FACT SHEET

EPRI Research Activities on Renewable and Battery End-of-Life Management and Circularity

New types of end-of-life (EOL) materials are being created as the power industry transitions to increased deployment of renewable energy and energy storage technologies. Cumulative EOL volumes of solar photovoltaics, wind turbines, and grid-scale battery energy storage systems are each projected to increase by a factor of 5 to 10 by 2030–2050. One significant emerging challenge for utilities is how to effectively plan for the full lifecycle of these assets, including choosing between various EOL management options. Thus, the EPRI Renewables and Battery End-of-Life Strategic Initiative (3002016314) was created to provide an integrated platform for EPRI research across the institute, as well as research performed by external stakeholders, policy makers and regulators. Upon completion of the Initiative, EPRI launched the Circular Economies for Clean Energy Technologies Interest Group (3002023087) to provide a peer forum to discuss leading practices, lessons learned, and motivate external stakeholders on circular economy research priorities. The goal of these efforts is to support the electric power industry in proactively managing technology EOL issues, developing sustainable solutions, integrating circular economy practices into business strategies, and avoiding potential environmental liabilities in the future.

This fact sheet summarizes the range of current and prior EPRI research deliverables on EOL management and circular economy topics for various energy technologies. It is intended as a resource for EPRI members and public stakeholders interested in specific research projects and is a starting point for further reading. EOL work is undertaken in a variety of research programs across EPRI, including in both the Generation and Energy Delivery and Customer Solutions sectors. Access to the reports can be had through program websites or by searching the product ID numbers on EPRI.com. A list of EPRI researchers involved in these projects can be found at the end of the fact sheet. You are encouraged to contact them with questions.

CROSS-CUTTING TOPICS

EPRI Washington Seminar on Electric Sector Challenges in Circular Economies for Renewables and Batteries. March 23, 2021. Agenda and materials available.

Electric Sector Challenges in Circular Economies for Renewables and Batteries: Proceedings of the March 2021 Washington Seminar. EPRI, Palo Alto, CA: 2021. 3002022231.

Guidelines for Assessing End-of-Life Management Options for Renewable and Battery Energy Storage Technologies. EPRI, Palo Alto, CA: 2021. 3002020594.

A Framework for the Application of Global Circular Economy Principles for the Electric Power Industry. EPRI, Palo Alto, CA: 2021. 3002020568.

The Global Circular Economy for the Electric Power Industry and Opportunities for Solar Photovoltaics. Shaw, S. et al., 2021 IEEE PV Specialists Conference (PVSC). Available upon request.

Operationalizing Circular Economy Principles for Renewables and Batteries: Electric Power Company Practices. EPRI, Palo Alto, CA: 2021. 3002023085.

Circular Economies for Clean Energy Technologies Interest Group. EPRI, Palo Alto, CA: 2021. 3002023087.

Circular Economy for Lithium-Ion Batteries and Photovoltaic Modules – Status, Challenges, and Opportunities. Schichtel, B.A., Stevenson, E.D., Braun, G., Shaw, S.L., Tarroja, B., and Chao, C.C. 2022. Journal of the Air and Waste Management Association, 72:10, 1053-1062, https://doi.org/10.1080/10962247.2022.2118473.

Circular Economy Metrics for the Electric Power Industry: Overview and Grounding Discussion. EPRI, Palo Alto, CA: 2022. 3002025718.

Circular Economies for Clean Energy Technologies Interest Group: 2022 Insight Summary. EPRI, Palo Alto, CA: 2022. 3002025822.

Traceability and Circularity for the Energy Transition. EPRI, Palo Alto, CA: 2023. 3002028421.

Measuring the Value of a Circular Economy for the Energy Industry. EPRI, Palo Alto, CA: 2023. 3002028517.

Solar Photovoltaic, Lithium-Ion Battery, and Wind Turbine Blade End-of-Life Service Providers. EPRI, Palo Alto, CA: 2023. 3002025769.

Insights on Implementing Environmental Product Declarations and Other Product Assessment Tools in the Electric Power Sector. EPRI, Palo Alto, CA: 2024. 3002029101.

Comparisons of Different Circular Economy Strategies for the Energy Industry. EPRI, Palo Alto, CA: 2024. 3002030233. Pending publication.

SOLAR PHOTOVOLTAICS

Relevant EPRI programs: 252 Environmental Aspects of Solar (3002019433); 207 Solar Generation.

Solar Photovoltaic Life Cycle Analysis: A Practical Handbook for Solar Photovoltaic Power Plant Owners and Operators. EPRI, Palo Alto, CA: 2016. 3002008832.

Program on Technology Innovation: Insights on Photovoltaic Recycling Processes in Europe, A Survey-Based Approach. EPRI, Palo Alto, CA; Alliance for Sustainable Energy, Operator of the National Renewable Energy Laboratory, and Wambach-Consulting: 2017. 3002008846.

PV Plant Decommissioning Salvage Value: Conceptual Cost Estimate. EPRI, Palo Alto, CA: 2018. 3002013116.

Evaluating PV Module Sample Extraction Methods for TCLP Testing. TamizhMani, G. et al. 2018 IEEE PV Specialists Conference (PVSC). Available upon request.

Solar PV Module End of Life: Options and Knowledge Gaps for Utility-Scale Plants. EPRI, Palo Alto, CA: 2018. 3002014407.

Supplemental Project Notice: Improving PV Sampling Methods for End-of-Life Leach Testing. EPRI, Palo Alto, CA: 2018. 3002014825.

Program on Technology Innovation: Assessing Variability in Toxicity Testing of PV Modules. EPRI, Palo Alto, CA: 2019. 3002016890.

Assessing Variability in Toxicity Testing of PV Modules. TamizhMani, G. et al. 2019 IEEE PV Specialists Conference (PVSC). Available upon request.

Environmental and Economic Considerations for PV Module End-of-Life Management. Libby, C., and Shaw, S. 2019 IEEE PV Specialists Conference (PVSC). Available upon request.

Application Insight Brief: Solar Photovoltaic Rooftop Decommissioning Case Study at the EPRI Palo Alto Office; Technology Brief. EPRI, Palo Alto, CA: 2020. 3002017793.

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Research and Development Priorities for Silicon Photovoltaic Module Recycling Supporting a Circular Economy. Heath, G. et al. Nature Energy 5, 502–510 (2020). https://doi.org/10.1038/s41560-020-0645-2.

Utility-Scale Solar Permitting: Requirements and Compliance Strategies. EPRI, Palo Alto, CA: 2020. 3002019033.

Decommissioning Plans for Large-Scale Solar Plants: Issues, Uncertainties, and Opportunities. EPRI, Palo Alto, CA: 2020. 3002019089.

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Solar Photovoltaics End-of-Life Management Infographic. EPRI, Palo Alto, CA: 2021. 3002021132.

Review of Decommissioning Plans for Large-Scale Solar Plants. Powicki, C., Libby, C., and Shaw, S. 2021 IEEE PV Specialists Conference (PVSC). Available upon request.

Hail Damage Assessment and Module Removal, Replacement, and Recycling Case Study for a Solar Power Project in North Carolina. EPRI, Palo Alto, CA: 2021. 3002022047.

Improved Sampling Methods for Toxicity Testing of PV Modules for End-of-Life Decisions. TamizhMani, G., Shaw, S., Libby, C, Sinha, P., Curtis, T., Tatapudi, S., Bicer, B. 2021 IEEE PV Specialists Conference (PVSC). Available upon request.

End of Use, Circularity, and Sustainability Considerations in Solar Photovoltaic Module Design and Product Development and Support. Powicki, C., Li, W., and Libby, C. 2022 IEEE PV Specialists Conference (PVSC). Available upon request.

PV Module Toxicity Testing Methods and Results: A Literature Review. 2022 IEEE PV Specialists Conference (PVSC). Available upon request.

Guidance on PV Module Replacement. Fregosi, D., Libby, C., Smith, M., and Bolen, M. 2021 IEEE PV Specialists Conference (PVSC). Available upon request.

PFAS in PV Modules: A Concern for Environmental Releases or End-of-Life Management? EPRI, Palo Alto, CA: 2022. 3002023374.

Technology Innovation: Environmental and End-of-Use Considerations in Solar Photovoltaic Module Design and Manufacturing. EPRI, Palo Alto, CA: 2022. 3002021734.

Advances in Photovoltaic Module Recycling: Life Cycle Inventory Assessment for Six Recycling Facilities. EPRI, Palo Alto, CA: 2023. 3002025345.

PV Module Management Across the Value Chain: Key Takeaways from NSF SOLAR Module Management Working Group. EPRI, Palo Alto, CA: 2024. 3002028004.

Utility-Scale Solar Photovoltaic Decommissioning FAQ. EPRI, Palo Alto, CA: 2024. 3002028347.

Potential Environmental and Human Health Risks of Lead Halide Perovskite Photovoltaic Modules. Rencheck, M.L., Libby, C., Montgomery, A., Stein, J.S. Solar Energy, Vol. 260, 2024. https://doi.org/10.1016/j.solener.2024.112337. [EPRI 3002028928]

A review of toxicity assessment procedures of solar photovoltaic modules. Li, F., Shaw, S.L., Libby, C., Preciado, N., Bicer, B., Tamizhmani, G. Waste Management, vol. 174, pp. 646-665, 2024, doi: https://doi.org/10.1016/j.wasman.2023.12.034. [EPRI 3002025982]

Review of End-of-Life Solar Photovoltaic Services in the United States. EPRI, Palo Alto, CA: 2024. 3002024944. Pending publication.

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A Circular Economy Roadmap for Solar Photovoltaics. Shaw, S.L., Rencheck, M.L., Siegfried, G.A., and Libby, C. Pending publication at Solar Energy. [EPRI 3002029481]

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Wind Turbine Blade Recycling Preliminary Assessment. EPRI, Palo Alto, CA: 2020. 3002017711.

Decommissioning Plans for Wind Farms: Issues, Uncertainties, and Opportunities. EPRI, Palo Alto, CA: 2021. 3002019651.

Wind Turbine Blade End-of-Life Management Infographic. EPRI, Palo Alto, CA: 2021. 3002022425.

Co-Processing of Decommissioned Wind Turbine Blades in Cement Production: Literature Review and Evaluation of Wind Turbine Blade Sample Tests. EPRI, Palo Alto, CA: 2022. 3002022690.

Survey of Technologies and Strategies for Processing End-of-Life Wind Turbine Blades and Impact on Potential End-of-Life Pathways. EPRI, Palo Alto, CA: 2023. 3002026691.

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BATTERY ENERGY STORAGE

Relevant EPRI programs: 94I Environment, Safety and Community Aspects of Energy Storage

Recycling and Disposal of Battery-Based Grid Energy Storage Systems: A Preliminary Investigation. EPRI, Palo Alto, CA: 2017. 3002006911.

Review of Environmental Life-Cycle Assessments of Lithium Ion Batteries for Grid-Scale Storage. EPRI, Palo Alto, CA: 2017. 3002009392.

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Environmental Impacts of Battery Recycling: A Summary of Recent Environmental Life Cycle Assessment Results. EPRI, Palo Alto, CA: 2022. 3002023723.

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Investigation of Battery Energy Storage System Recycling and Disposal: Industry Overview and Cost Estimates. EPRI, Palo Alto, CA: 2022. 3002023651.

Cedartown Battery Energy Storage System Decommissioning Case Study: Lessons Learned from Decommissioning an Early-Stage Utility-Scale Lithium Ion Project. EPRI, Palo Alto, CA: 2023. 3002027944.

Second Life for Large Format Lithium-Ion Batteries. EPRI, Palo Alto, CA: 2023. 3002028618.

De-energization and Decommissioning Strategies for Damaged, Defective and Recalled Lithium-Ion Batteries. EPRI, Palo Alto, CA: 2024. Pending publication.

Novel Lithium-Ion Battery Deactivation and Recycling Developments. EPRI, Palo Alto, CA; 2024. 3002029517. Pending publication.

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Hydrogen Fuel Cell and Electrolyzer End-of-Life Management Review. Low-Carbon Resources Initiative, EPRI, Palo Alto, CA: 2023. 3002028907.

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Circular Economy Considerations for Transformer Refurbishment. EPRI, Palo Alto: CA, 2023. 3002028540.

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About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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3002030366 **May 2024**

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