“A resource in and of itself”: Grid-scale Batteries and the Politics of Storage

by

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ABSTRACT

From Tesla’s experimental ‘Virtual Power Plants’ to the US’s Energy Storage Grand Challenge, grid-scale batteries – which attach to the electricity grid to buffer supply and demand – are sites of intensifying research, speculation and legislation. They are increasingly positioned as a transformative means to mitigate and adapt to climate change. Indeed, batteries are not the only form of storage in the spotlight: A variety of stored forms, including seed banks, metals stockpiles, and sequestered carbon dioxide have become central in generating, and ameliorating, anxieties about environmental futures. ‘Storage’ offers a potent analytic to analogize phenomena across scales and contexts, in part because of the increasingly visible status of its emic instantiations. As a means to store electricity, a uniquely ephemeral commodity, batteries, like other stored forms, both mediate power and capital and can defuse political potency. Though batteries can smooth the integration of renewable energy into the grid by disciplining the unruly schedules of sun and wind, their potentials (and proponents) extend to the fossil fuel industry as well: They are ‘fuel-neutral’, allowing all kinds of electrons to become more cost-efficient. In these multivalent contexts, I suggest, securing the status and value of a battery’s stored electricity, or trading on its ambiguity, can signal and effect political agendas, even as such arbitrations can recast politics in a techno-juridical domain.

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In January 2020, two weeks after yet another public dressing-down of wind energy as anti-American, unreliable, and dangerous, Donald Trump approved an allocation of $158 million in the 2020 budget for research and development into energy storage technologies. With this financial endorsement, the U.S. Department of Energy promptly announced the Energy Storage Grand Challenge, a multi-year strategy summed up by the slogan: "innovate here, make here, deploy everywhere." The challenge's "draft roadmap," true to this tagline, positions energy storage at the nexus of an agenda with both nationalist and expansionist aspirations. In the DOE roadmap, electricity storage (including batteries) becomes a means of alternately restricting and smoothing the distribution of "critical materials" – namely, metals such as cobalt, lithium, graphite, and certain rare earth elements (REEs). Batteries in the roadmap comprise a means to shore up domestic electricity in the name of "energy security." They signify the opportunity to bolster U.S. domestic manufacturing capacity and research prowess, not just for consumption but also for export. They, finally, authorize the domestic extraction of "critical minerals," motivating and guiding a concerted effort to "secure [a] domestic manufacturing and supply chain that is independent of foreign sources of critical materials" (U.S. Department of Energy, 2020: 1).

Speaking at an Ivy League energy conference nearly a year after the Grand Challenge launch, the director of the U.S. Energy Storage Association equivocated on the relationship between storage, renewable energy, and politics. In one sense, she said, storage was "a little bit of the trojan horse of renewables." Batteries could buffer the intermittency in wind and solar supply, "enabl[ing]" smoother and more reliable integration into the U.S. electricity grid, which requires instantaneous calibration of supply and demand. Yet, she offered, as the Grand Challenge demonstrated, storage, unlike renewables, was "grid-focused rather than climate-focused." Where renewables were intermittent, storage was "reliable," offering "flexibility" that wind and solar lacked. “Storage,” she explained, “can be placed by itself to help any electron that comes its way; it doesn’t really discriminate about where [the electron is] coming from.” Thus, she concluded, “energy storage is an extremely bipartisan, or even nonpartisan, issue” – in a context, she reminded her audience, where almost nothing is.

Batteries facilitate the distribution of political and energetic power across space and time, to various effects. They can accumulate, facilitating the (often uneven) distribution of electricity and metals at multiple scales. They can buffer, materializing an ethos of grid- and nation-scale reliability that is at once pragmatic and, in the unreliability it evokes, ominous. They, finally, can conceal, blending electrons and, in the process, effacing their source. Their flexibility in tempo, distribution, and contents affords a political ambiguity that can both diffuse and embolden.

The capacity to mediate across space, time, and provenance characterizes many forms of storage. Storage can meter and distribute material flows (Cowen, 2014: 11; Hannam et al., 2006: 12; Orenstein, 2019: 18; Randle, 2021). It can, moreover, reflect and instantiate futurities, sustaining certainty, threat, or possibility (Duffield, 2011; Peebles, 2014; Radin, 2017: 3; Reddy, 1967; Vinen, 2019). Storage coalesces substances; it can contain things yet also comprises a (permeable) carapace that, itself, might serve multiple functions (Bevan, 2014; Orlandi, 2017; Parker, 2013: 381–385). These materialities, often, have origins and afterlives; compel and configure locales; have use; are incompletely commensurable; and degrade (Cronon, 1992: 147; Graeter, 2020; Harrison, 2017; Hendon, 2000: 46; Keck, 2017). Storage, finally, often conceals its contents – or, perhaps, its vacancy (Bhowmik, 2019; Eisler, 2017; Rodrigue and Notteboom, 2009: 3).

In this essay, I ask two questions that engage storage as, respectively, an actors’ term and an analytic. First, what are the effects and potentials of the grid-compatible batteries now positioned, by some actors, as a transformative means to store electricity? Second, what dynamics and perspectives might ethnographic inquiries that center different forms of storage surface? In other words, what could storage, as a category of analysis, offer to anthropological studies of science and technology?

My responses to these questions are related: I argue that the analytic of storage is generative in part *because* of the increasingly central role of its various instantiations, whether batteries, seed banks, metals stockpiles, or sequestered carbon dioxide, in generating, and ameliorating, anxieties about the future. Critical attention to storage as a "spatial form" – to borrow a phrase from historian Dara Orenstein – might attune STS scholars not only to salient environmental, technological, and infrastructural futurities but also to some key material and discursive mechanisms by which actors articulate and negotiate these futures, and their human stakes (2019: 2).

I investigate these questions through an exploration of grid-compatible batteries, placing them into conversation with recent scholarship on a variety of stored forms, among them stockpiles, seed banks, cold storage, shipping containers, and warehouses. Batteries, though formidably complex, are in some ways an archetypal stored form; as such, they are particularly fruitful to think with. They have also become pivotal nodes that yoke hot-button issues such as climate change, energy distribution, and mining.

In particular, my analysis engages anthropologist Stephanie Graeter's elaboration of "toxic storage" and anthropologist Gustav Peebles' analysis of the "hoard." Both authors use the motif of storage to analogize phenomena across scales and contexts. Graeter demonstrates that the caching of value often facilitates, and requires, the sequestration of wastes. In an ethnography of a Peruvian port where lead is warehoused for export, she recasts the buildup of the toxic metal in the bodies of local residents as a form of "embodied debt," an enduring effect of corporate costcutting (2020: 24). Lead, some of it intended for batteries, accumulates both as a commodity in warehouses and as toxic waste in adjacent soils and bodies. Though opposed in form and context, both accumulations smooth capital flows, in the process generating inequality, injurious exposure, and dispossession. My analysis draws on Graeter's insights to engage batteries as accumulations of both metals and electricity – and, correspondingly, of power and capital. In stocking electricity in the name of climate mitigation, I argue, batteries also require and authorize the uneven, pollutive extraction of the metals they comprise.

Gustav Peebles, meanwhile, has recently critiqued discourses among financial analysts that the "unbanked" – individuals, largely in Africa, who keep cash on hand rather than depositing it in banks – are "hoarding." Peebles argues that, in fact, hegemonic financial systems similarly "hoard" liquid capital: stocks of unused capital held by federal reserve banks are crucial to securing large-scale investments. Yet though it is ubiquitous, he suggests, high levels of household hoarding also index institutional stability, which can make the expansive commensurability and unimpeded growth of financial assets worth foregoing for the circumscribed, degradable usability of liquid cash (2014: 604).

Peebles attributes the strategy of calibrating hoarding and uncertainty primarily to consumers in the Global South glossed as "African." Yet battery discourse demonstrates that storage can also buffer anxieties about climate change, cyber-insecurity, and infrastructural decline in the Global North, for institutions and individuals alike. Shadowing the flamboyant techno-optimism of battery marketing is an equivocal futurity: neither "aspiration" nor "failure" but rather a shallow promise of stability that evokes and submerges unease (cf. Appel et al., 2018). Corporate marketing of household-scale storage, moreover, hails a neoliberal subject more scrappy than the rational Global North user assumed by the financial analysts in Peebles' account. Borrowing an obscure term coined in 2019 by a group of energy economists (Sioshansi, 2019), I call this subject the *prosumager*, the electricity consumer who also – generally via a combination of solar panels and residential batteries – produces and stores. In the abstract, the prosumager is both entrepreneurial and well-prepared: a household battery maintains electricity in a state of deferred possibility, suitable for either use or exchange. Yet in practice, would-be prosumagers are often stymied by inscrutable contracts, inconsistent regulations, and material unruliness.

While certain qualities of stored forms can articulate across multiple contexts, scholars have also demonstrated that as a category of analysis, storage is not singular. Dara Orenstein, for instance, distinguishes storage, the caching of goods for future use, from warehousing, a historically emergent industry that rendered containment as a commodity by momentarily pausing goods in transport (2019: 30–31; see also 57). In an analysis of flu preparedness, anthropologist Frédéric Keck, meanwhile, differentiates the storage of virulent samples from the stockpiling of vaccines (2017). I diverge from these authors by opposing battery storage to banks and archives. While stored electricity is incompletely commensurable, both used and exchanged, and decays, banked currency aspires to liquidity, alienability, and growth (Peebles, 2014). Where batteries homogenize, archives classify, often according to source (e.g. Radin, 2017: 75).

Though battery applications span products from consumer electronics to vehicles, those batteries hooked up to the electricity grid offer one particularly rich site of negotiation across these domains. The grid (itself a multi-scalar, relational category), for one thing, shapes experiences and environments for collectives of people (Edwards, 2002; Gupta, 2015; Özden-Schilling, 2016). Its deregulation in the U.S. beginning in 1992 has also opened the former poster child for "natural monopolies" to uneven, inchoate political, economic, and climatic changes. Today, renewable energy penetration, aging grid infrastructure, cyberattacks, and extreme weather events are challenging utilities companies' ability to provide reliable, continuous energy, even as safe electricity provision requires continuous calibration of supply and demand (Bakke, 2016; Preston et al., 2016). Grid batteries have become key objects of investment and attention in part because of their potential to help remedy these challenges (Bhowmik, 2019; Eisler, 2017). Yet batteries have defined dimensions, efface electrons' energetic sources, and concern things rather than people. When cast as a corrective, therefore, a battery project can function as an "anti-politics machine" to delimit, decontextualize, and render technical the problems it is mobilized to address (cf. Ferguson, 1994).

This essay is based on virtual ethnography conducted largely in Fall 2020, primarily of grid-scale battery companies and industry organizations in the United States (and, briefly, Australia). Following Sherry Ortner's method of "interface ethnography," I examined industry websites, publications, videos, and other marketing materials – as well as regulatory documents, news articles, and blog posts (2010). I also attended events at five virtual conferences and presentations, which were attended by a mix of scientists, industry experts, and government officials. Finally, I read forums and comment threads, largely populated by individuals who already own, or curious about, residential-scale storage. My method led me to explore instances across multiple scales, contexts, and locales, a dispersal that reflects the aspatial globality of the industry ads I examined. Though illustrative in some respects, this approach has substantial limitations.[1]

The essay is structured in three parts that, loosely, map onto a line from the U.S. Energy Storage Association website, which holds that storage "can act as a generation, transmission or

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[1] Historian Deborah Cowen, for instance, discusses the limitations and potentials of studying "distributed phenomena," particularly if the phenomenon is distribution itself (2014: 17–18).

distribution asset – sometimes in a single asset" (2021). Batteries, in other words, can be classed as infrastructure (transmission and distribution), energy resource (generation), or financial asset. I investigate the three functions in turn, exploring how each engenders one key quality of storage: reliability, stockability, and flexibility.

In Part I, I explore the temporal affordances and discourses of grid-scale batteries, which crystallize in their multivalent promise to secure "reliability." Batteries, at least per their promoters, can regularize and sustain electricity infrastructures at multiple scales, at once invoking and distancing futurities of both gradual decline and punctuated disruption. In Part II, I investigate the various social stakes activated by regimes of electricity and the use of metals in battery energy accumulation or stockability. Though as caches of electricity batteries can ground various ethical projects, I argue that the political pliability of their siting overlooks the extractive endeavors that battery futures, increasingly, authorize. Lastly, in Part III I detail how batteries, unlike banks or archives, sustain electricity's ambiguity with respect to two qualities: electricity's value and its provenance. I suggest that securing the status of stored electricity, or trading on its ambiguity, can signal and effect various environmental and infrastructural futurities, even as such arbitrations can recast politics in a techno-juridical domain.

Part I: Reliability

"If you think of energy storage in its broadest sense, it's literally decoupling the element of time" from energy generation and use. Thus, reflected the CEO of the Energy Storage Association in a recent presentation, energy could be "saved for later." In Part I, I investigate this promise, made in many industry marketing materials, that batteries might maintain continuous electricity provision, reinforcing the grid's status, for all but its closest caretakers, as *ground* — that is, as the unquestioned foundation of energy supply and management. Current and anticipated disruptions from renewable energy, grid aging, extreme weather, and cyberattacks threaten the conceit of infrastructural "invisibility" in the U.S. (Bowker and Star, 2000; Star, 1999). Batteries thus offer a means to insulate power makers and users from not only the material disruptions of these unpredictable rhythms, but also the apprehensive futurities that such irregularities index. Batteries might temper multi-scalar uncertainty through their configuration as "reliable."

"Reliability," a nearly ubiquitous word in industry publications, is a multi-scalar promise, signifying both daily predictability and a more abstract certainty. A video by the company Tesla, advertising a grid-scale battery installation on the island of Kauai in Hawaii, evokes one sense of the word. The video opens with a translucent, minimal clock over a backdrop of sky. Its hands spin swiftly as words appear: "A sustainable energy future needs reliable, renewable energy around the clock"(Tesla, 2017). The clock, here, visualizes an aspiration of hourly consistency in electricity provision. This image articulates one sense of reliability, a quotidian predictability that the OED calls "The ability of a product, etc., to perform in a required manner, or produce a desired result consistently" (*OED Online*, n.d.).

Reliability, however, is not a quality inherent to electricity provision but rather an aspiration that arose through specific historical conjunctures in parts of the Global North (Gupta, 2015). Historian Julie Cohn documents how in the weeks and months after the U.S. blackout of 1965, during which about 30 million customers lost power, the U.S. government's mandate for utilities shifted from optimizing "conservation" and "efficiency" to maximizing reliability (Cohn, 2017: 218–19; 231; 238). By 1965, Cohn explains, years of consistent provision had already accustomed U.S. users to the controllable and comfortable interior environments that, as Paul Edwards argues, have come to both signify and reproduce a particular experience of modernity

(Edwards, 2002). The goal of "reliability" took this demand as inelastic, locating the effort of calibration instead in a nimble supply. Crucial to maintaining this consistency today are "peaker plants," gas-powered plants that are generally the most pollutive and costly power sources. Peakers are kept on standby for rapid deployment when demand spikes, such as when air conditioners are cranked up during heatwaves.

The increasing "penetration" of renewable energy into the grid complicates sustaining this consistency by introducing a supply out of sync with both generation and use. In the energy industry, renewables are considered an "intermittent" supply: the sun shines during the day while wind is strongest at night; both are also seasonal and can surge or abate unexpectedly. In the context of this intermittency, coal and gas plants – which once revved up generate consistent, predictable power – are, in turn, referred to as "baseload" resources. Yet the term "baseload" has a second, related meaning: the minimum supply needed to service an electricity grid over a 24-hour period. As so-called "baseload" resources, fossil fuels are as always-already foundational; renewables, in turn, are *a priori* supplemental.

In the rare cases when renewables *are* used to meet baseload demand, as anthropologists Phillip Vannini and Jonathan Taggart demonstrate, they breed less profitable schedules than fossil fuels (2015). Among families in Canada who live off the grid with solar panels and basic batteries (and have the privilege to reconnect to grid infrastructure), activities slow and align closely to the sun. Time is not spent but tended to: "efficiency, in this lifeworld…is about investing time with care and exercising care over time" (2015: 644).

After informing viewers that until now Kauai had burned fossil fuels at night, the Tesla video closes with another translucent image, this time over a backdrop of Tesla brand solar panels and Powerpack batteries. Where the clock was we now see a horizontal bar labelled "battery storage," which fills onscreen from zero to one hundred percent. As the video shifts to a nighttime shot of the island lit up, the bar empties again. "Solar stored during the day," the screen reads, "powers Kauai at night." The batteries in Tesla's video seamlessly mediate the sun's intermittencies so that electricity can continue uninterrupted through the night.[2]

Batteries, in this video, subject the unruly schedules of sun and wind – seasonal; daily; sometimes random – to "time-discipline" (cf. Thompson, 1967). Indeed Tesla's powerpacks, which are lithium-ion (Li-ion) batteries, are well-suited to reproducing the daily reliability of fossil fuels. Li-ion batteries, which generally hold one to four (or up to eight) hours of power, can mimic peaker plants to equilibrate electricity on hourly timescales by charging when demand is low or supply high and discharging when demand spikes or supply from renewables dips (Burger and Ragazzi, 2020). By tempering their unsteady temporalities, batteries can recast renewables as – to borrow from anthropologist Casper Bruun Jensen – "a supplement, rather than a threat" to electricity-as-usual (2019: 230–231). Moreover, unlike the self-optimizing smart grid users that Canay Özden-Schilling describes (2016: 143–161), they allow for price- and climate- inelastic demand, satisfying even electricity users interpellated as capricious and inflexible. Li-ion batteries, in other words, promise to mediate these fuels' asynchronicities, letting wind and solar play nice with the steady, rigid meters of natural gas and coal.

The potential of batteries to mediate flow is not unique; many forms of storage can hold and release excess to maintain the (semblance of) unremarkable consistency in price, distribution, or schedule. In the 20th century, (semi-)durable commodities like tin, rubber, and coffee were

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[2] It is perhaps unsurprising that Kauai is the object of this advertisement. Islands have a history, as much in anthropology as in science, of being treated as "laboratories," often in imperial contexts and often to damaging effect (Özden-Schilling, 2016: 141; Smith-Norris, 2016). More recently, islands have also become sites of renewable energy and energy storage experiments (Hermanson, 2003; Sperling, 2018).

internationally stockpiled to maintain price stability (Gilbert, 1987). The warehousing of commodities starting in the early 20th century similarly synchronized temporalities of "work," "circulation," and "production," serving as "a spatio-temporal apparatus for modulating flows of capital" (Orenstein, 2019: 30). Locales such as airports where motion is tempered by stillness are key to easing the transport of people and so likewise "enable the fluidities of liquid modernity" (Hannam et al., 2006: 3). Like friction, such interruptions (imperfectly) attune situated and "sticky" materialities to abstract aspirations for unimpeded circulations of people, goods, and capital – even as they also subvert (and tarnish the verisimilitude of) such conceits (Tsing 2005).

Neither the capacities of storage to mediate nor the meters it might synchronize are stable. Refrigeration, for instance, delays decay and thus extends the temporal horizon for arbitrage, smoothing capital through time by aligning schedules of production and distribution (Radin and Kowal, 2017). Practitioners of cryonics, the unproven science of freezing people for future resuscitation, operate at the extreme end of capital's temporal horizons. Putting faith in human freezers, anthropologist Jonny Bunning argues, might be read as an effort to synchronize schedules over indefinite durations, to "decoupl[e] biological from technological time…a kind of vital arbitrage or temporal tourism" (2017: 236). Shifts in storage technologies and in circulatory aspirations can, moreover, be mutually configured. The shipping container, as historian Deborah Cowen chronicles, was "a necessary underpinning for the rise of just-in-time (JIT) production techniques" as practice and ideal (2014: 41).

Read in this light, grid-scale batteries are innovation indeed: they promise to extend electricity's endurance as a commodity, which on the grid has often been limited to seconds. The upper limit of battery discharge times, propelled by research flush with investment, continues to rise. Form Energy for one, a company developing batteries that would store 150 hours of energy, has wooed financing from a venture capital firm funded by Bill Gates (Colthorpe, 2020). Founded by a former Tesla executive and MIT materials scientists, Form's batteries are less dense, less powerful, and slower to charge and discharge than Tesla's (Iaconangelo, 2020). These batteries were made to even out weekly and seasonal surges and dips – not to replace peakers but to phase out those coal and gas plants that generate energy consistently for decades (Hanley, 2020). As a company publication explains, Form aims to "prov[e] that the vision of an affordable, renewable future is possible without sacrificing reliability" – in part by "help[ing] planners reduce exposure to extreme weather events and minimize uncertainty around commodity prices under a variety of future grid scenarios" (Form Energy, 2020).

Form's promise of reliability has a hopeful tone. Yet the future it anticipates is one of possible compromise – in which "reliability" is, once again, up for grabs. Yet this is a different sense of the word, I would argue, one that operates not at hourly scales but over a more formless future timespan. Here, reliability means not so much predictability as *certainty*, what the OED defines as the "ability to be relied on with confidence; trustworthiness, sureness, reliableness" (*OED Online*, n.d.). Batteries, here, might secure infrastructures against the geological-scale changes that now intrude onto human and infrastructural timescales, in part by acting as generators to sustain power when production or transmission is disrupted (cf. Edwards, 2002).

The webpage for the Megapack, Tesla's newest grid-scale battery, also promises reliability in this drawn-out sense. Alongside "renewable smoothing," the website reads, the megapack can "defer the need to upgrade aging infrastructure," likely by facilitating the kinds of attuned buffering and metering capacities that infrastructural upgrades would achieve (Tesla, 2021). Here, batteries offer the potential to forestall the effects of "late industrialism," four decades of deregulation of "public works," particularly in the U.S. and U.K (Fortun, 2012). This promise recalls Jerry Zee's "chronopolitics of stalling," which he coins to articulate how state efforts in Mongolia to slow desertification reconfigure national futurities, trading progress for the postponement of environmental collapse. Like the windbreaks installed to slow encroaching desert sand, batteries, here, offer the prospect to hold at bay "an ending already in progress" (2017: 223). Yet how long the Megapack can feasibly defer, Tesla does not specify.

Batteries are not the first commodities to have been cached for geologic-scale, unpredictable, potentially catastrophic events. In the U.S. the Cold War precipitated unprecedented, variegated stockpiling (Folkers, 2019; Kaiser, 2002; Radin, 2017). Today seed banks, mostly in the Global North, insure biodiversity against the risks of land use and climate changes (Chacko, 2019; Harrison, 2017; Lewis-Jones, 2019). Like other iterations of storage, batteries operate at multiple registers, alleviating future uncertainty as much symbolically as materially (cf. Lakoff, 2007). They insulate against unpredictability at multiple scales, sustaining the possibility that business might continue as usual. When deployed uncritically they may also, perhaps, narrow other infrastructural and imaginative potentials. After all, a battery can only do so much to stave off, say, rising sea levels.

Part II: Stockability

"We as an association think that energy storage should be able to be counted as a resource in and of itself. It shouldn't have to be coupled with solar in order to be valued." This statement from the CEO of the Energy Storage Association surfaces a second aspect of batteries' plural functionality. Batteries operate on, and as, not only infrastructures but also *resources*: they authorize the accumulation and distribution of both electricity and metals under the sign of climate change. As electricity repositories, their flexible scalarity can materialize varied ethical projects. Yet as alloys, their spatio-political reach, while more expansive, is perhaps more circumscribed: futurities of unfettered battery growth increasingly authorize extraction. In this section, I investigate how batteries at once facilitate and obscure uneven geographies of accumulation. I first examine the political pluralities of their siting, which just as readily organize collective publics as private endeavors. I then examine how battery demand projections invoke climate change to spur metal stockpiling above and underground.

Batteries accumulate electricity, a form of energy that, until recently, could not be stored at household- or utility-scale (barring proximity to a pumped-hydropower reservoir). As Timothy Mitchell details, coal and oil's materialities each had particular accumulative potentials that, in turn, helped shape the political systems they fueled (2011). Energy from wind and sun is, in contrast, ephemeral and distributed. Though these "renewable" qualities, alone, do not guarantee political or economic redistribution, futurities of sun and wind *have* guided endeavors to "reimagine industrialized energy as a potential means of upending systems of institutional oppression" (see also Boyer, 2019; Howe, 2019; Lennon, 2017: 20). Like other forms of storage, batteries both mediate and are, themselves, material. The tailoring of batteries can alter the parameters of accumulation – which, among other effects, can further "fix" or disperse prior gridded publics (cf. Harvey and Knox, 2015: 181).

In May 2020, Form Energy announced a partnership with the Minnesota utility Great River Energy, the fifth largest energy cooperative in the U.S.[3] The co-op covers about two thirds of Minnesota's area, as well as parts of Wisconsin; members elect the board of directors and control a portion of surplus profits. The project with Form aims not only to bolster resilience but also to support the integration of large inputs of wind energy (Form Energy, 2020). The co-op's website

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[3] Energy cooperatives were formed to serve rural areas where it was not profitable to extend power lines.

characterizes electricity distribution as a “community” endeavor: members are vested with “democratic control” to steward “common property” (*Great River Energy*, 2015). The envisioned battery’s expansive capacity and duration mirror the scale at which this gridded public is conceived. Its placement in front of the meter, moreover, positions it as part of this energy commons. Though its dimensions do not determine how energy will be shared in a blackout (rather, Form’s software will govern dispersal of power), they do “generat[e] the conditions of possibility” for an electrified collective (cf. Harvey and Knox, 2015: 181).

Not all batteries, however, aspire to substantiate prior publics. The batteries that Bob Shulter owns, certainly, do not. Bob lives in a stately home in upstate New York. He, I learned from an inbound marketing blog post by the company Simpliphi, which makes cobalt-free batteries, had used the company’s services to install an “award-winning” mix of solar panels, batteries, and a back-up generator (Simpliphi, 2017). Bob, the post relates, owns the installation, though the timing and direction of energy movement between batteries, solar panels, and the grid is attended to by Simpliphi’s software. His installation can also detach from the grid to function self-sufficiently. The post elucidates the stakes of Bob’s batteries via a historical example: “After Hurricane Sandy, it took New York utilities 13 days to restore power to 95 percent of their customers.” In contrast, Bob’s detachable energy apparatus would “ensure zero interruption of power to [his] home” – placing him among the five percent not subject to such vulnerability.

This post makes clear that all batteries are not ethically equivalent. While Form’s batteries sustain a pretense of mutual reliance, Simpliphi’s let Bob stock electricity alone. Two qualities are key to this objective: private control and detachability. Bob’s batteries, first, are behind-the-meter (BTM): they are located on the domestic side of the meter, the apparatus that measures the electricity that enters (or leaves) every grid-connected building. This means that energy can pass from his solar panels, to battery, to appliances without touching infrastructure owned by the utility company. Just as crucially, the house can be cut off from the grid entirely to form a tiny "microgrid," a technique known as "islanding." In the event of a blackout, Simpliphi's software would likely island Bob automatically so he could use energy while his neighbors went without. BTM batteries and microgrids thus become what Rob Nixon calls "strategies for distancing," for maintaining a comfortable environment in the face of disruptions, even intimately proximate ones (cf. Nixon, 2011: 220).

As technology, islandable batteries facilitate the (option for) detachment from a gridded public. As metaphor, "islanding" positions batteries as a refuge of finite abundance in a sea of scarcity. Microgrids are signified under multiple ethical frameworks, offering, for instance, a means to sustain power to hospitals. Yet many companies and politicians peddle such detachability via libertarian rhetoric. In Michigan, for instance, microgrid reform is a pillar of a proposed "Energy Freedom Bill." The bipartisan bill would allow any institution to island if their microgrid includes critical infrastructure such as a hospital (Balaskovitz, 2019a, 2019b). It would also ban utilities from charging "standby rates" while a customer is islanded (Johnson et al., 2019). Michigan State Representative Gary Glen (a republican), advocating for the Energy Freedom Bill in 2018, articulates the public's disintegration that this accumulative form foresees: "every man a prepper, so to speak" (LeBlanc and Oosting, 2018).

The metal in batteries coalesces geographies distinct from those of electricity. Demand for batteries, and thus for the metals that they comprise, is projected to multiply in the coming decades (Morgan Stanley, 2017). For some metals, such as cobalt and lithium, meeting growth projections would require a multifold increase in the volume mined (Arrobas et al., 2017). Partaking in this postulated battery-rich future would thus require securing access to yet-unavailable supply.

Projections of future battery use, I observe, have begun to authorize and influence extraction plans that endeavor to calibrate supply to outsized future demand (cf. Barandiarán, 2019; Bustos-Gallardo et al., 2021).[4] The performative power of these projections stems in part from their link to climate change: they are substantiated by reports that figure an unprecedented boom in battery production as climate change's globalized, inevitable, and most promising solution.

Tesla's 2020 Battery Day, an extended announcement about the company's EV battery innovations, offers an example of how manufacturers invoke battery futures to authorize mining projects. On Battery Day, standing before an audience of socially-distanced Teslas, CEO Elon Musk described Tesla's various initiatives to decrease the cost of battery production. Alongside technical and manufacturing innovations, he detailed the company's plan to decrease the cost of obtaining battery metals that, for the moment, were hard to replace such as lithium, cobalt, and nickel. He had, he related, entreated the CEOs of the world's largest nickel mining companies to "please, make more;" he was optimistic they had taken heed. Tesla, he continued, would also soon source lithium from not foreign salt flats but a recently secured 10,000 acre clay deposit in Nevada. Lithium, he underscored, "is not like oil."

Though Musk invoked the supply chain, the dimensions of this chain diverged from the distributed, externalized forms that Anna Tsing describes as characteristic of "supply chain capitalism" (2009). Both geographically and jurisdictionally, Musk domesticated mining. In the case of lithium the supply chain was shortened, the tail tugged onto national territory. With nickel, Musk exerted influence over the end of the chain not with the weight of Telsa's present-day production, but the promise of its future manufacturing volume. In his speech, high-volume, high-

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[4] Though such planning is not unusual, the volumetric disjuncture between current and planned for supply, and the long timescales for which supplies are being shored up, are notable.

speed production – of both batteries and the metals they require – mirrored the urgency and scale of climate change. Compressing manufacturing time became synonymous with hastening carbon mitigation: “It matters if sustainable energy happens faster or slower.”

Part III: Flexibility

“Flexibility,” one Energy Storage Association publication avers, “is the core benefit of energy storage” (2019). In other words, batteries can serve multiple functions and do so with varied energy sources. Along with sustaining reliability and facilitating accumulation, batteries are thus also “flexible” along (at least) two dimensions: in the value and the provenance of the electricity they contain. First, stocked electricity might be either used or sold, alternately configured as a material, degradable commodity or as a commensurable, abstract “asset” (Energy Storage Association, 2021). Second, batteries store, and homogenize, electrons from any fuel source. These flexibilities stay with a battery after it is installed, operating not through a battery’s placement but via technocratic adjudications that often displace politics into “micro-political terrain” (cf. von Schnitzler, 2013: 677). Along both dimensions, securing the stable status of stored energy – or trading on its ambiguity – can signal agendas and effect change in political and environmental domains. In this third section, I first examine how the disjuncture between legal, material, and temporal bounding of batteries complicates efforts to negotiate the use and exchange value of the electricity they contain. Then, I detail how efforts to differentiate “clean” from “dirty” stored electrons both draw on and reshape these valuations.

“I’m already resentful of the increased intrusion of market mechanisms into my time. Let alone my life. Just like renewable electricity, if I don’t consume my time usefully I lose it. Never to be seen again. Unlike electricity I can’t store time. I have better things to do with my time than understand and consider the market implication of switching a light on. Give me 'set and forget'" (Franklin and Jotzo, 2018). I came across this remark in the comments section of an article concerning Virtual Power Plants (VPPs), a means of connecting dozens to thousands of behind-the-meter batteries via a third-party software. The commenter, named Julian, contests the collapse of the use and exchange values of electricity and storage. Neither time nor electricity, he asserts, are equivalent when used versus when stored. Renewable energy, like time, to him is valuable only when used immediately; he also differentiates it from 'electricity' writ large.

At first glance, Julian seems to reject the kind of "value optimizer" subject that market-based electricity technologies like smart grids elicit – an accountable user who calibrates demand to price cues (cf. Özden-Schilling, 2016). Yet Julian responds most directly to a different interpellation. He contests not only the expectation that his use will be elastic, but also the requirement that he choose when to neither use nor not use, but store. Julian, it seems, rejects the subject position not of the rational consumer but of what I have referred to as the "prosumager," the consumer who also produces and stores (Schill et al., 2019; Sioshansi, 2019).

Before prosumagers there were prosumers, those consumers who also produce – including (though not solely) electricity, most commonly via rooftop solar panels installed behind the meter.[5] U.S. prosumers have for decades partaken in both the use and exchange value of electricity due to net [electricity] metering (NEM) laws, state-specific policies that were created to incentivize customers to purchase solar panels by paying them, at their own electricity purchase rate, to sell solar power to the grid. Though different NEM policies work differently, solar is often exchanged not for money but for electricity credits. These credits thus, in a sense, function like a wheat

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[5] Futurist Alvin Toffler coined "prosumer" in his book *The Third Wave* (1980). The word is often used today to describe utility customers who sell solar energy to the grid (Parag and Sovacool, 2016).

elevator “receipt,” rendering distinct electrons equivalent across time and source. In this instance, the grid functions as the elevator to the prosumer’s wheat. As with the wheat futures that historian William Cronon describes in his analysis of Chicago as a relay point for commodities across the Midwest, NEM credits constitute electricity as a kind of currency by “obscuring its physical identity and displacing it into the symbolic world of capital” (1992: 120).

Yet as with wheat, electricity is not a perfect currency: it retains crucial uses. In this case, the “uneasy truce” between its abstraction and use does not span actors and time; each prosumer engages both values (cf. Cronon, 1992: 147). Nevertheless, navigating these two valuations is generally straightforward when electricity cannot readily be stored. Use takes precedence as prior to exchange: electricity not immediately used is automatically sold. Prosumers’ hold on exchange is, meanwhile, tenuous, captive to the shifting regulatory, informational, and economic landscape that Canay Özden-Schilling calls the grid’s “informational infrastructure” (2016: 71–72). Indeed, as distributed solar has proliferated, utilities have pushed back against net metering, in part because buying electricity wholesale is cheaper than paying the customer’s price (Helm, 2020).

The introduction of batteries complicates the relationship between electricity and value. Storage, in theory, opens opportunities for arbitrage by maintaining electricity in a state of potential, ready for use or exchange. The option to delay can insulate against blackouts and in some cases allow customers and companies to more easily sell electricity for profit. Yet a prosumager’s control over whether and when stored electricity is used or exchanged is dubitable, dependent on a shifting, heterogeneous, and often opaque discursive-material landscape.

Electricity also diverges from ideal currency in another way: battery efficiency decreases with every charging cycle. The more a battery is used, the more rapidly its value as carapace degrades. Moreover, leveraging batteries for profit, which requires synchronizing charge-discharge cycles with rapid electricity price fluctuations, can hasten their degradation.[6] Some environmental conditions, such as low temperatures, can also decrease battery life (Vidal et al., 2019). Batteries' situated pace of decay means that, like solar panels (Cross and Murray, 2018), they may be discarded before their on-paper lifetime is over.[7] As with solar panels (Mulvaney, 2019), moreover, they contain toxic components that, for the moment, are logistically difficult and unprofitable to recycle. In part because of these toxicities, they are also designed to be 'tamper proof', a black-boxing that has stifled user maintenance and repair (Bhowmik, 2019). At both household and industry scales, planned-for rates of battery decay – like the volumes of metal such devices are anticipated to require – hinge, in part, on speculative projections of use.

Virtual Power Plants, which Julian so pithily dressed down, encapsulate how laws, software, and hardware create ambiguities that at once sustain and foreclose potentials for energy access and use. VPPs use third-party software to control multiple behind-the-meter batteries *en masse*, functioning as a grid-scale battery that can buffer against blackouts, regularize renewables, or maximize profit. In exchange for joining, participants receive financial incentives, which vary between VPPs. Some must own a battery but qualify for electricity rate cuts; others are sold a battery at a discount. Whether and how consumers, utilities, and corporations can enter into and control VPPs is under ongoing dispute (Bandyk, 2020).

The reactions of Newman!, icarus26 and AnotherDayInParadise to the announcement of a

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[6] Tesla's 2016 and 2017 Powerwall warranties demonstrate the nuances of battery lifespan calculations: the contracts imposed slightly stricter warranty compliance requirements on customers who leveraged their battery to exchange electricity with the grid compared to those who used their battery only to store homemade solar power for personal use (Peacock, 2016; Tesla Powerwall Limited Warranty (USA), 2017).

[7] Battery lifespans, moreover, have also been conditioned by a century of battery research agendas geared towards equipping them not for the electronic vehicles of the early 20th century, but for the small electronic devices of the late 20th and 21st. Technologies such as laptops and cellphones require high energy density and power, even at the expense of battery longevity. Indeed, due to the profitability of selling electronics that rapidly become obsolete, attuning batteries to such small-scale applications may have even, in some contexts, disincentivized investing in research to lengthen battery lifetimes (Pecht, 2006; Eisler, 2017; Bhowmik, 2019).

VPP in Southern Australia demonstrate how the complexity and heterogeneity of battery initiatives can disempower even as they hail would-be participants as prosumagers. In one energy forum, the three traded notes on how to guarantee a spot in the new pilot project. Newman! was anxious: “There is HIGH DEMAND for this from consumers…I am going to keep on their back[s]…[I] want it installed this round- the numbers are great for me.” icarus26 agreed that, particularly due to the short list of suburbs prioritized, the chances of being picked were unclear. But, though enthusiastic, icarus26 was planning to carefully review the numbers and would join only “assuming I like the T&Cs [Terms and Conditions] ;)” (*Whirlpool*, n.d.).

Yet for these entrepreneurial enthusiasts, despite careful research, legal and economic opacity merged with messy materialities to cloud their sense of the VPP’s implications. No one knew the terms of the agreement, including how often and how much power the utility company would draw (which would impact both battery life and control over charging). Electricity’s unstable use status further complicated any attempts to calculate the program’s benefits.

Newman! was resigned to a lack of clarity: “[the utility has] the right to control it how they wish, at the end of the day you have to trust them.” icarus26, though, was worried about how the program would affect the “back pocket,” his battery’s profit potentials: “Before now AGL had no control of your system past the Meter. Now they can control your whole storage system and how it behaves – that's why the terms and conditions are so important to understand. Trust them, no thanks.” AnotherDayInParadise was most suspicious, but cited limitations on not the sales but the private use of electricity as the most pernicious element of the agreement: “[the utility] exports power to the Grid when IT needs it, but that means that there is no power available when YOU need it.” In the commenters’ exchange, the appeal of banking electricity behind the meter for profit is undermined by its critical uses, regulatory opacity, and distrust.

Alongside its flexible valuations, the electricity stored in batteries is of ambiguous origin. Like batteries' ability to synchronize renewables to consumer whim, this quality in one sense reflects the broader capacity of many stored forms to conceal and homogenize (Bhowmik, 2019; Eisler, 2017). Shipping containers, for instance, have increased the ease with which illicit goods can be transported; containers can also conceal their own vacancy (Parker, 2013). As Deborah Cowen describes, efforts to differentiate containers by the legality of their contents can sometimes hinder the "seamless" flow of goods (2014: 85), generating what Dara Orenstein calls a tension "between the sovereign and the capitalist logics of territory" (2019: 2).

Yet in another sense, the opaque origin of batteries' stored electrons reflects the broader ambiguities – the material, and ethical, irreducibilities – of grid-based energy. On the grid, electricity from renewables and fossil fuels commingles. Among other effects, this means that the renewable energy power plans sold by utility companies, which furnish users with electricity that has passed through communal power lines, do not guarantee that the energy customers actually *consume* will come from renewables. Rather, such plans offer only the guarantee that a certain quantity of renewable energy has been *produced*. All entities that use power from a grid, whether to charge batteries, power appliances, or fuel industrial production, draw from whatever fuel mix is instantaneously available – the same mix their neighbors use.

The unparsable provenance of stored electrons lends batteries a political pliability that can complicate efforts to enroll them in climate mitigation. Yet batteries, unlike utility renewable energy plans, also offer users a mechanism to eliminate this ambiguity – to guarantee that the electricity they consume comes from clean sources, no matter the time of day. Indeed, in the name of aligning batteries with climate goals, some state legislators have attempted to enroll them in projects to distinguish "clean" from "dirty" stored electrons at the user scale.

Such projects, like shipping container risk assessments, negotiate the tensions between market and sovereign logics of space. The question of whether batteries should qualify for net metering benefits offers a salient example. Allowing energy stored in household batteries to be exchanged for credits is one way to incentivize storage – and reap its climate-mitigating potentials. Yet if all storage were eligible for net metering, stored electrons sourced from fossil fuels could just as readily be exchanged for credit, potentially hindering rather than facilitating the growth of renewables. Leveraging arbitrage conditions for climate goals, therefore, requires the arbitration of electrons: regulators must delineate the contexts in which stored electricity qualifies for credits.

Yet parsing clean from dirty electrons is knotty. Even if only batteries co-located with solar panels were eligible for NEM, batteries could still exchange electrons directly with the grid. One solar magazine articulates the "NEM integrity" issue that such flexibility poses: "the battery could charge up at night with 'dirty' electrons and then discharge these… during the day…This is not allowed because NEM credits are for clean energy only" (Hyde, 2020).

In Massachusetts, the solution has been to classify batteries as "clean" based on the number and direction of the connections between these batteries, co-located renewable energy sources, and the grid. Solar-battery installations in which the battery has only a one-way grid connection are eligible. But if a battery has a two-way connection to the grid – if it can charge from a co-located solar panel, charge from the grid directly, *and* discharge power into the grid, it is not eligible. Under this policy, adding a battery to a solar installation could, counterintuitively – depending on the grid connection set-up – disqualify the solar panels for net metering entirely.

Once again, energy enthusiasts have offered potent critiques. In one Tesla Motors Club chat room, Ampster, upon learning that the government could regulate the contexts in which energy stored in their Tesla Powerwall was eligible for net metering, was incredulous. "How are they going to do that?" Ampster asked, "Have they been talking to Monsanto? LOL. Is there a genetically modified electron that I don't know about? I would challenge them to see what I am doing behind the meter"(Ampster, 2016). Ampster's comment, one suspects, reflects in part an ethos of energy freedom. Yet their comparison of state environmental initiatives to a corporate policy that has wrought environmental and social damage is, nevertheless, jarring. Ampster's incredulity illuminates the disjuncture between these laws' intents and effects: their detachment from the climatic imperatives that comprise their most obvious rationale.

In some sense, policies that parse the value of electrons re-politicize batteries, casting them not as the fuel-neutral mediators of Energy Storage Association lobbying efforts but rather as partial devices key to renewable energy transitions. Yet such policies operate within a similarly technocratic discourse, staging electricity storage as what Antina von Schnitzler, in an ethnography of water meters in South Africa, calls "a *political terrain* for the negotiation of moral-political questions" (2013: 671). A battery, precisely installed, allows its user to calibrate investment in renewables with personal power use – to guarantee the clean, ethical provenance of all electrons privately consumed, irrespective of renewables' temporal intermittencies.

As with other exercises in renewable energy accounting, this outsourcing can bury political stakes and narrow conceivable interventions (cf. Lennon, 2020: 947–8). Just as they sometimes atomize climate adaptation efforts, batteries can constrain the parameters of accountability for climate mitigation to the dimensions of the household, institution, or corporation behind each electricity meter. Though their scale is larger and more heterogeneous than that of the individual, such behind-the-meter entities are well-suited to existing conceptual-legal frameworks that govern at natural- and composite- person scales (cf. Shever, 2012: 193–199). Paired with grid-isolated batteries, renewables, and their ethical imperatives, emerge as readily divisible. The resources and expertise required to partake in battery markets, moreover, can also narrow these markets' potential participants, limiting access to the profit, and virtue, that storage endeavors might impart. After all, if the likes of Ampster, Nelson!, and icarus26 cannot optimize storage incentives, who – apart from armies of experts – could?

Conclusion

In 1907, Robert A. Fessenden filed a patent from Brookline, Massachusetts. Though Fessenden is known mainly for his innovations in radio, this patent detailed a "system of storing power" with enough capacity to service whole cities (1917: 2). The mechanism was not chemical but hydraulic, one of a cohort of contemporaneous ideas for storing electricity by pumping water to elevation (which releases energy as it flows downward). Fessenden's particular contribution was to store water at ground level and dig a reservoir underground into which it could flow when energy was needed.

Despite its difference in substance, the function of his storage invention, which was finally granted patent in 1917, is recognizable. His explanation of its importance might have been pulled from Form Energy's website. "It has long been recognized," he wrote, "that mankind must, in the near future, be faced by a shortage of power unless some means were devised for storing power derived from the intermittent sources of nature." His techno-optimism, like Tesla's and Form's, fends off an uneasy futurity. Yet here, too, this uncertainty takes on the parameters of the product he has made. With his device, he declares, "The vital problem of storage of power from natural intermittent sources is thus definitely and finally solved" (1917: 2).

The familiarity of Fessenden's long-passed futurity illuminates how solutions can help constitute the problems they aspire to solve. Neither today's grid-scale storage innovations, it turns out, nor the unprecedented wrongs they seek to right are novel: both are over one hundred years old. In the face of this century-scale correspondence, one might wonder about the precise directionality of causation between the two: was the multi-scalar unreliability of electricity – alternately intermittent or scarce – always already prior to the storage that could stave off its uncertainty?

I would argue that both then and now the qualities of the solution (figured as reliable storage) and problem (a scarce or intermittent energy indexical of broader unease) are mutually constitutive. When cast as technologies to sustain smooth circulation, batteries are signified as crucial via a rendering of demand as a given and of schedule stability as supreme. On the grid, battery size and siting are malleable: their reach can help fix or unsettle the dimensions at which not only electricity, but solidarity and shared experience, extends. When configured as detachable, on the other hand, they can discursively and materially substantiate the inevitable, evident need to privatize insulation against uncertainty. Modulating batteries helps actors navigate the temporal discord between renewables and fossil fuels (Vannini and Taggart 2015) – to subvert, or sustain, the production and demand regimes such fuels have helped engender.

The meanings and affordances of batteries, I think, can be generatively engaged via the analytic of storage – even though their mechanisms exceed the mental models that the term typically evokes (see, for example, Bakke, 2019). Like many forms of storage, batteries are in part a technology of mediation: they can meter, direct, and coalesce circulations of both electricity and metals across time and space. They, like warehouses, airports, or containers, interrupt as much as they smooth, in part because the materials they comprise and contain, unlike abstract currency, have not only exchange value but use, can degrade, and are not fully liquid. Like seed caches and commodity stockpiles, batteries evidence, instantiate, and forestall multivalent futurities that, I suggest, are often characterized by anticipations of unpredictable destruction or decline.

Indeed, batteries, conceptualized and fabricated as modes of storage, play an increasingly central role in climate and energy futurities. Most climate mitigation plans figure an increase in electrification – in transport, industry, and more – as one key strategy for sustaining the meters of contemporary life while reducing greenhouse gas emissions. The plausibility, and salability, of these projections hinges upon the convincing performance of renewables – on their perceived capacity to sustain a vastly expanded electricity system further strained by anticipated climate-related extreme weather events. In turn, the productive efficacy and rhetorical persuasiveness of renewable energies – which, in isolation, are unruly, intermittent, and unpredictable – depends crucially upon energy storage technologies such as batteries. Pairing renewable energy resources with storage, so-called "firming" renewables, does not just fortify but configures their spatiotemporal and productive capacities, constructing renewables as "resources" at all.

Batteries and other forms of energy storage such as green hydrogen, solar thermal plants, and pumped-storage hydropower are thus crucial and generative sites for studying the politics of energy transformations and climate change. Energy storage, which offers a mechanism to spatially and temporally de-link renewables from the electricity grid, opens up new vectors of complexity for actors and analysts alike: new alignments and disjunctures between electrification, renewable energy, and power. Engagement with storage might also help STS scholars nuance ongoing efforts to make visible the relationships between renewables, production, and extraction by attuning scholars to a key mechanism by which such relationships are imagined, materialized and, sometimes, obscured. Though perhaps inevitably inadequate for the problems they are leveraged to solve, batteries and other modes of energy storage are key sites where actors enact environmental futures – and finesse these futures' interpretive frames.

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