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James Morton Turner. *Charged: A History of Batteries and Lessons for a Clean Energy Future.* Weyerhaeuser Environmental Books Series. Seattle: University of Washington Press, 2022. xv + 234 pp. $34.95, cloth, ISBN 978-0-295-75024-8.

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A Least Worst World: Battery Lifecycles, Clean Energy, and Learning to Live with Waste

In James Morton Turner's new book on the environmental history of batteries, the author makes a shocking confession: he throws away spent disposable batteries he once religiously placed in the recycling bin. The admission is doubly dissonant, both because it seems to violate a key sensibility of our times (a sustainable society is a society that recycles everything) and because Turner, a professor of environmental studies at Wellesley College, identifies as an advocate for environmental justice. Turner dumps old disposables because he calculates it costs more energy to transport them to distant recycling depots than it saves by recycling them.

It is this big-picture perspective that makes this meticulously researched and highly readable book much more than a history of batteries, a ubiquitous yet obscure technology. Turner tells a story of industrial coproduction, the socialization of risk, and the technopolitics of trade-offs at global scale, one that importantly complements other recent monographs in environmental studies, including Victor Seow's *Carbon Technocracy: Energy Regimes in Modern East Asia* (2022), David E. Nye's *Conflicted American Landscapes* (2021), Daniel S. Cohan's *Confronting Climate Gridlock: How Diplomacy, Technology, and Policy Can Unlock a Clean Energy Future* (2022), and my own *Age of Auto Electric: Environment, Energy, and the Quest for the Sustainable Car* (2022). Batteries use complex and sometimes toxic mixtures of chemicals to store and release electricity and are a key enabling technology of consumer electronics, electric cars, and, crucially, renewable energy. They are also an archetypal black box, notoriously recondite to consumers who pay them mind only when they need replacing or recharging. Turner illuminates the externalities that inform the closed world of power source chemistry through lifecycle studies of several exemplary types of battery, engaging the challenges and paradoxes of the quest to build a circular carbon-neutral economy.

Woven into these case studies are a series of intersecting social histories, of the scientists and technologists who innovate battery chemistries, of the working people (mainly of color) who recover battery materials and who live and work in the sacrifice zones around mines and recycling depots, of the corporations that commercialize batteries, and of regulators who try to clean up the resulting environmental mess, sometimes with unintended consequences. It is masterly storytelling that seamlessly blends ideas in the environmental humanities and sciences. Some aspects of the narrative will be familiar to readers of environmental studies. The "dirty little secret" of commercial batteries, Turner observes, is that a lot of dirt has to be shifted to obtain their raw materials, at a heavy cost in energy, carbon emissions, and human bodies (p. 4). Turner paints a harrowing picture of landscapes and lives ruined in the drive for profit and consumer convenience, in the United States and abroad.

What distinguishes ***Charged*** from other works in environmental studies is the author's incisive analysis of the vexing economics of recycling and the circumstances in which actors decide that a material is a waste or a feedstock. There are no technological panaceas, Turner asserts, only least worst choices, with materials toxicity a key consideration in this calculus. After manufacturers began removing mercury from alkaline disposable batteries from the late 1980s, writes Turner, the least worst environmental choice at the end of the technology's lifecycle became the landfill.

The history of the lead-acid rechargeable, the most "inherently unsustainable" battery chemistry, is much more complicated, in part because it intersects with the history of automobility, a set of infrastructures that touch practically every corner of society (p. 18). In many ways, this is the most compelling of Turner's case studies, emblematic of the difficult choices humanity faces on the road to sustainability. Lead is highly toxic, so spent lead-acid batteries do not belong in the dump, says Turner. But where do they belong? On this question, Turner is less clear. He argues that lead-acid is an obsolete power source technology, unsuited for contemporary electric vehicles owing to its high-mass and low-energy capacity. Turner favors high-energy lithium-ion rechargeables for this and other roles.

Yet the lead-acid battery is also the most recycled type of battery, partly owing to the technology's relative chemical simplicity, which makes it relatively easy to process and, hence, it is an attractive feedstock at scale. The commercial lead-acid rechargeable was coproduced along with the commercial automobile, initially as the prime mover of electric cars but increasingly in an auxiliary role starting and lighting vehicles powered by internal combustion engines. As the fleet scaled, an increasing proportion of the lead in lead-acid battery production was derived from recycled batteries. By the 1930s, writes Turner, the American Bureau of Metal Statistics perceived that lead in this context was being "loaned" rather than "consumed" (p. 31).

In the 1970s, however, the economy of lead-acid battery recycling was undermined by environmental regulations aimed at mitigating another application of lead in industrial automobile technology: gasoline. The phase-out of leaded gasoline eliminated the most pernicious vector of lead poisoning, but it also cut the cost of lead, disincentivizing the recycling of lead-acid batteries and increasing the volume of solid lead waste in the environment. The story is ironic on multiple levels, but the postscript is not all gloom. Broken by short-sighted public policies, observes Turner, the lifecycle loop of the lead-acid rechargeable was restored in the 1990s and 2000s with new regulations and investments in centralized and highly automated recycling facilities.

It is this lifecycle success story that compels Turner to reconsider the lead-acid battery as an energy storage technology. Two salient points emerge from the author's deep engagement with

trade-offs: first, the stock of solid lead embodied in lead-acid batteries cannot safely be disposed of; and second, much of the human and environmental cost to extract this metal has, in a sense, already been amortized. In the United States, at least, the lead mines have long been closed, and Turner admits, somewhat grudgingly, that the lead-acid battery can continue to give useful and relatively safe service within the confines of its closed lifecycle. In contrast, lithium-ion batteries are less toxic but also less recyclable, partly owing to their greater chemical complexity. Hardly any are recycled at present. Unlike in the other case studies, the least worst lifecycle scenario for the lithium-ion battery, suggests Turner, is not yet clear.

Much of this fascinating and provocative book's appeal lies in the writer's willingness to test assumptions and arrive at counterintuitive and sometimes unpalatable conclusions that challenge received wisdom, a refreshing departure from the certitude and cant that characterize many of the more normative works in environmental studies. In analyzing battery lifecycles, Turner focuses not so much on energy as *energy conversion*, a frame of reference that conjures the sociotechnical relations that enable primary energy to be made to do useful work and, hence, avoids the energy and materials essentialization that often informs contemporary environmental scholarship. But Turner does not ignore the affordances of materials, although he often leaves it up to the reader to probe the broader implications of his toxicity maxim. The idea of borrowing rather than consuming natural resources, as articulated in the lead-acid battery recycling case, has great appeal, of course, but I wonder how appropriate it is in other materials contexts. Closing the loop on nuclear fuel, for example, would necessitate fast breeder reactors and a plutonium economy, anathema to many although not all environmentalists.

In its broad sweep, *Charged* reads as a manifesto of green pragmatism. Turner traces the environmental movement's longstanding failure to reconcile social with environmental justice to its inability to grasp the materiality and scale of problems and solutions. On the one hand, the Malthusian messaging of the movement's austerity wing, whose (usually wealthy and Western) proponents have enjoyed all the benefits of well-developed energy conversion infrastructure, alienates the developing world. On the other, liberal proponents of the Green New Deal do recognize the relationship between clean energy and social justice but strongly oppose the extractive industries.

To Turner, both ways of thinking ignore the material and social realities of global industrial civilization, inhibiting development of the state-coordinated lifecycle governance he believes is necessary to mitigate the risks of building battery storage capacity as an indispensable component of renewable energy. While the circular economy is a worthy long-term goal, writes Turner, treating it as a literal model mystifies and complicates the clear-eyed calculating of trade-offs. It is a call to reappraise ideas about sustainability and consider an alternative philosophy of waste that accommodates certain relatively low-risk forms of pollution. The alternative, Turner all but hints, is to fully close the circle by applying the ecological principle of balance to social relations, a step with radical ideological and practical ramifications. Engrossing and sobering, *Charged* is essential reading for anyone concerned about environment, energy, and the sustainable future.

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