Electrochemical Energy Storage (Batteries) Overview

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Brookhaven Interdisciplinary Science Department: Resilient Energy Focus

Energy Efficiency

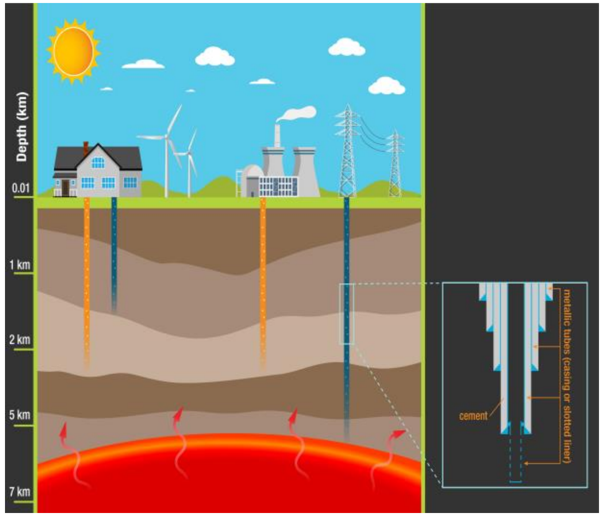
- Building efficiency
- Alternative fuels including biofuels and hydrogen
- Emissions measurement and analysis
- Geothermal materials

Grid Modernization

- Data analytics and machine learning applications
- Probabilistic risk assessment
- Grid modeling and simulation
- Grid system assessment and design

Energy Storage

- *In-situ* and *operando* studies
- Batteries for electric vehicles
- Batteries for grid scale storage
- Center for Mesoscale Transport Properties EFRC



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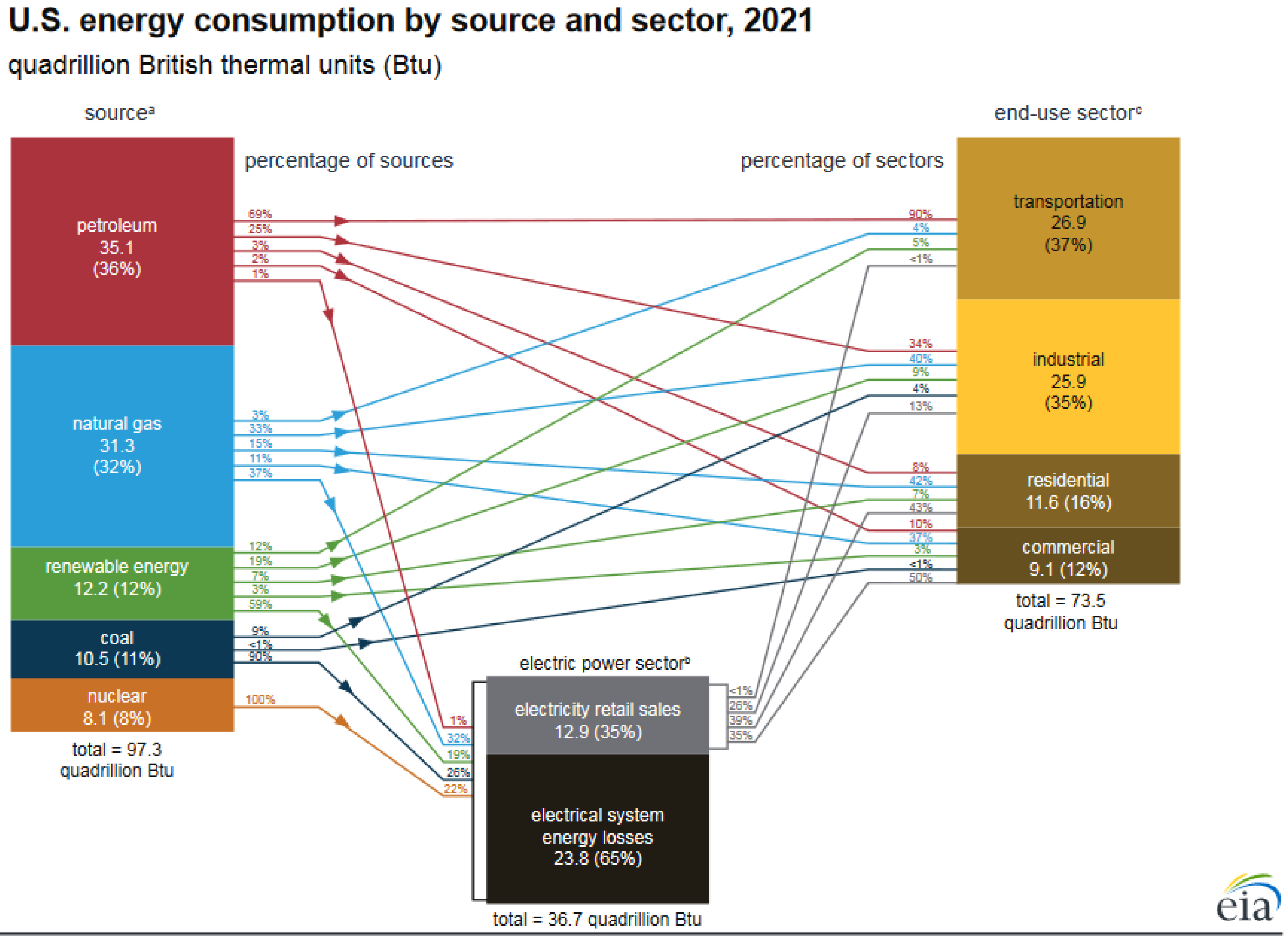
US Energy Consumption



Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (April 2022), Tables 1.3 and 2.1-2.6.

Note: Sum of components may not equal total due to independent rounding. All source and end-use sector consumption data include other energy losses from energy use, transformation, and distribution not separately identified. See "Extended Chart Notes" on next page.

[a] Primary energy consumption. Each energy source is measured in different physical units and converted to common British thermal units (Btu). See EIA's *Monthly Energy Review* (MER), Appendix A. Noncombustible renewable energy sources are converted to Btu using the "Fossil Fuel Equivalency Approach", see MER Appendix E.

[b] The electric power sector includes electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Energy consumed by these plants reflects the approximate heat rates for electricity in MER Appendix A. The total includes the heat content of are electricity net imports, not shown separately. Electrical system energy losses calculated as the primary energy consumed by the electric power sector minus the heat content of electricity retail sales. See Note 1, "Electrical System Energy Losses," at the end of MER Section 2.

[c] End-use sector consumption of primary energy and electricity retail sales, excluding electrical system energy losses from electricity retail sales. Industrial and commercial sectors consumption includes primary energy consumption by CHP and electricity-only plants contained within the sector.

In 2021, the US consumed 97.3 Quads of energy.

Transportation accounted for ~40% of electricity consumption.

The grid lost ~65% of the energy it generated.

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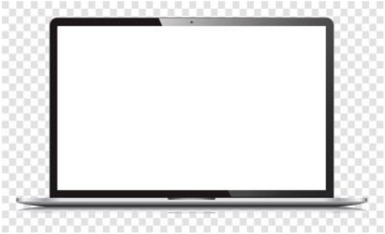
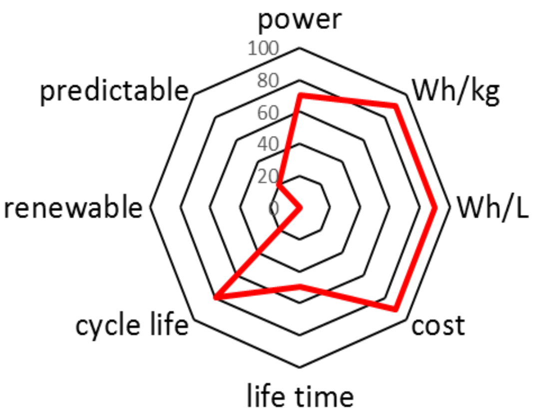
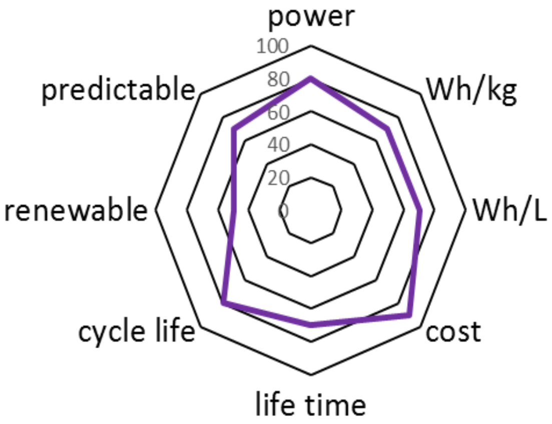
Energy Storage Must Meet Application Need

Consumer Electronics

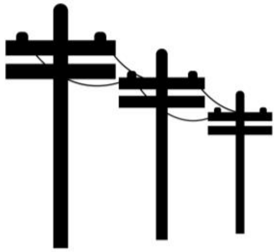


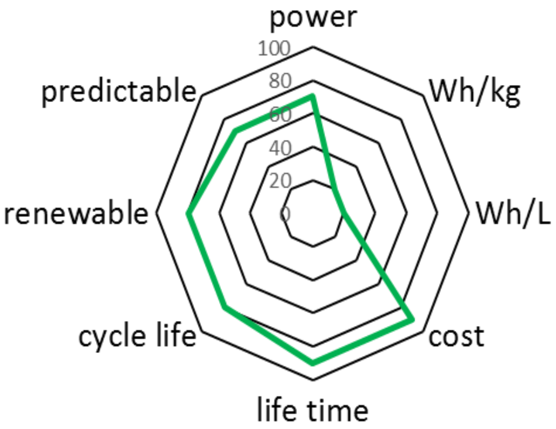


Electric Vehicles



Grid-Level Storage





Application specific technology begins with understanding of the science and the requirements

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E. S. Takeuchi, Ashton Cary Lecture, "From Medical Applications to the Environment: The Important Role of Energy Storage", Georgia Institute of Technology, Atlanta GA, March 4, 2020.

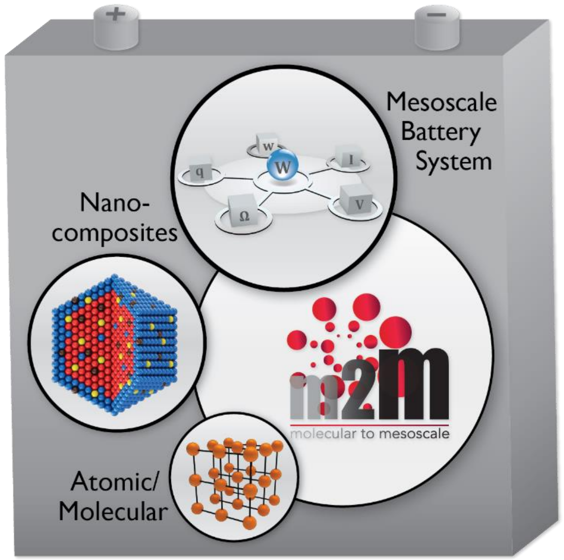
Stony Brook University

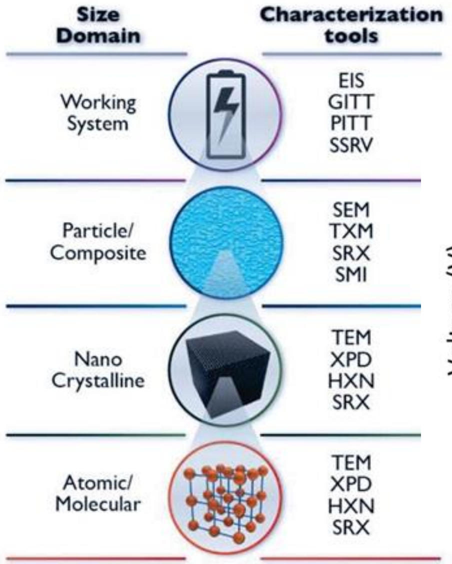
Center for Mesoscale Transport Properties (*m2m, m2m/t, m2m#s*)

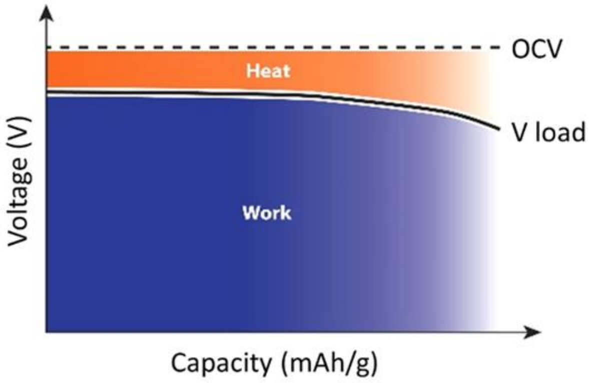
http://stonybrook.edu/m2m

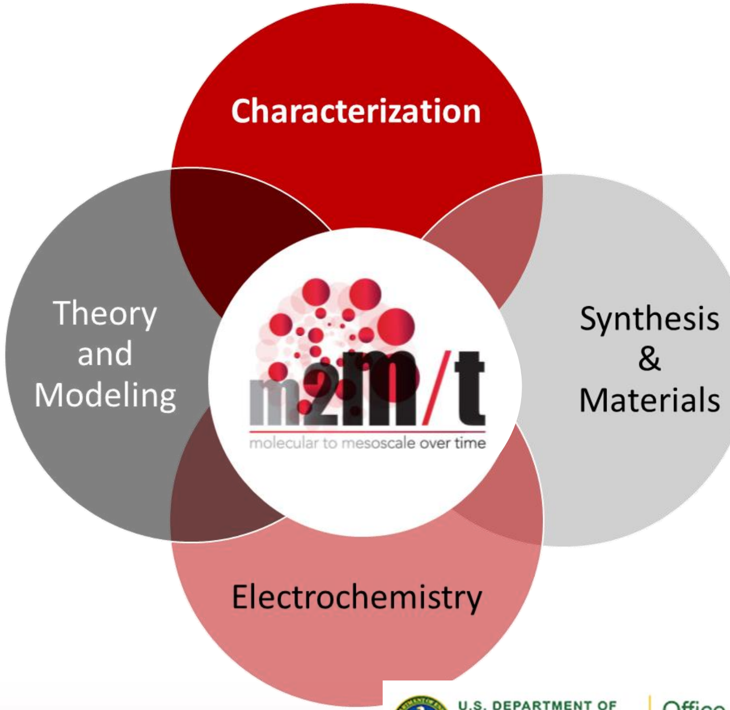
Mission: To understand and ultimately control transport properties in complex battery systems with respect to multiple length scales

Mission: To build the scientific knowledge to enable creation of ***scalable*** energy storage systems with high energy, power, and long life









A. Abraham, L. Housel, C. Lininger, D. Bock, J. Jou, F. Wang, A. West, A. Marschilok, K. Takeuchi, E. Takeuchi, *ACS Cent. Sci.*, **2016,** 2 (6), 380–387.

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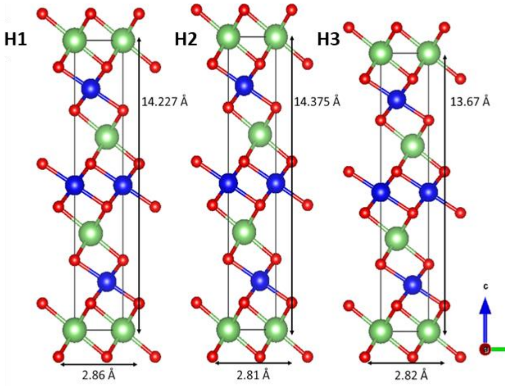
Drexel University
Xavier University of Louisiana
Oak Ridge National Laboratory
Berkeley Lab

Characterizing Battery Lifetime and Mechanism *Operando*

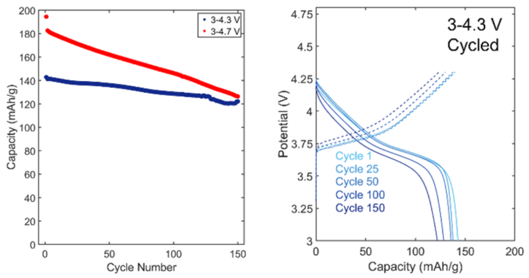
Battery degradation mechanisms were elucidated using *operando* synchrotron based X-ray characterization, scanning probe methods, and microcalorimetry



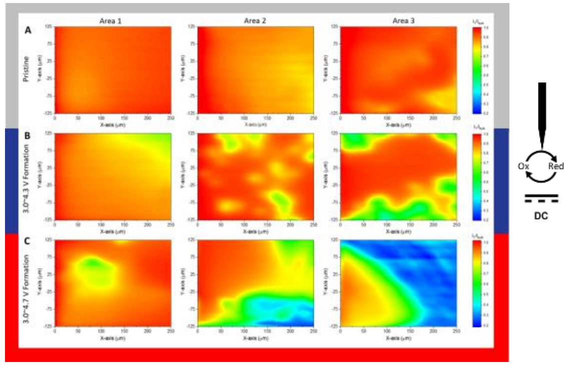
Lithium nickel manganese cobalt oxide (NMC), $LiNi_xMn_yCo_zO_2$

National Synchrotron Light Source II (NSLS-II) at BNL

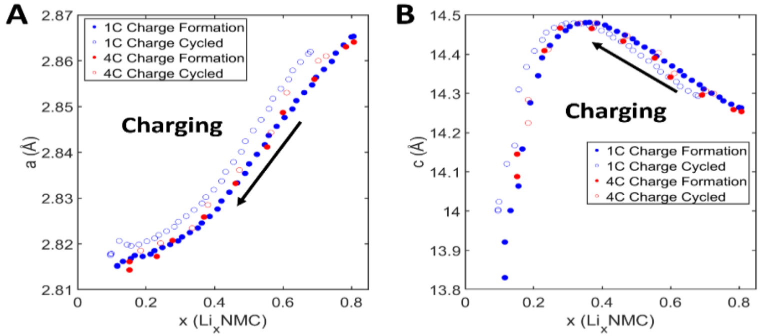
electrochemistry

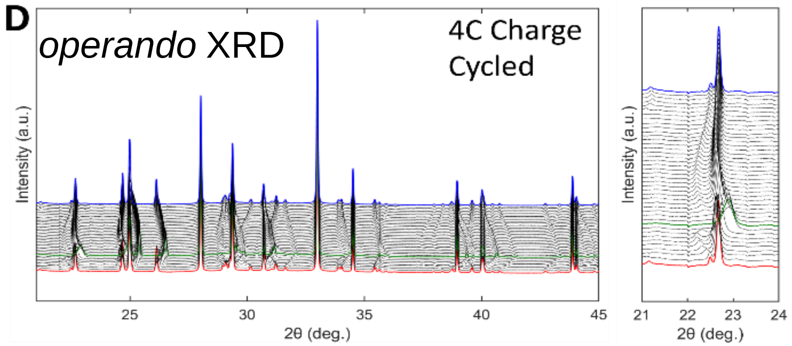


scanning probe analysis



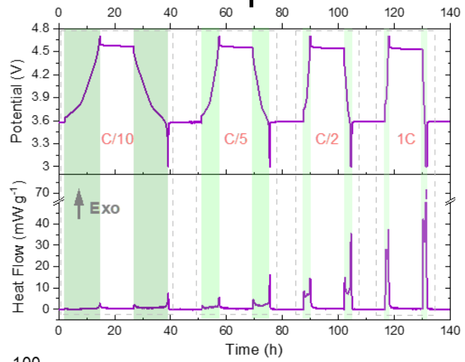
tracking structural change during fast charge

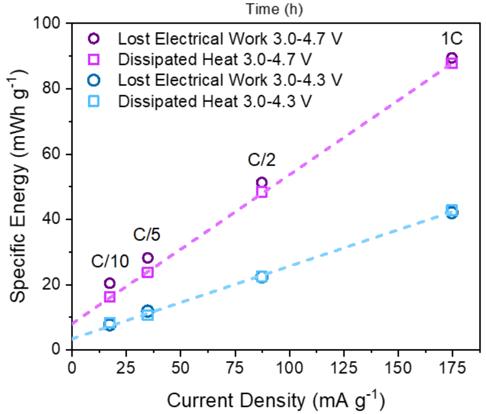




quantifying heat vs work

$\Delta E = q + w$





W. Li, L.M. Housel, G.P. Wheeler, D.C. Bock, K.J. Takeuchi, E.S. Takeuchi, A.C. Marschilok, *ACS Appl. Energy Mater.*, **2021,** *4(11),* 12067-12073.

C.D. Quilty, G.P. Wheeler, L. Wang, A.H. McCarthy, S. Yan, K.R. Tallman, M.R. Dunkin, X. Tong, S. Ehrlich, L. Ma, K.J. Takeuchi, E.S. Takeuchi, D.C. Bock, A.C. Marschilok, *ACS Appl. Mater. Interfac.* **2021,** *13(43),* 50920–50935.

C.D. Quilty, P.J. West, G.P. Wheeler, L.M. Housel, C.J. Kern, K.R. Tallman, L. Ma, S. Ehrlich, C. Jaye, D.A. Fischer, K.J. Takeuchi, D.C. Bock, A.C. Marschilok, E.S. Takeuchi, *J. Electrochem. Soc.*, **2022,** *169,* 020545.

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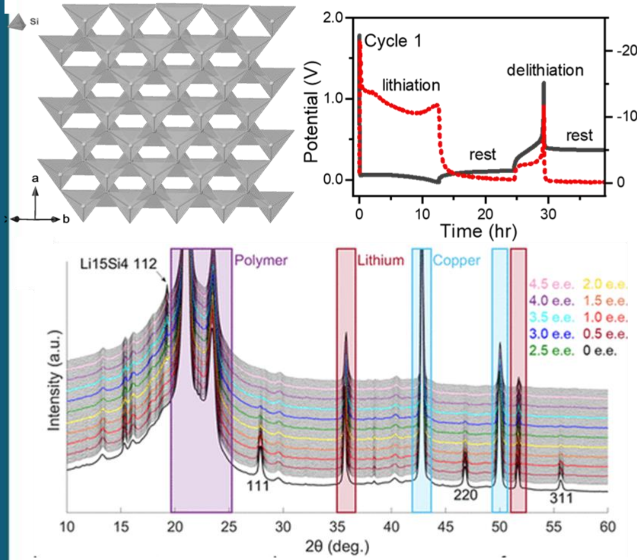
Programs on New Lithium Ion Technologies

Energy Density

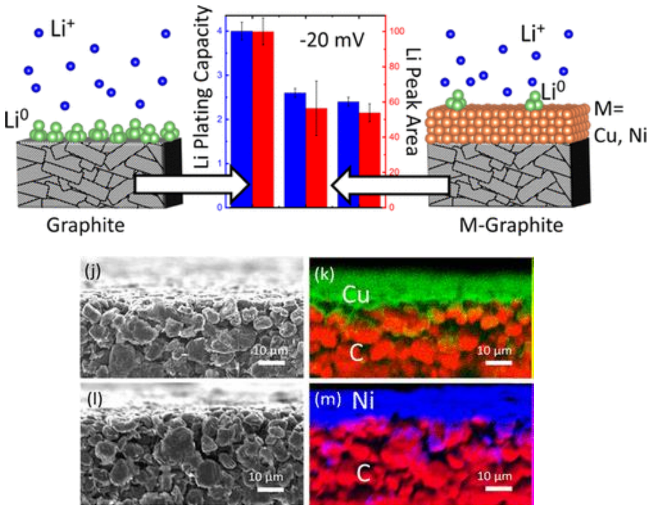
Conversion/Alloying



L.M. Housel, W. Li, C.D. Quilty, M.N. Vila, L. Wang, C.R. Tang, D.C. Bock, Q. Wu, X. Tong, A.R. Head, K.J. Takeuchi, A.C. Marschilok, E.S. Takeuchi, *Appl. Mater. Inter.* 2019, *11* (41), 37567-37577.

Fast Charge

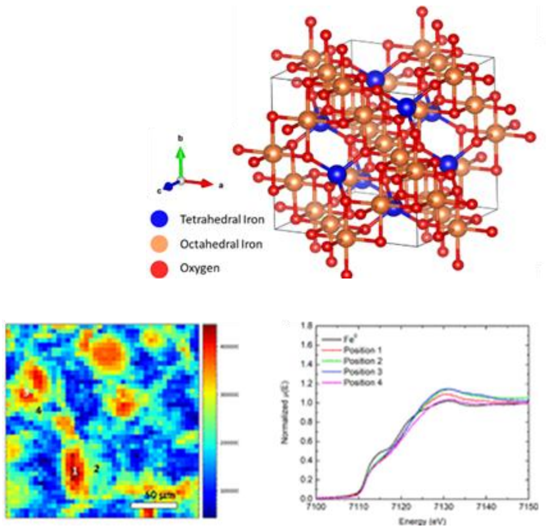
Surface Modifications



K.R. Tallman, B. Zhang, L. Wang, S. Yan, K. Thompson, X. Tong, J. Thieme, A. Kiss, A.C. Marschilok, K.J. Takeuchi, D.C. Bock, E.S. Takeuchi, *ACS Appl. Mater. Inter.* **2019,** *11* (50), 46864-74.

Cost Effective

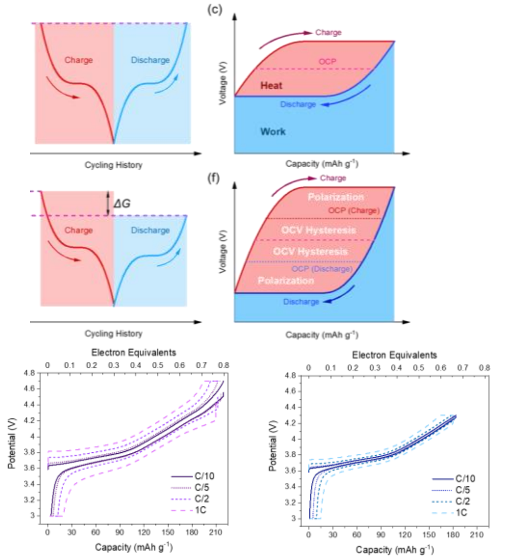
Earth Abundant Materials



M.M. Huie, D.C. Bock, A.M. Bruck, K.R. Tallman, L.M. Housel, L. Wang, J. Thieme, K.J. Takeuchi, E.S. Takeuchi, A.C. Marschilok, *ACS Appl. Mater. Inter.* **2019,** *11* (7), 7074-7086.

Lifetime

Increasing Usable Life



Li, W.; Housel, L. M.; Wheeler, G. P.; Bock, D. C.; Takeuchi, K. J.; Takeuchi, E. S.; Marschilok, A. C., *ACS Applied Energy Materials* **2021**. *4(11)*, 12067–73.

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Mercedes-Benz Research and Development North America
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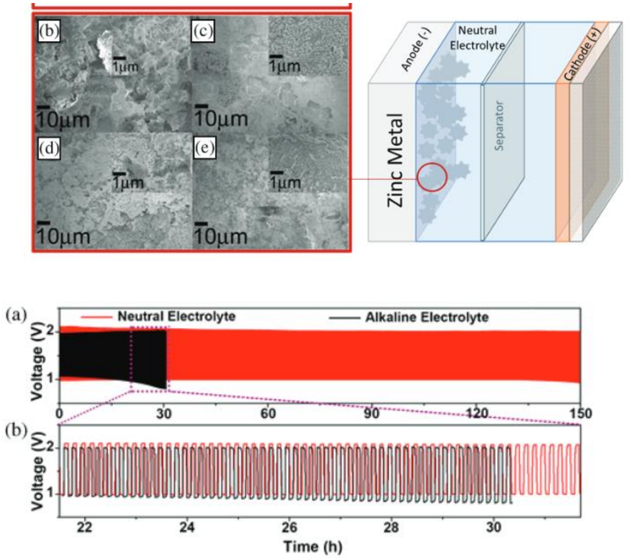
Programs on New Water Based Battery Alternatives

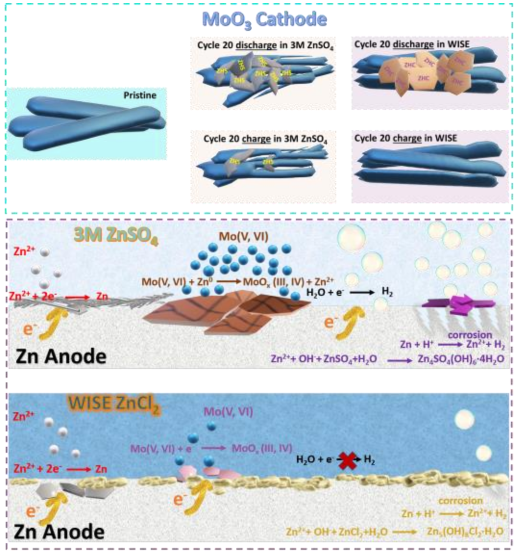
Aqueous Electrolyte, Scalable, Low Cost, Environmentally Friendly

Zn Air Battery



Kuang, J.; Renderos, G. D.; Takeuchi, K. J.; Takeuchi, E. S.; Marschilok, A. C.; Wang, L. Zinc–air batteries in neutral/near-neutral electrolytes. Functional Materials Letters 2021, 14, 2130012.

Zn/MoO_3 Battery



Wang, L., Yan, S., Quilty, C. D., Kuang, J., Dunkin, M. R., Ehrlich, S. N., Ma, L., Takeuchi, K. J., Takeuchi, E. S., Marschilok, A. C., *Adv. Mater. Interfaces* 2021, 2002080, back cover.

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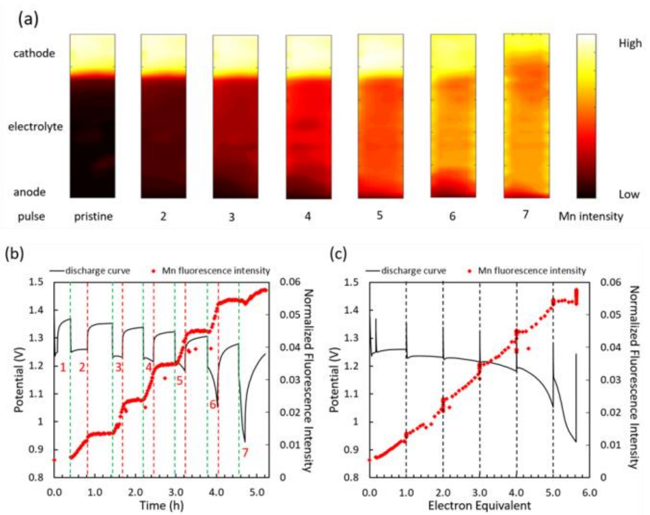
Zn/MnO_2 Battery



D. Wu, L.M. Housel, S-J. Kim, N. Sadique, C.D. Quilty, L. Wu, R. Tappero, S.L. Nicholas, S. Ehrlich, Y. Zhu, A.C. Marschilok, E.S. Takeuchi, D.C. Bock, K.J. Takeuchi, Energy & Environmental Science (2020). DOI: 10.1039/d0ee02168g.

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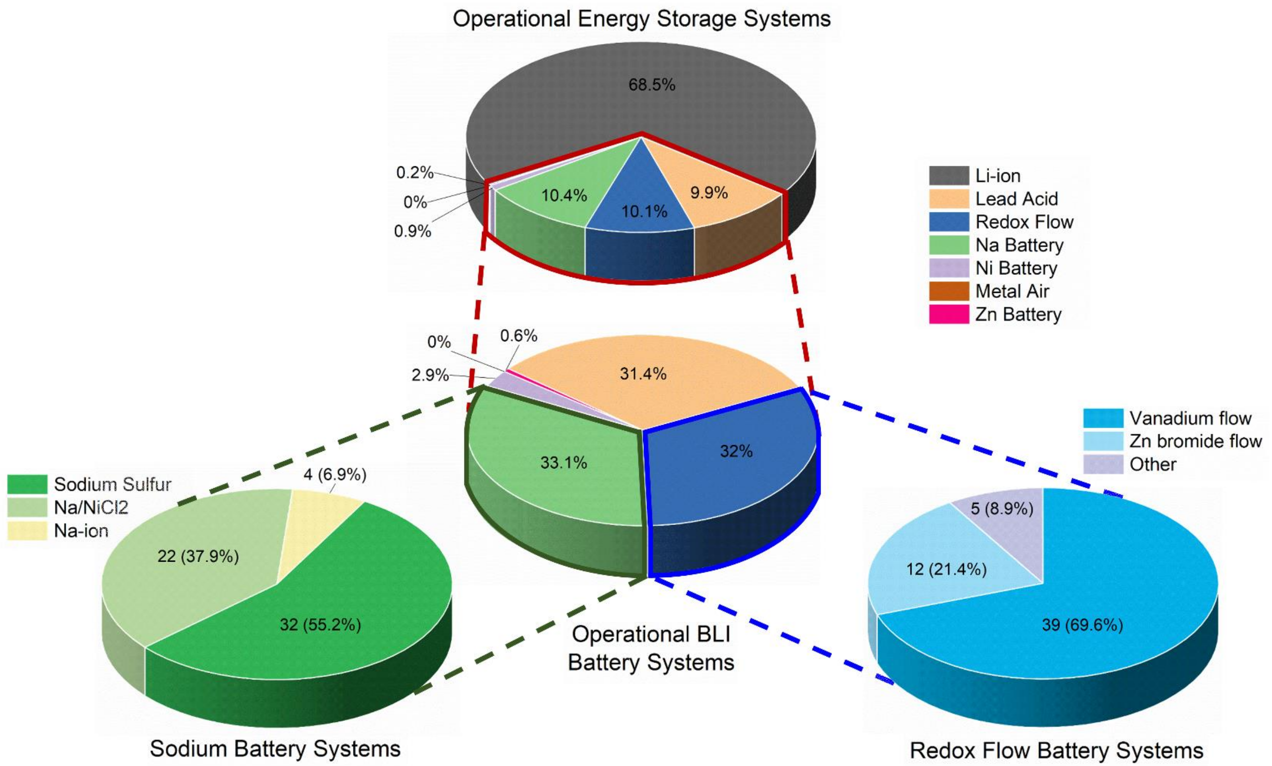
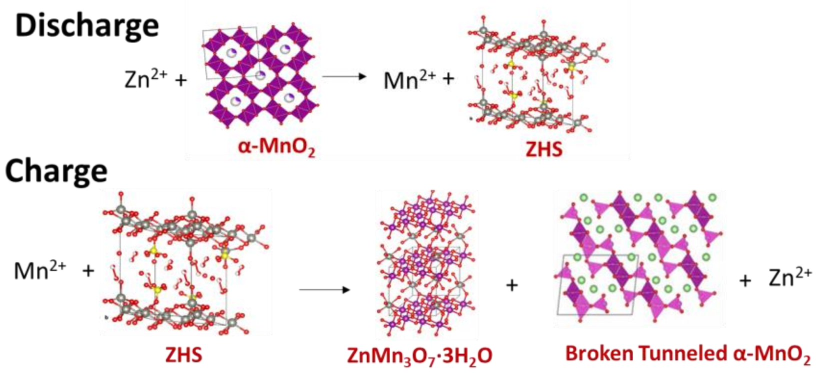
Grid Scale Batteries

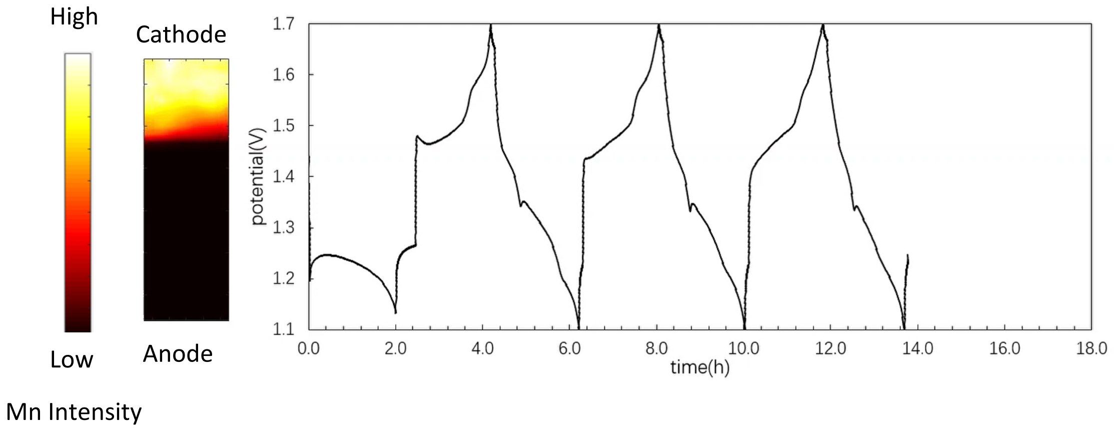
Due to lifetime, safety, and raw material sourcing concerns, alternative technologies to lithium ion battereis are desired for large scale (grid level) energy storage

Investigating new materials and chemistries for next-gen safe, sustainable batteries



Zn/MnO$_2$ Battery





“Beyond Li-Ion Batteries for Grid-Scale Energy Storage,” G.P. Wheeler, L. Wang, A.C. Marschilok, in *Elements in Grid Energy Storage,* Ed. B. Chalamala, V. Sprenkle, I. Gyuk, R. Masiello, R. Byrne, V. Gupta. *Cambridge University Press,* ***2022.***

D. Wu, L.M. Housel, S-J. Kim, N. Sadique, C.D. Quilty, L. Wu, R. Tappero, S.L. Nicholas, S. Ehrlich, Y. Zhu, A.C. Marschilok, E.S. Takeuchi, D.C. Bock, K.J. Takeuchi, *Ener. Environ. Sci.,* **2020,** *13,* 4322-4333.

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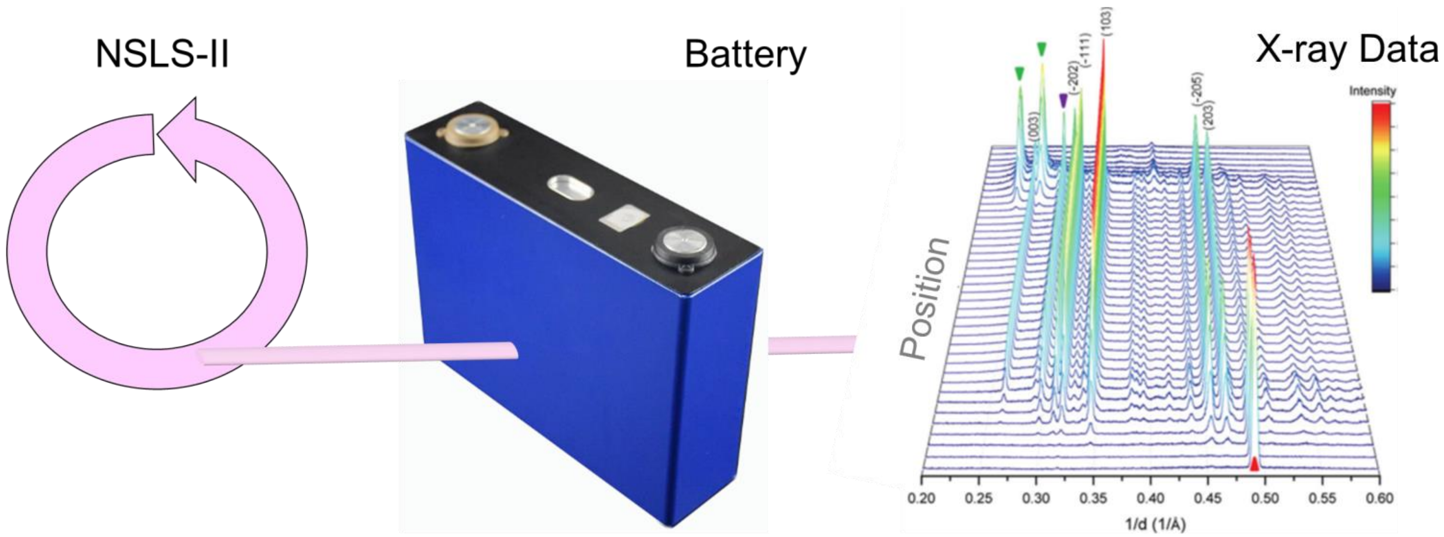
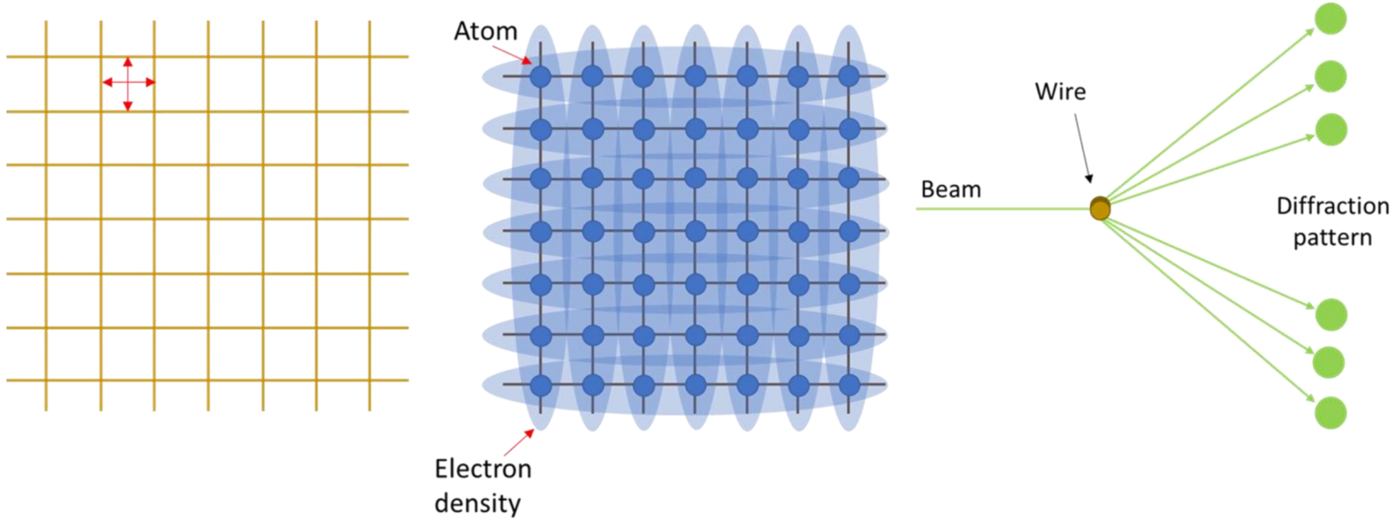
HEX as a Tool for Designing Better Batteries





HEX uses X-ray diffraction to visualize atom arrangement.

The High Energy Engineering X-ray Scattering (HEX) beamline enables the study of batteries during use, with unprecedented brightness, spatial and temporal resolution, providing critical insight into electrochemical function.

$25 M Investment

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

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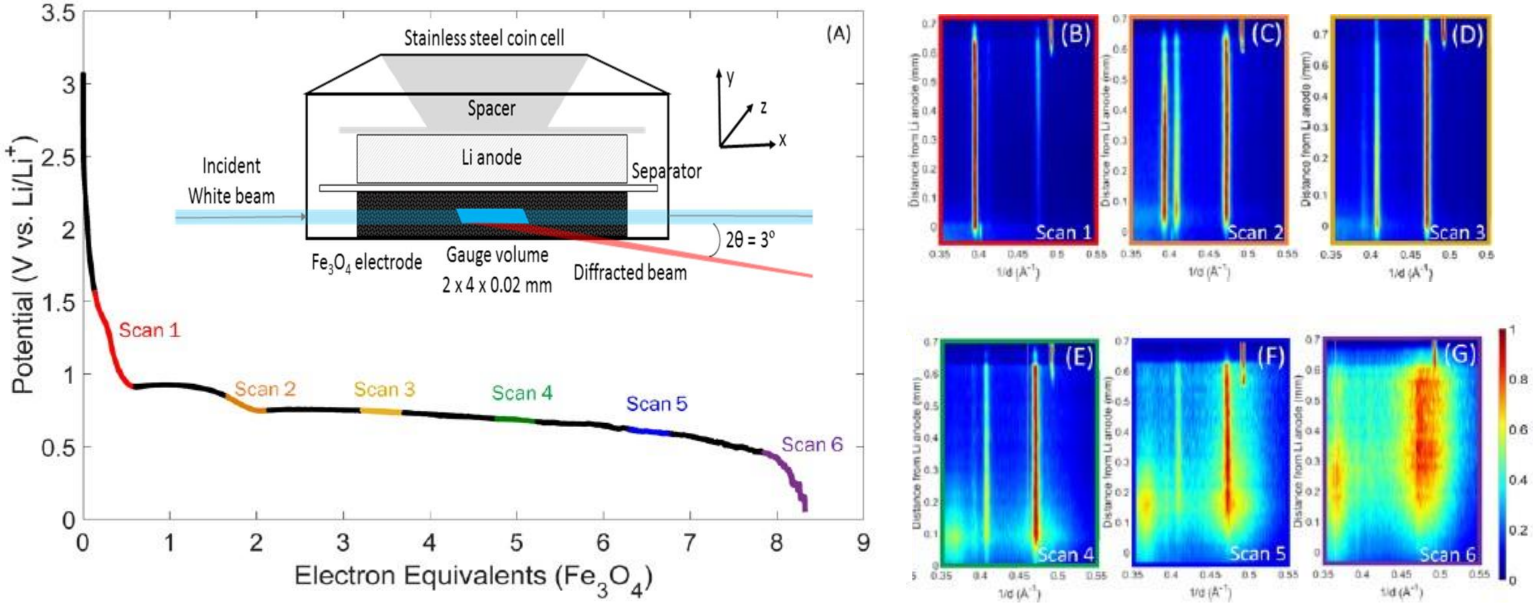
$25 M NY State Investment – HEX Beamline at NSLS-II

The High energy Engineering X-ray beamline (HEX) is designed to track crystallographic changes in solids to decipher insertion and conversion processes important for Li-ion batteries



A. Bruck†, N. Brady†, C. Lininger, D. Bock, A. Brady, K. Tallman, C. Quilty, K. Takeuchi, E. Takeuchi, A West*, A. Marschilok*, *ACS Appl. Energy Mater.*, **2019,** *2(4),* 2561.

A.C. Marschilok*, A.M. Bruck, A. Abraham, C.A. Stackhouse, K.J. Takeuchi, E.S. Takeuchi, M. Croft*, J.W. Gallaway*, *Phys. Chem. Chem. Phys.*, **2020,** *22,* 20972, *invited*.