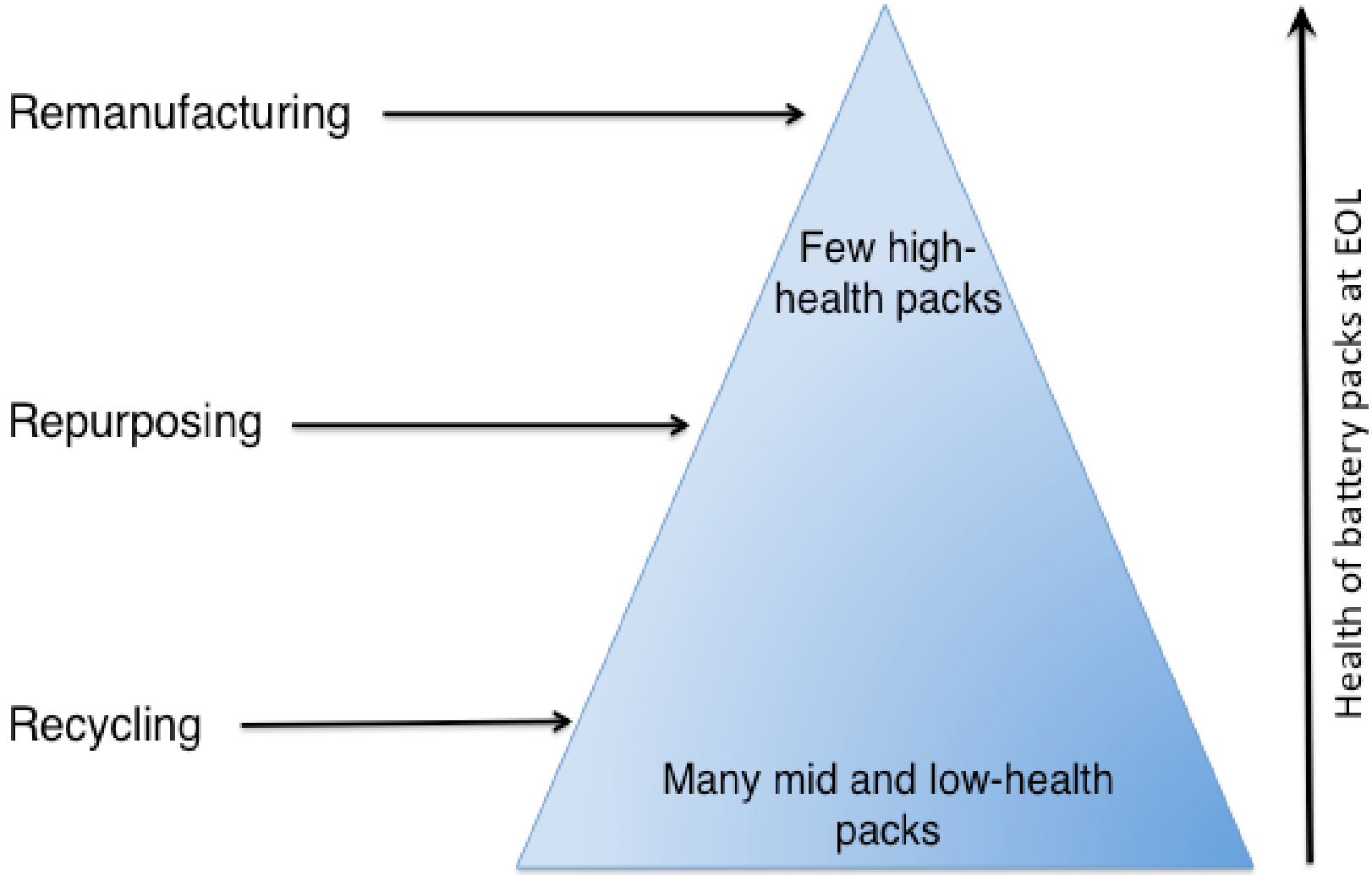


Global Li-ion Battery Capacity



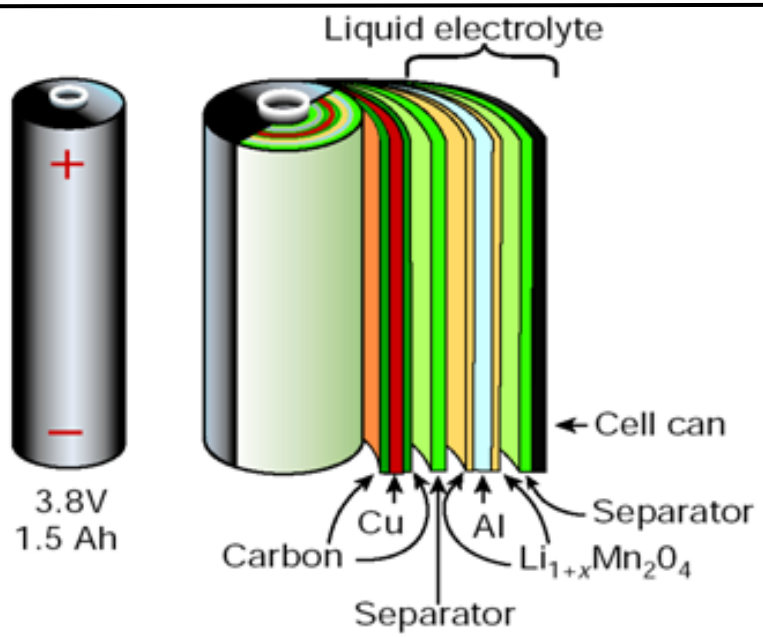
Reference: *Wood Mackenzie 2020, based on 119 facilities operational, under construction or announced by >50 vendors*

Options of End of Life EV/HEV Batteries

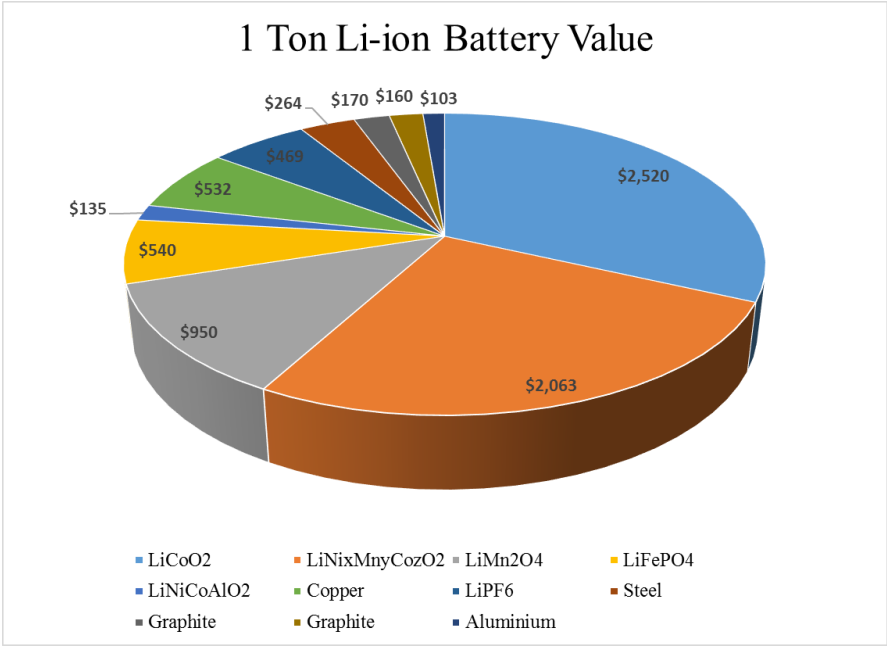


DeRousseau, M., Gully, B., Taylor, C. et al. JOM (2017) 69: 1575. https://doi.org/10.1007/s11837-017-2368-9

Material Value of Li-Ion Batteries



Battery component	Wt%
Casing	25
Cathode material	25
Anode material	14
Electrolyte	10
Copper foil	8
Aluminium foil	5
Separator	4
Other	6

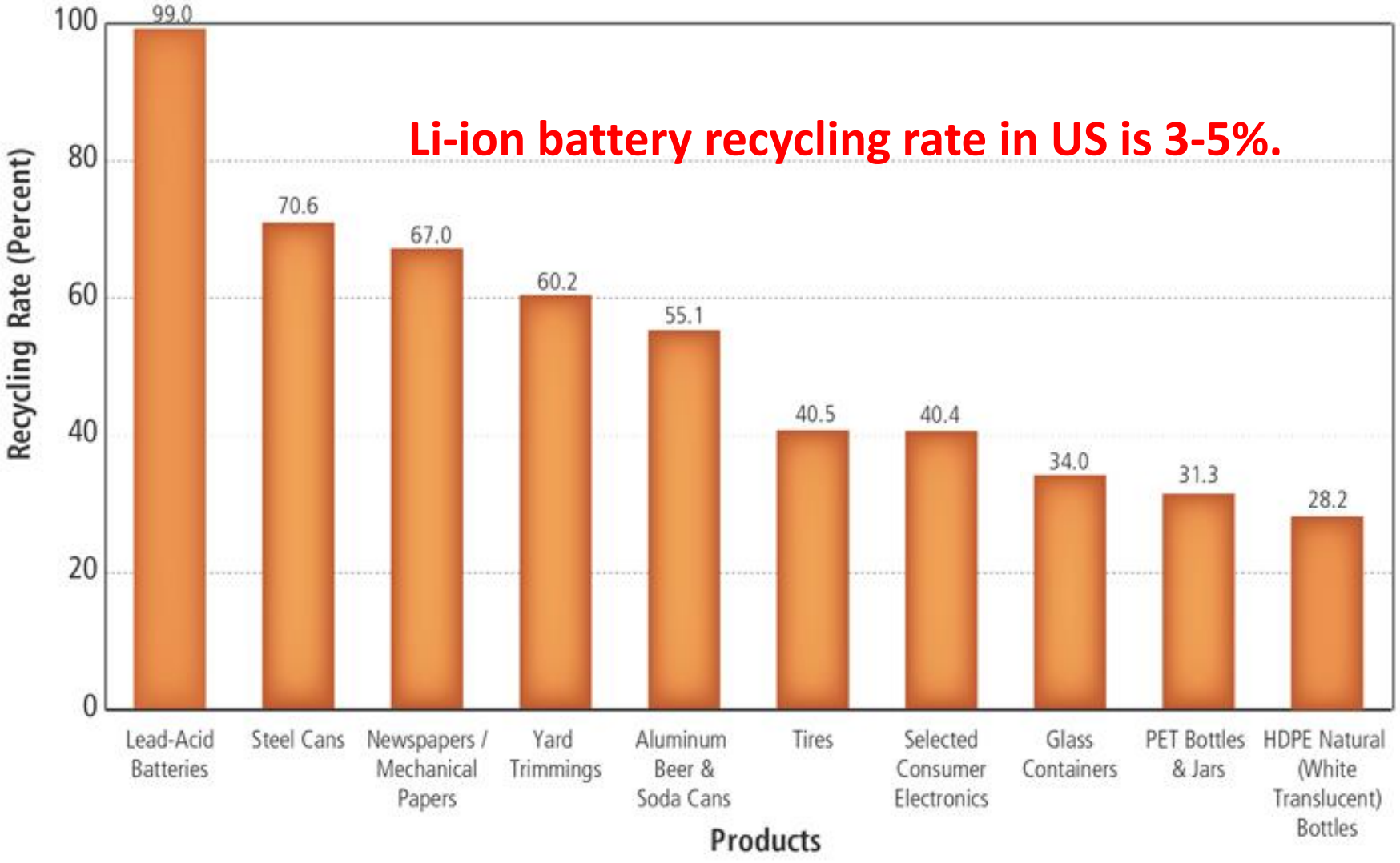


~$7,900/ton, ~70% is cathode material

Georgi-Maschler, T., et al., Journal of Power Sources, 2012. 207, 173-182, (2012).

J.-M. Tarascon, Nature 414, 359 - 367 (2001)

Recycling Rate in US (2010)



Source: EPA

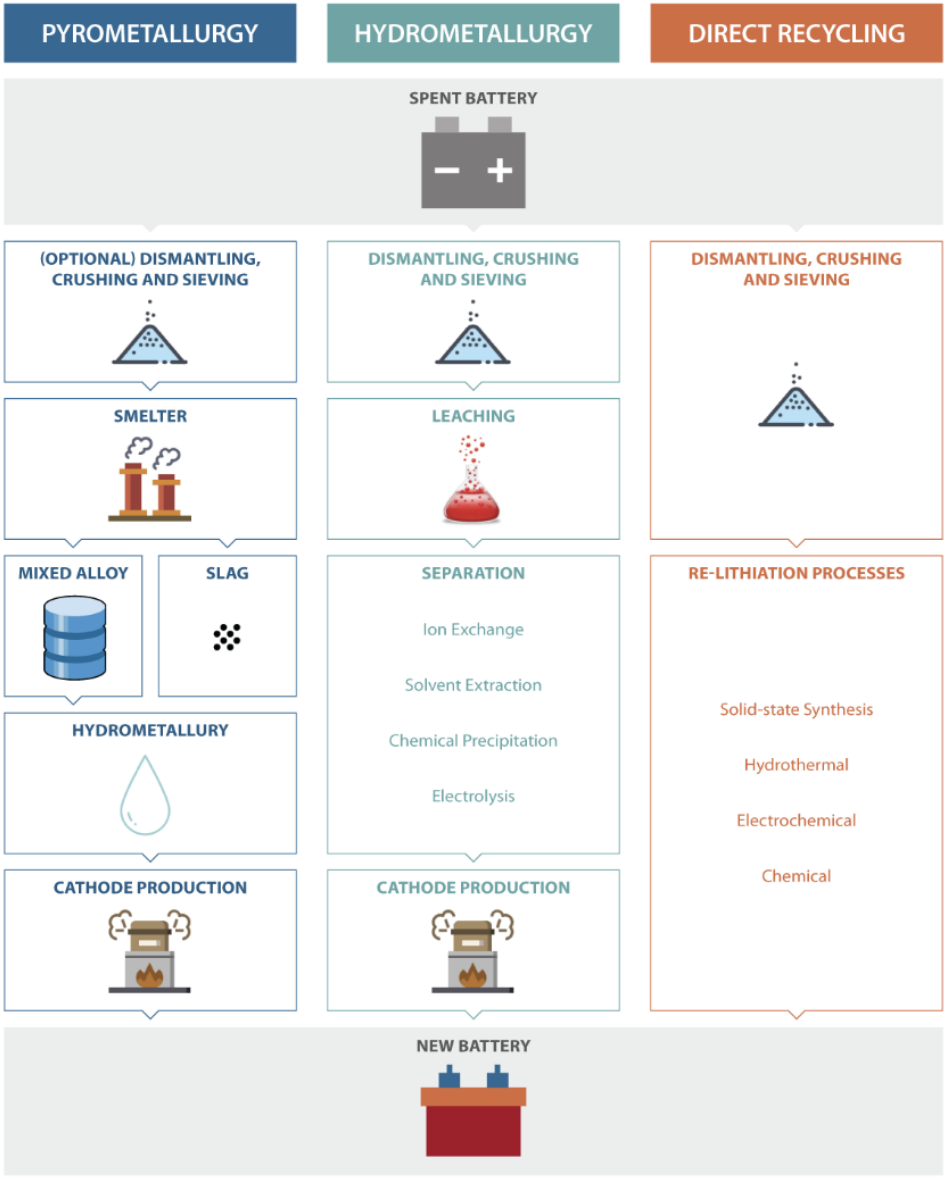
Comparison between Lead-Acid and Li-Ion

	Lead-Acid	Li-Ion
Cathode	PbO_2	$LiMO_2$ or $LiFePO_4$
Cathode foil/plate	Pb	Al
Anode	Pb	Graphite
Anode foil/plate	Pb	Cu
Electrolyte	H_2SO_4	$LiPF_6$ + Org. Solvent
Separator	PE or PVC w/Silica	PE/PP
Cell Case	PP	Metal or laminate

Lead-Acid compared to Li-Ion

- Low number of distinct materials (Pb is 60% of battery mass)
- Design and material composition rarely varies by manufacturer
- Active materials composition does not change over time

Current Li-Ion Battery Recycling Processes



Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N. and Wang, Y., 2019. Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries. Joule.

Current Li-Ion Battery Recycling Processes

	Pyrometallurgical	**Hydrometallurgical**	**Mechanical**
Temperature	high	low	low
Materials recovered	Co, Ni	metal salts, Li_2CO_3 or LiOH	cathode, anode, electrolyte, metals
Battery sorting	not required	required	required

Can we develop a technology with low temperature, no sorting and recovering high valuable materials?

Opportunity and Challenges of Li Ion Battery Recycling

- Opportunity
  - The market of Li ion batteries is kept increasing
  - There is high material value (especially cathode materials)
  - Spent EV batteries start to be recycled

- Challenges
  - Many different materials are used in Li ion batteries
  - Li ion batteries are very dynamic (different size, shape and chemistry)
  - Battery grade materials have very high requirements
  - Collection and transportation can be difficult
  - No nationwide regulation yet

Our Closed-Loop Recycling Process

- Zheng, Zhangfeng, et al. "High Performance Cathode Recovery from Different Electric Vehicle Recycling Streams." ACS Sustainable Chemistry & Engineering 6.11 (2018): 13977-13982.
- Heelan, J., et al., Current and prospective Li-ion battery recycling and recovery processes. Jom, 2016. 68(10): p. 2632-2638.
- Sa, Q., et al., *Synthesis of Diverse LiNi x Mn y Co z O2 Cathode Materials from Lithium Ion Battery Recovery Stream.* Journal of Sustainable Metallurgy, 2016. **2**(3): p. 248-256.
- Sa, Q., et al., *Synthesis of high performance LiNi 1/3 Mn 1/3 Co 1/3 O 2 from lithium ion battery recovery stream.* Journal of Power Sources, 2015. **282**: p. 140-145.
- Gratz, E., et al., *A closed loop process for recycling spent lithium ion batteries.* Journal of Power Sources, 2014. **262**: p. 255-262.
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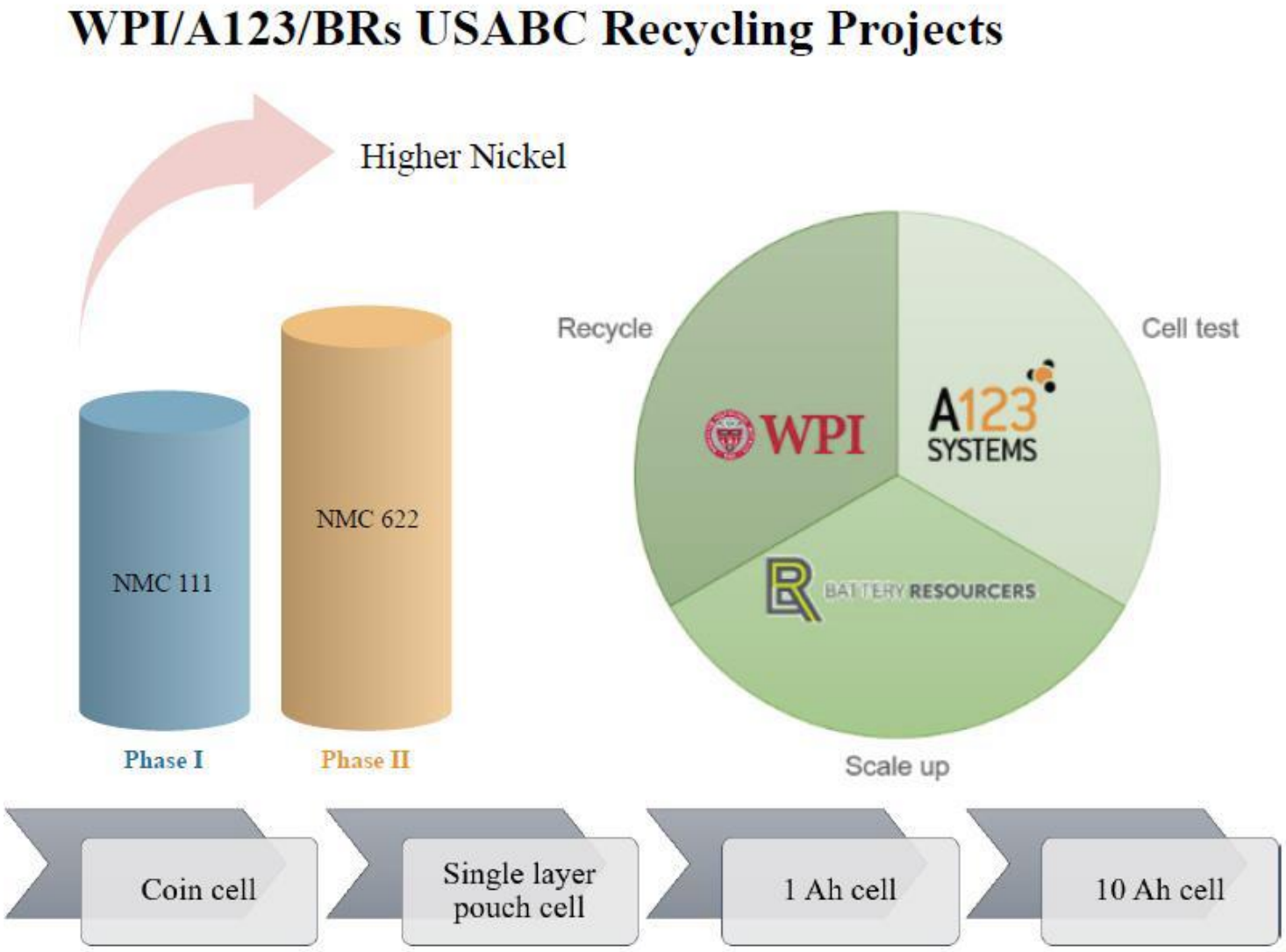
- Y. Wang, et. al., Patent Pending, 2016
- Y. Wang, et. al., Patent issued, 2014
- Y. Wang, et. al., Patent Issued, 2012

United States Advanced Battery Consortium Project

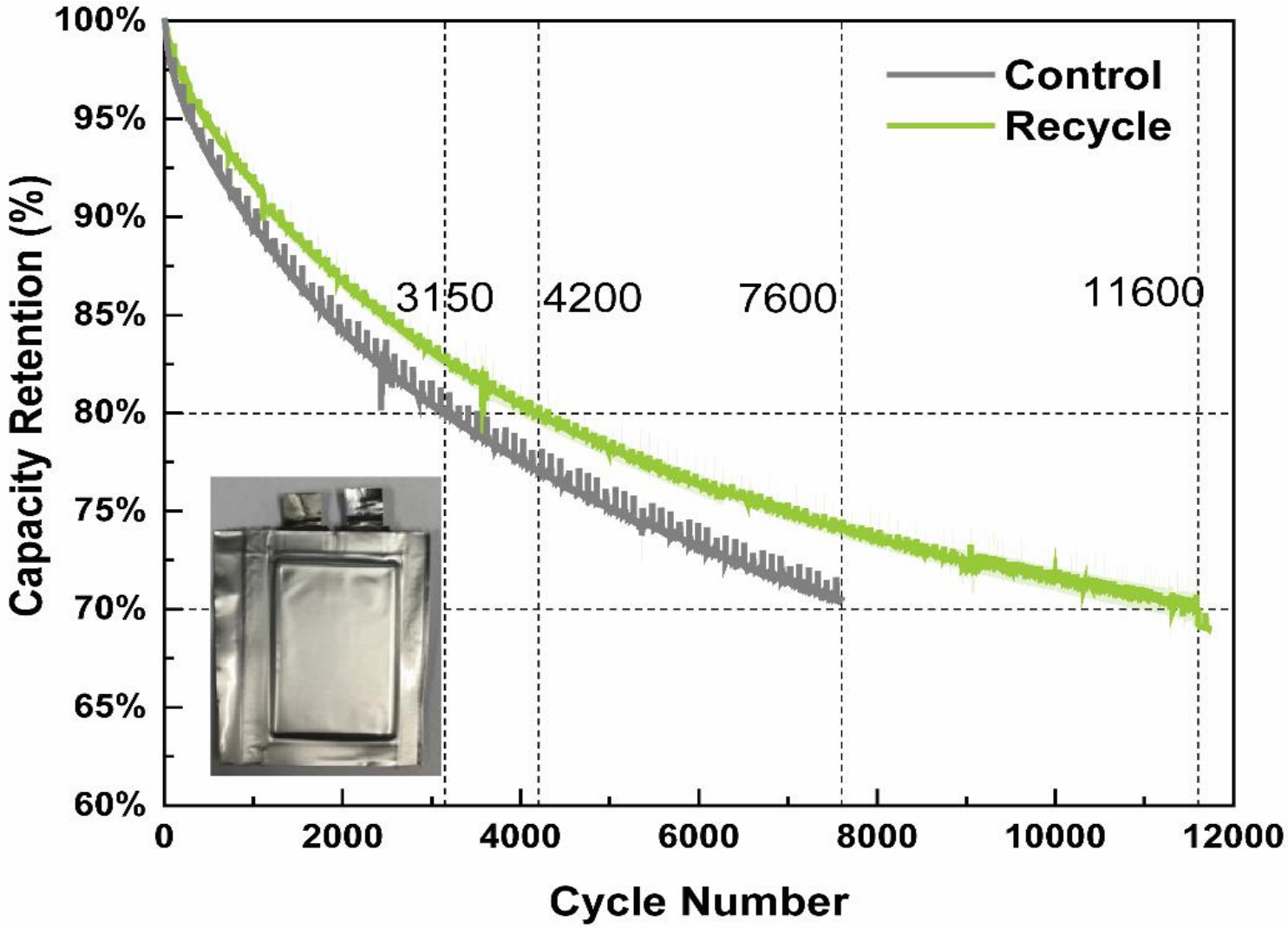


A123 Testing Results-Coin Cells

Test	Metric	Control Powder (A)	03272017 3Kg Powder	04212017 3Kg Powder	05152017 3Kg Powder	06202017 3Kg Powder
Tap Density	g/cc	2.28	2.15	2.31	2.36	2.51
FCC/ FDC	mAh/g	164.6/ 145.9	177.3/ 163.5	178.1/ 152.3	170.1/ 149.2	177.3/ 157.0
Efficiency	%	88.6	92.2	85.5	87.7	88.6
1C	mAh/g	132.9	136.3	123.1	137.4	129.2
2C	mAh/g	122.3	128.6	113.0	128.4	120.8
5C	mAh/g	36.7	59.5	75.4	76.2	76.2
Full coating		Complete	Complete	Complete	Complete	Complete

Coin cell → SLP cell → 1Ah cell → 10Ah cell

A123 Testing Results-1Ah Cycle Life



Battery Resourcers Inc

Lithium-Ion Battery Recycling and Manufacturing Startup Raises $20 Million From Global Industry Leaders

BATTERY RESOURCERS

Orbia, TDK, TRUMPF, Doral Energy and Jaguar Land Rover are betting on innovative technology from Battery Resourcers

NEWS PROVIDED BY
Battery Resourcers →
Apr 12, 2021, 07:02 ET

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WORCESTER, Mass., April 12, 2021 /PRNewswire/ -- Battery Resourcers, a vertically integrated lithium-ion battery recycling and manufacturing company, recently completed a $20 million Series B equity round with financing led by Orbia Ventures, the venture capital arm of the multinational Orbia, and participation from other investors including At One Ventures, TDK Ventures, TRUMPF Venture, Doral Energy-Tech Ventures andJaguar Land Rover's InMotion Ventures.

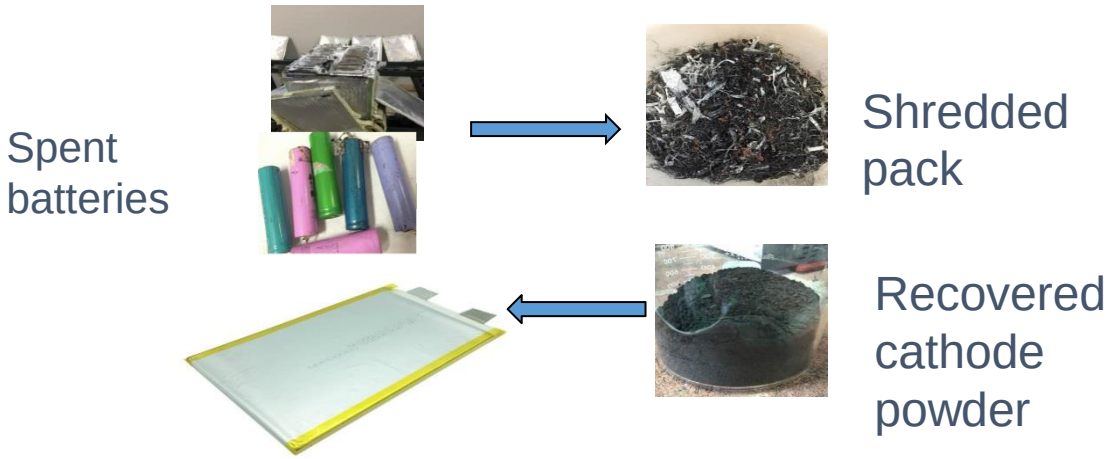
Battery Resourcers CEO Mike O'Kronley at the company's Novi, Mich. facility on April 9, 2021. On April 12, 2021, Battery Resourcers announced completion of a $20 million Series B equity round with financing led by Orbia Ventures and participation from international investors including At One Ventures, TDK Ventures, TRUMPF Venture, Doral Energy-Tech Ventures and Jaguar Land Rover's InMotion Ventures.

- Recently closed $20M Series B
- Occupy three facilities in north Worcester, Westborough MA and Novi MI
- Will be able to process 10,000 ton of spent Li ion batteries

Summary

- Challenges and opportunities of Li-ion battery recycling are summarized

- Can recycle Li-ion batteries regardless of chemistry, size or shape



- Our recovered cathode materials have better performance compared to commercial powder

Acknowledgements

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- My Team: Zhangfeng Zheng, Mengyuan Chen, Xiaotu Ma, Yadong Zheng, Bin Chen

Questions?

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