Hawai‘i Natural Energy Institute

School of Ocean and Earth Science and Technology
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Waste Management of EOL PV Panels and LIBs in Hawai‘i

Prepared for the Hawai‘i State Energy Office

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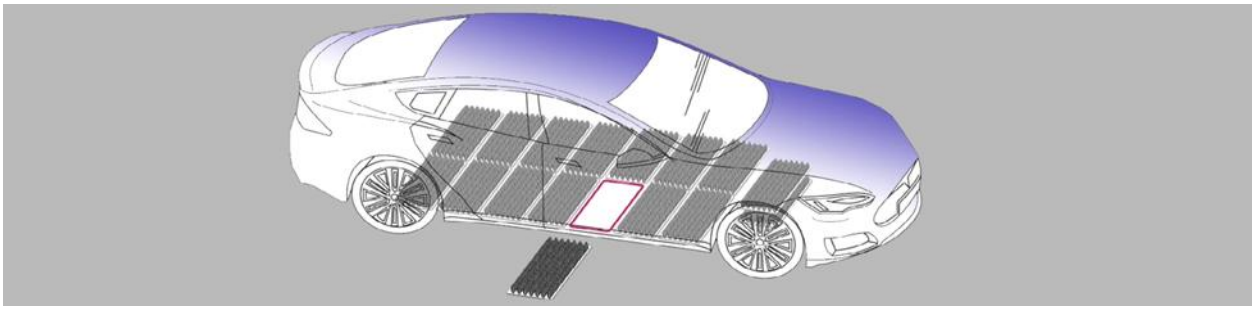
FOREWARD

The Hawai‘i State Energy Office convened a working group to report on the current state of End of Life (EOL) Li-ion Batteries (LIB) and photovoltaic (PV) panel accumulation in Hawai‘i, to identify current roadblocks and future options for their EOL treatment and removal from the islands. This document refers to and provides supplemental information to two previous reports authored by the Hawai‘i Natural Energy Institute. The initial report, submitted to the 2023 State Legislature, is available at https://www.hnei.hawaii.edu/wp-content/uploads/2023-HNEI-Act92-Final-Report-Clean-Energy-Products-Waste-Management.pdf and its supplemental report can be found at https://www.hnei.hawaii.edu/wp-content/uploads/HNEI-Act92-Supplemental-Report-Clean-Energy-Products-Waste-Management.pdf.

The material contained herein summarizes the conclusions of a LIB working group and is intended to add depth to policy recommendations for the EOL treatment of LIBs in Hawai‘i.

This report specifically focuses on the road blocks, costs and risks associated with the processing of EOL LIBs in Hawai‘i, as well as introducing current state of the art efforts in California. As these events are updated, removed, adjusted, or modified the correlated recommendations can likewise be updated.

Input has been obtained from a wide variety of sources but, as done in the original two reports, sources are referenced and notations are made when data has been approximated or translated to the Hawai‘i context.



ACKNOWLEDGEMENTS

This publication is the output of a LIB working group convened under the auspices of the Hawai‘i State Energy Office. Dr. Michael Cooney (UHM, Hawai‘i Natural Energy Institute) was the lead author. Members of the working group represented local businesses whose operations are either targeting or are disrupted by the current state of EOL management and disposal of PV panels and LIBs. The author and working group are grateful for their input as well as technical input from various professionals in the field who presented to the working group: Randall Lund (Sr. Marine Risk Consultant, Allianz Commercial | Allianz Risk Consulting), Doug Kobold (Executive Director, California Product Stewardship Council), Eric Frederickson (Call2Reycle), Todd Coy (Executive Vice President, KBI Recycling), Jessica Dunn (Union of Concerned Scientists), Hank Benson (Vice President, Operations at Industrial Battery Solutions, LLC), and Sandy Ferreira (Atlas Insurance).

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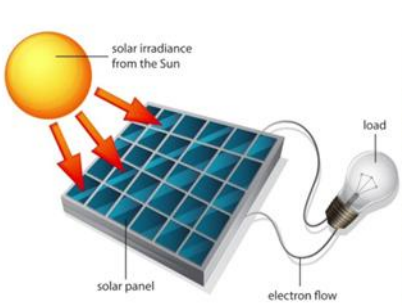
LIST OF ABBREVIATIONS

BTS	Battery Test Summary	**HNEI**	Hawai‘i Natural Energy Institute
CalEPA	California Environmental Protection Agency	**LIBs**	Li-ion Batteries
CalRecycle	California Department of Resources Recycling and Recovery	**MSDS**	Material Safety Data Sheet
CFR	Code of Federal Regulations	**NGO**	Non-Government Organization
DDR	Defective, Damaged, and Recalled	**OEM**	Original Equipment Manufacturers
DOH	Department of Health	**PV**	Photovoltaic
DOT	Department of Transportation	**RCRA**	Resource Conservation and Recovery Act
EOL	End of Life	**SOC**	State of Charge
EPR	Extended Producer Responsibility	**SOH**	State of Health
EV	Electric Vehicle	**TCLP**	Toxic Characteristic Leaching Procedure
HS	Harmonized System		



EXECUTIVE SUMMARY

The State of Hawai‘i faces a substantial risk with respect to its goals to achieve full renewable energy by 2045[1]. This risk is associated with the management of waste streams generated by these products. In particular, their transport off island at the end of their useful lifetimes. Unlike “Blue” states on the mainland, Hawai‘i does not have access to freeways and railroad lines to “Red” states where processing of EOL PV panels and LIBs are permitted. As such, operators in Hawai‘i must initially transport these EOL products via ocean transport. This creates significant risks. EOL LIBs, for example, are facing all increasing restrictions and costs to ocean shipping. The threat is real that at some point mainland or international ports, as well as ocean shippers, will simply decline to accept these products owing to the ever-increasing cost and unavailability of insurance.

Owing to the added costs of ocean shipping, the cost to recycle EOL PV panels and LIBs will always be a net cost activity for Hawai‘i. Moreover, these costs are expected to increase with the emergence of required specialized shipping containers, enhanced surveillance, and fire suppression systems.

Given the explosive and flammable nature to LIBs, especially EOL and DDR LIBs, the increasing restrictions on ocean transport pose a great risk to Hawai‘i. Even if EPR laws are passed and successfully implemented, they could fail if the ocean shippers decline to transport EOL LIBs. Also, the costs of packaging materials that satisfy DOT guidelines for shipment of EOL LIBs can further discourage their collection. To avoid these costs and risks, pretreating PV panels and LIBs in Hawai‘i should be considered because in the absence of a pre-processing facility in the islands, the shipment of EOL LIBs will increase the risk of catastrophic fires during shipment. Also, the costs of packaging materials to reduce this risk will dramatically increase the costs of shipping EOL LIBs which will indirectly encourage improper storage or accumulation at unsafe sights around the islands.

[1]https://energy.hawaii.gov/hawaii-clean-energy-initiative/#:~:text=The%20initiative%20has%20grown%20stronger,RPS)%20by%20the%20year%202045.

INTRODUCTION

The 2021 Hawai‘i State Legislature passed and the Governor enacted Act 92, Session Laws of Hawai‘i 2021 (HB1333, House Draft 1, Senate Draft 1, Conference Draft 1), relating to energy. This law required “the Hawai‘i Natural Energy Institute (HNEI), in consultation with the Department of Health (DOH), to conduct a comprehensive study to determine best practices for disposal, recycling, or secondary use of clean energy products in the state.”

Specifically, the law required HNEI to address and evaluate the following six topics:

1. The amount of aging photovoltaic and solar water heater panels in the state that will need to be disposed of or recycled;
2. Other types of clean energy materials are expected to be discarded in the state in substantial and growing quantities, including glass, frames, wiring, inverters, and batteries;
3. The type and chemical composition of those clean energy materials;
4. Best practices for the collection, disposal, recycling, or reuse of those clean energy materials;
5. Whether a fee should be charged for disposal or recycling of those clean energy materials; and
6. Any other issues that the Hawai‘i Natural Energy Institute and Department of Health consider appropriate for management, recycling, and disposal of those clean energy materials.

This report was submitted at the end of 2022. In a follow-on supplemental report, further depth was added to topics #5 and #6 – making use of extended travel to recycling sites, meetings with personnel at CalEPA, extensive discussions with senior personal from mainland stewardship programs, participation in working groups on PV recycling convened in 2023, and discussions with stakeholders in Hawai‘i. The supplemental report was posted on the HNEI website in December of 2023.

- Section 5 (**CONSIDERATIONS FOR DISPOSAL OR RECYCLING**) provides an evaluation of the costs and issues associated with the collection, disposal, and recycling of clean energy materials, as well as a discussion on how these costs and issues should be addressed in policy development.
- Section 6 (**OTHER ISSUES TO CONSIDER FOR MANAGEMENT, RECYCLING, AND DISPOSAL)** identifies additional issues related to the management, recycling, and disposal of clean energy systems that may be pertinent to the Act 92 request.

This current report follows up both the original and the supplement reports with commentary on the state of EOL PV panel and LIB waste streams in Hawai‘i. Specifically, we added data on accumulation of unaccounted for PV panels and LIBs, the current state of options for their waste management, and the major risks associated with both.

CURRENT OUTLOOK

This section provides data an overview on the current conditions regarding waste EOL PV panel LIB and management and accumulation in the state of Hawai‘i.

Context

In our supplemental report [1], it was noted that “while the technology and associated “know how” to recycle LIBs and PV panels does exist, these industries are relatively new, under development, and still evolving [2-4].” Moreover, it was also noted that “*the companies that produce both PV panels and LIBs are also relatively young, unpredictable, weighted to foreign ownership, inclined to modify design and, in the case of LIBs, manufactured across multiple entities - those that manufacture the individual cells, those that packaged those cells into larger battery packs, and those that incorporate the battery packs into the final EV car or energy storage system battery*.” [2] In aggregate, these issues have constrained the development of standardized technologies for recycling as well as the concomitant establishment of effective extended producer reasonability (EPR) laws[3]. When combined with the added costs associated with ocean shipment, the EOL treatment of both PV panels and LIBs is disorganized and a growing concern for Hawai‘i.

Imports versus Exports

Given the absence of any tracking mechanisms in Hawai‘i, along with the unwillingness of businesses to share data, the working group attempted to estimate the accumulation of both products in the islands by evaluating import/export data.

PV panels. To estimate the amount of PV panels accumulating in Hawai‘i, the difference between the declarations of imported versus exported PV panels was researched. The data, shown in Figures 1 and 2, was mined from the U.S. Census Bureau reporting on harmonized system (HS) port level data[4]. Through this, we were able to find the gross weight in kilograms of shipments made by seafaring vessel at customs, the Honolulu District Port (includes FEDEX Corp Honolulu, Hilo HI, Honolulu International Airport, Kakului HI, Kona HI, an Nawiliwili – Port Allen), of 854143 Photovoltaic Cells in Modules OR Panels, from 2003 through 2023. The data in Figure 1 shows a significant discrepancy between imported solar modules versus their export. Figure 2 also shows that as a result of the Hawai‘i DOH’s push to classify solar panels as universal waste in 2021 [5], there is no longer any ability to track export numbers of PV panels as declared at customs. The working group did note that given the long lifetime of PV panels, on average 20 years, part of this discrepancy can be explained by modules having not yet reached their EOL.

[2]Although sometimes the latter two steps are done in the same company.
[3]https://earth.org/impossible-to-recycle-the-limitations-of-extended-producer-responsibility-policies/
[4]https://usatrade.census.gov/

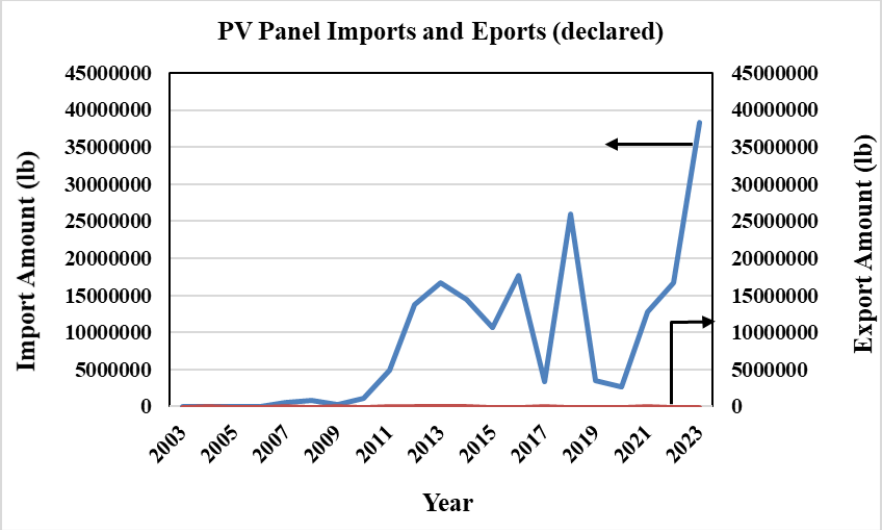


Figure 1. PV panel imports versus exports as declared through customs.

	PV Panel Import		PV Panel Export	
Year	kg	lb	kg	lb
2003	0	0	0	0
2004	3,263	7178.6	74	162.8
2005	420	924	0	0
2006	7553	16616.6	0	0
2007	219302	482464.4	7748	17045.6
2008	354812	780586.4	0	0
2009	128666	283065.2	15979	35153.8
2010	494236	1087319.2	0	0
2011	2246824	4943012.8	1464	3220.8
2012	6279299	13814458	809	1779.8
2013	7,592,022	16702448	1155	2541
2014	6,595,729	14510604	10,000	22000
2015	4,857,369	10686212	0	0
2016	8,042,685	17693907	0	0
2017	1,542,265	3392983	817	1797.4
2018	11,791,677	25941689	0	0
2019	1,614,835	3552637	0	0
2020	1,233,800	2714360	0	0
2021	5,827,588	12820694	20000	44000
2022	7,596,330	16711926	0	0
2023	17,396,454	38272199	0	0

The classifying PV panels as universal waste under Chapter 11-273.1, HAR has led to their declaration under a generic category that does not permit their tracking at customs.

Figure 2. PV panel imports versus exports as declared through customs.

Lithium-ion batteries. To estimate the amount of LIBs imported into and exported out of Hawai‘i, data on LIBs was mined from the U.S. Census Bureau reporting on harmonized system (HS) port level data[5]. Through this, we were able to find the gross weight in kilograms of shipments made by seafaring vessel at customs, the Honolulu District Port (includes FEDEX Corp Honolulu, Hilo

[5] https://usatrade.census.gov/

HI, Honolulu International Airport, Kakului HI, Kona HI, an Nawiliwili – Port Allen), of 850650 Primary Cells and Batteries, Lithium, and 850760 Lithium Ion Batteries, from 2003 through 2023. The results are presented in Figures 3 and 4. Similar to the case for PV panels, both Figures 3 and 4 show an analogous discrepancy between declared imports versus declared exports. While some of this discrepancy can be explained by the lag between import and end of life, the working group did note that LIBs have much shorter lifetimes (than PV panels) and are beginning to show up Hawai‘i waste streams.

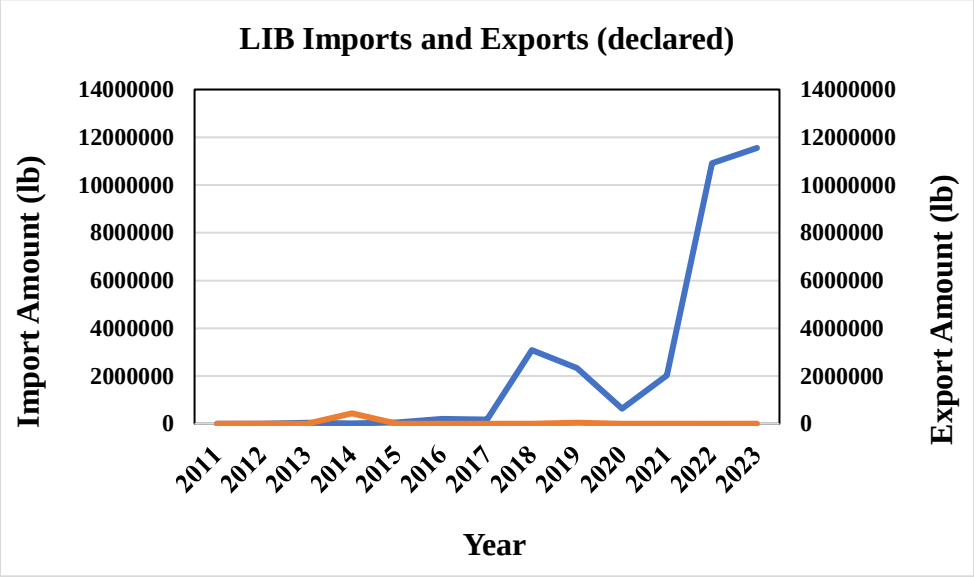


Figure 3. Plot of LIB imports versus exports as declared through customs.

	LIB Import		LIB Export	
Year	kg	lb		
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	0	0	0	0
2008	0	0	0	0
2009	0	0	0	0
2010	0	0	0	0
2011	0	0	0	0
2012	947	2083	770	1694
2013	17737	39021	0	0
2014	6903	15187	198281	436218
2015	24172	53178	0	0
2016	93443	205575	0	0
2017	78824	173413	0	0
2018	1399541	3078990	52	114
2019	1062614	2337751	19244	42337
2020	288886	635549	0	0
2021	920752	2025654	351	772
2022	4959939	10911866	0	0
2023	5251241	11552730	2970	6534

The classifying of LIB as universal waste under Chapter 11-273.1, HAR has not led to a complete absence in declarations at customs.

Figure 4. Table of LIB imports versus exports as declared through customs.

Figure 4 does show, however, the declaration of LIBs as “universal waste” did not reduce the amount declared as exports to be zero (as occurred with PV panels). It is likely that this small fraction of EOL LIBs were declared as “for reuse” or “new but with software issues” as opposed to universal waste. In this case, these LIBs would have been declared at customs. LIBs declared this way avoid the more costly requirements prescribed for DDR LIBs although they must still be packaged in such a way as to prevent short circuits and damage to the batteries[6]. Figure 5 presents a stockpile of LIBs that were replaced under warranty at major solar farm in 2023. While the working group was unable to elucidate how these LIBs were declared when shipped, the general consensus was that LIBs such as these are likely labeled as “for reuse” or “software issues” in order to avoid the more costly shipping requirements that go with EOL or DDR LIBs. Whether these LIBs were actually used for reuse (after they arrived on the mainland) or simply listed as such to avoid the costly packaging associated with shipment of DDR LIBs was discussed by the working group. The general consensus was it was more likely (than not) that these kinds of manipulations of manifest declarations are commonly used and that without the presence of stewardship programs in Hawai‘i that both manages and tracks disposal of LIBs in Hawai‘i over their full life cycle, the degree to which these types of activities occur cannot be tracked.

[6] 49 CFR § 173.185 - Lithium cells and batteries

Figure 5. Images of used and replaced LIBs in 2023 prior to off island shipment.

Verification of port harmonized data. To verify the use of census data to reasonably estimate imports and exports of both products, the amount of LIBs imported into Hawai‘i in 2023 was estimated from alternative routes to see if the two calculations verified each other. These results are shown in Figure 6. In this analysis, the number of newly registered EVs in 2023 was sourced and average weight per EV LIB used to estimate the mass contribution from this source. The number of residential and commercial scale LIBs imported was likewise estimated by sourcing data from DBET reports on solar battery installations. Again, average weights per units were used to estimate the mass contribution from this source. Similarly, sales of e-bikes, e-scooters and e-motorcycles in Hawai‘i were estimated from scaling down national sales to Hawai‘i’s percent population. Average weights for LIBs in these products was used to estimate the mass contribution from this source. Finally, the amount of LIBs imported via power tools was estimated by downscaling national sales by Hawai‘i’s percent population[7]. When accounting for inputs from all sources, almost 75% of imports (as posted in the census data) were accounted for. Given the obvious play in the data from all sources, reaching 75% consensus suggests high confidence in the import data as reported at customs.

[7]The data on power tools was provided by Eric Frederickson of Call2Recycle.

Item	Weight (lb)	#	kg	lb	
LIB imported in 2023			5251241	11552730	from US census
EV LIB	1000	6317		6317000	https://hawaiiev.org/#:~:text=EV%20Adoption%20in%20Hawaii%20%2D%20We,passenger%20vehicles%20in%20the%20state.
R battery	290	7000		2030000	DBET report https://files.hawaii.gov/dbedt/economic/data_reports/reports-studies/Solar_PV_Battery_Installation_2023%20update.pdf
C battery	2900	36		104400	DBET report https://files.hawaii.gov/dbedt/economic/data_reports/reports-studies/Solar_PV_Battery_Installation_2023%20update.pdf
e-bike	7	1143.7934		8006.5538	Statista (for U.S. and then multiplied by 0.0041)
consumer rechargeable batteries				187500	From Call2Recycle
e-scooter	10	89.1996		891.996	Statista (for U.S. and then multiplied by 0.0041)
e-morticycle	10	154.4347		1544.347	Statista (for U.S. and then multiplied by 0.0041)
	Amount of LIB unaccounted			2903387.3	
	% unaccounted			25.1	

Figure 6. PV panel imports versus exports as declared through customs.

Stockpiling

With the census data on imports being verified as a good estimate, the working group considered what happens to the EOL LIBs not declared in the export data (in 2023, for example, 0.056% of the amount of LIB imported). At first glance, the data in Figures 3 and 4 suggests LIBs are accumulating in Hawai‘i. The reality, however, is likely somewhat blurred. Options discussed by the working group included: (i) exported EOL LIBs are not being declared at customs but, rather, being packaged in mixed cargo or simply undeclared; (ii) EOL LIBs are being improperly stored/disposed in Hawai‘i; and (iii) most of the existing LIBs are still functioning and therefore not exported. The working group concluded the reality is likely combination of all three scenarios, with options i and ii being more significant than option iii. Evidence supporting this is presented in Figures 6 and 7, where images of LIBs currently being improperly stored in Hawai‘i are presented. The members of the working group generally agreed these photos captured only a small fraction of large-scale LIBs being stockpiled, and generally agreed this level of stockpiling of EOL LIBs is significant and increasing.

Figure 7. DDR LIBs stored at (i) a commercial business (left) in 2024; backyard of a home in 2023 (middle); and behind a commercial business in 2024 (right).

Figure 8. Images of improperly stockpiled LIBs at commercial business.

Waste Management

PV panels. PV panels are showing up the waste stream flows to landfill and H-Power, as well as being improperly stored [6]. Given the absence of any functional tracking mechanisms in Hawai‘i, a definitive assessment of how many are dumped or improperly stored is not possible to ascertain. Finally, given the reclassification of PV panels as universal waste, PV panels that are sent off island are no longer being declared at customs under classifications that can be tracked (Figure 2). As such, the ability to track PV panels through their EOL pathways is negligible. Members of the working group noted, however, the increasing appearance of PV panels in wastes streams at their facilities for which their only option (other than to simply move them on) is to deny acceptance of the shipments entering their facility. The working group further noted that imposing such restrictions will impose disruptions upon the day-to-day work flow of both the receiving site and the truck drivers. The working group also noted difficulties in contacting/accessing Inter-Island Solar's recycling program, the only one operating in the islands, as well as accessing their data. Nevertheless, transfers stations and other waste collection sites do not have the funds to pay Inter-Islands $60 fee per panel. More so, the working group noted a complete lack of any official and organized take back program for EOL PV panels (that could be used by operators to manage waste panels that show up in their waste streams moving through their facilities).

Lithium-ion batteries. Small scale LIBs are being improperly dumped into waste streams across Hawai‘i (Figure 9) while large scale LIBs are being stockpiled (Figures 6 through 7). Many of the smaller scale LIBs are brought to these stations through trash collection as end users simply dump their LIBs into the trash. The working group noted that these events are becoming common, with multiple fires occurring this year across transfer stations, H-Power[8], and other dump sites. An additional concern raised by the working group was the lack of any system or procedures to organize the mass collection and processing of LIBs so as to avoid this level of improper disposal. Of the many problems mentioned, the most notable were the lack of any incentive or reasonable process to dispose of their LIBs properly. Moreover, the working group also noted that there is no capacity (currently) to process the number of LIBs that could be captured even if collection sites were opened.

[8] https://www.hawaiinewsnow.com/2024/07/16/ems-5-men-treated-smoke-inhalation-2-alarm-fire-h-power-plant/

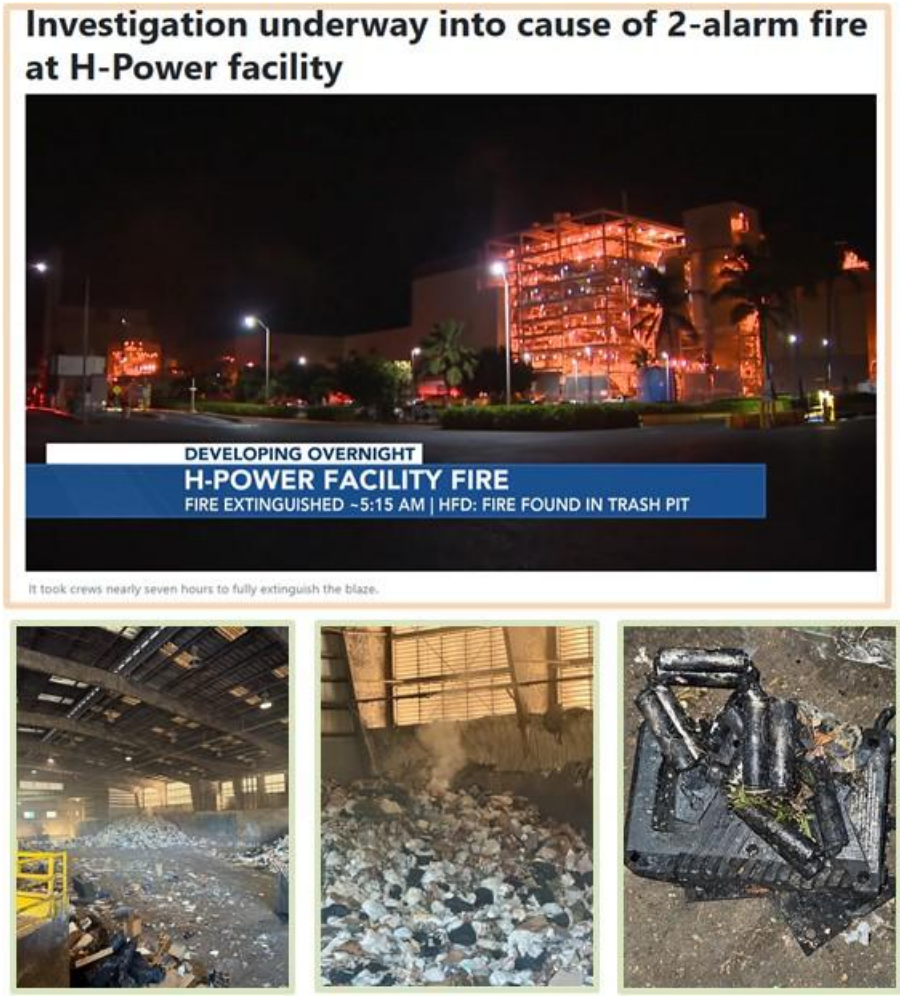


Figure 9. Recent LIB caused fires at H-Power (upper) and Middle Street transfer station (lower).

LEGISLATION

When considering the various pathways to dispose of EOL PV panels and LIBs, the working group reviewed relevant laws.

National

While the Resource Conservation and Recovery Act (RCRA) regulates solar panels as solid waste, there are no federal regulations mandating the collection or recycling of solar panels. That being said, solar panels that contain hazardous materials like lead, cadmium, or arsenic must be disposed of as hazardous waste. By contrast, LIBs are subject to several national laws in the United States. These include DOT's Hazardous Materials Regulations **HMR 49 C.F.R., Parts 171-180** which includes specific packaging and standard hazard communication requirements (e.g., markings, labels, shipping papers, emergency response information) and hazmat employee training requirements, **UN DOT 38.3** [7], which requires testing before LIBs can be shipped into the United States, and **RCRA regulations** 40 CFR 262.11[9] which require generators to accurately determine if a waste is hazardous and manage it accordingly. Finally, PV panels and LIBs are classified as universal waste, a process that streamlines the hazardous waste management standards for certain categories of hazardous waste that are commonly generated by a wide variety of establishments[10].

There have also been some key advisory notices put out by the U.S. Department of Transportation, including the DOT Safety Advisory Notice for Disposal and Recycling of Lithium Batteries in Commercial Transportation[11] and the DOT Guidance for Damaged, Defective, or Recalled (DDR) Lithium Ion Batteries[12]. These advisory notices have highlighted the increased risk of shipping LIBs as well as underscoring the proliferation of improper labeling and shipping techniques. Because of this, the working group discussed the reality that in response to these events ocean shippers as well as their insurers are likely to react in ways that are unfavorable to the long-term shipment of EOL and DDR LIBs.

California

At the time of this report, the issues discussed above remained relevant although moves towards effective ERP laws have increased. In California, AB-2, a bill that would have expanded the definition of "covered electronic device" to include a "customer-owned solar PV module," was merged into AB1238 on 06/10/24 before dying in the Senate on appropriations on 08/16/2.[13]

[9]https://www.ecfr.gov/current/title-40/chapter-I/subchapter-I/part-262/subpart-A/section-262.11
[10]Title 40 of the Code of Federal Regulations (CFR) in part 273
[11]https://www.phmsa.dot.gov/training/hazmat/safety-advisory-notice-transportation-lithium-batteries-disposal-or-recycling
[12] https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2023-03/final.pdf
[13] https://www.calpsc.org/legislation

AB1238, would have required “a consumer or a service provider serving the consumer, including a developer or installer of a consumer-owned solar photovoltaic system, to pay a consumer-owned PV panel (or solar photovoltaic module) recycling fee (in an amount determined by CalRecycle) upon the purchase of new consumer-owned PV panel[14].” AB128 also died in the Senate on 07/03/24. Most recently, Governor Newson vetoed SB 615, a bill that would have created a "responsible end-of-life management" program encouraging reuse, repair, and recycling and funded by battery suppliers[15]. SB 615 was vetoed on account of its placing onerous tracking requirements upon the Department of Toxic Substances Control (DTSC).

Hawai‘i

To date, Hawai‘i has not yet passed legislation addressing the EOL management of PV panels and LIBs. A bill, Hawai‘i Senate Bill 2311, seeking to establish “an electric vehicle battery recycling and disposal program” that prohibited “disposal of propulsion batteries as solid waste” was initially introduced on January 19 2024[16]. However, Bill 2311, which also prohibited “producers of propulsion batteries from refusing propulsion batteries for reuse, remanufacturing, repurposing, or recycling” died in committee. One significant feature (or issue) with Bill 2311 was that it sought to establish full “producer responsibility for propulsion batteries embedded into vehicles or sold separately in the State or through remote sale,” including requirements that they establish a “battery management plan” that would conceivably include extensive requirements on tracking. Moreover, Bill 2311 would have authorized the Department of Health “to inspect any place, building, or premise and issue warnings and citations for failure to comply.”

[14] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240AB1238
[15] https://www.gov.ca.gov/wp-content/uploads/2024/09/SB-615-Veto-Message.pdf
[16] https://legiscan.com/HI/bill/SB2311/2024.

OPTIONS

PV panels

Landfilling. PV panels can be landfilled in the U.S., although some states have enacted laws, regulations, and policies restricting this pathway[17]. For example, in 2020, California became the first state to add hazardous waste panels to its universal waste program[18]. As such, in California, PV panels can only be landfilled if they have been designated as non-hazardous by a qualified laboratory. Such a designation, however, requires a TCLP test – a toxicity characteristic leaching procedure – to determine its potential hazard. PV panels that fail the TCLP test are considered hazardous and cannot be sent to landfill[19]. TCLP tests, however, can be expensive with charges commonly upwards of $1,500, which (as noted by the working group) is more than most homeowners are willing to spend[20].

In 2021, Hawai‘i required any discarded PV panels to be recycled in a manner that’s compliant with hazardous waste rules, including PV panels that are manufactured but never used for whatever reason [5]. Specifically, PV panels must be recycled in a way that adheres to hazardous waste management rules, meaning they must be handled with proper safety procedures due to the potentially harmful materials within them [5]. As such, PV panels cannot be landfilled in Hawai‘i and because Hawai‘i has limited operational recycling centers, the primary option remains to send discarded EOL PV panels to off island recyclers. To ease this transfer, Hawai‘i (like California) has also classified solar panels as "universal waste", which eases the regulatory burden on retail stores and other generators[21]. Materials managed as universal waste can be stored for a year and are not required to be shipped with a manifest or by a hazardous waste transporter[22].

Reuse. The repair and/or refurbishment of used PV panels is one option to offset disposal [8]. The market for used or refurbished PV panels, however, has not yet gained significant traction in the United States, in part because the combination of foreseeable fall in prices and increased power ratings of new panels[23], as well as constrains on the demand for these products [1, 6]. Moreover, the working group noted that regulatory considerations, including electrical grid interconnection, as well as fire, building, and electrical codes provide additional hurdles limiting the reuse of used PV panels. Perhaps more problematic is the limited supply of used PV panels that are in good working order. Inter-island Solar Supply, for example, currently runs a program take in and arrange for the mainland-based reuse of PV panels [1]. The service, which costs upward to $60

[17]https://www.epa.gov/hw/end-life-solar-panels-regulations-and-management
[18]https://dtsc.ca.gov/2020/10/26/news-release-t-17-20/#:~:text=SACRAMENTO%20%E2%80%93%20On%20Jan.,our%20people%20and%20natural%20resources.%E2%80%9D.
[19] https://www.epa.gov/sites/default/files/2015-12/documents/1311.pdf
[20] https://www.phoslab.com/environmental-services/tclp-testing/
[21]https://www.epa.gov/hw/universal-waste
[22]https://www.epa.gov/hw/universal-waste
[23]See, for example, https://www.cnet.com/home/energy-and-utilities/why-the-cost-of-solar-panels-will-likely-keep-falling/.

per panel, works with a mainland company (Fabtech[24]) to take in and refurbish discarded PV panels [1]. Unfortunately, the majority of panels delivered to Fabtech by Inter-Island Solar are largely broken or beyond repair and could only be recycled or landfilled[25].

Recycling. Pretreatment of EOL PV panels generally refers to crushing, shredding, and milling, usually after removal of the frame and junction box[26]. When a used PV panel cannot be repaired or reused, recycling is the next preferable option before its disposal as waste [2]. Recycling EOL PV panels keeps them from being landfilled, which can leak toxins into the environment [9]. Recycling also allows for the recovery and reuse of valuable elements like silver, gallium and indium, and prevents harmful materials like cadmium and lead from ending up in landfills [10]. Indeed, the concept of recycling used PV panels suggests many components can be recovered [11]. For example, glass composes most of the weight of a solar panel (about 75 percent), and glass recycling is already a well-established industry. Other materials that are easily recyclable include the aluminum frame, copper wire, and plastic junction box.

The reality, however, is far different. Recycling EOL PV panels is expensive as recovery of embedded metals from the actual panels requires deployment of additional high-cost energy and chemically intensive unit operations to extract and purify relatively small amounts of precious metals per pound of material processed [12]. Further complicating this issue is the fact that recovery methods of metals from PV panels must be tailored to the unique material composition across manufacturers [13]. Also, PV panels are made up of multiple components that must be deconstructed and separated before recycling [12, 14]. These operations impose significant capital and operating expenses that make recycling a “cost positive” activity that requires tipping fees [6]. Recycling can cost between $20 to $30 per panel and will generally recover materials worth only between $3 to $12, leaving a net cost $8 to $27 – up to 13 times the cost of landfilling[27]. As an example, consider the case of recycling PV panels to recover silver [12]. To be profitable without charging a tipping fee, Granata et al. (2022) estimated that the volume processing loads of PV panels need to be relatively high (above 18,000 tons[28] per year for panels with silver concentrations of 0.2% or above 43,000 tons[29] per year for silver concentrations as lows 0.05%. The silver recovered needs to be priced above $600 per kg. For these reasons, EOL PV panels are generally sent to landfill or e-waste facilities that will salvage what they can – usually the aluminum, glass, and copper – while shredding the remainder of the panel’s components before sending them to landfill [15, 16].

Summary. The reuse market is limited and cannot be expected to service the majority of EOL PV panels. Despite overtures to a growing recycling market [17], in the U.S., there are no federal

[24]https://fabtech.net
[25]Personal conversation with Janette Freeman, Director of Business Development, Fabtech. May 20204.
[26]https://www.epa.gov/hw/solar-panel-recycling
[27]https://www.empirecenter.org/publications/renewable-solar-comes-with-recurring-waste-costs/
[28]Approximately 900,000 panels
[29] Approximately 2.1 million panels

regulations to mandate PV recycling [18] and, as such, less than 10% of the country's decommissioned panels are recycled [19]. The situation is limited in Hawai‘i where there are currently no operational preprocessing/recycling or facilities. Given the cost of ocean shipping, the disposal of EOL PV panels is and will therefore remain a cost-positive activity for residents of Hawai‘i [1, 6]. This will continue to result in a low capture rate of EOL PV panels, with the non-captured panels dumped or presumably sent to landfill[30]. Evidence of this can be seen in the discrepancy of imports versus exports through 2021, and from feedback reported to the working group.

Lithium-ion batteries

Landfill. LIBs are regulated hazardous materials, and most international regulations classify them as dangerous goods[31]. As such, they should not be transported to or placed in landfills[32]; but rather they should be disposed of properly through designated recycling programs at convenience centers, transfer stations, or separate waste collection points[33]. While this is the goal both nationwide and in Hawai‘i, the working group noted that this is not the reality, particularly Hawai‘i.

Reuse. EV LIBs that are retired due to vehicle damage or defective cells may be restored to a like-new condition through refurbishing or remanufacturing [20]. There are a number of challenges, however, to their reuse/repurposing that will restrict demand (and thus price). First, estimating the remaining capacity of used LIBs will be challenging owing to the variety in the make of EV and energy system LIBs in terms of electrode chemistry, size, and format [21]. Moreover, those who refurbish LIBs must first diagnose the state of health (SOH) on a cell level, replace worn or defective parts, then reconfigure the cells or modules to produce a pack with uniform SOH. The last step is referred to as "rebalancing the modules" to actively adjust the charge level of individual cells within a battery pack to ensure they are all at a similar state of charge (SOC). The difference between the two is that refurbishing is performed to restore new packs with minor defects to OEM-specifications, while remanufacturing restores used packs to a like-new condition by replacing worn parts. Second, standards for second life battery quality and performance are still being developed [22]. The absence of widely accepted standards can make potential buyers wary while their presence can reveal flaws that limit demand. It also requires testing and certification across all makes and brands [23], with limited numbers operating successfully on the mainland[34]. The working group noted that although useful, a refurbishing/reuse market/industry will be hard pressed to service the entirety of EOL LIBs in the U.S., let alone in Hawai‘i [24].

[30] https://www.hawaiipublicradio.org/local-news/2024-08-14/hawaii-demand-solar-panel-recycling
[31] https://www.epa.gov/recycle/used-lithium-ion-batteries
[32] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-I/part-268?toc=1
[33] https://www.epa.gov/recycle/used-lithium-ion-batteries
[34] See Bumblebee Battery Recycling which refurbishes Toyota and Honda LIB. https://bumblebeebatteries.com/.

On the other hand, LIBs with a lower but still sufficient SOH may be repurposed for “second-life” use in a stationary storage application [25]. Repurposing generally involves disassembling the pack into modules to break the chain of voltage, diagnosing the SOH of cells or modules, reconfiguring them to optimize efficiency, equipping the repurposed system with a new battery management system (BMS) and other software if the existing BMS is not available, and installing it in a shipping container or purpose-built battery enclosure. That being said, reusing or refurbishing LIBs presents several challenges, including the complexity of the process, potential safety concerns due to degradation, inconsistent battery performance, and the need for specialized equipment to properly assess and manage individual cells, making it often more cost-effective to simply recycle or dispose of EOL LIBs than to try to reuse them fully [26].

Recycling. Pretreatment of EOL LIBs, is generally defined as charge deactivation followed by crushing or shredding to reduce the battery to non-explosive and non-flammable components [27]. Recycling EOL LIBs require high-cost energy and chemically intensive unit operations to extract and purify relatively small amounts of precious metals per pound of material processed [6]. In your average battery recycling plant, for example, battery parts are shredded down into a powder, which is then either melted (pyrometallurgy) or dissolved in acid (hydrometallurgy) [28]. However, LIBs are lots of different parts that could explode if they're not disassembled carefully. And even when LIBs are broken down this way, the products aren't easy to reuse [28]. The current method of simply shredding everything and trying to purify a complex mixture results in expensive processes with low value products [28]. As a result, it costs more to recycle them than to mine more lithium to make new ones[35]. Also, since large scale, cheap ways to recycle LIBs are lagging behind, only about 5% of LIBs are recycled globally, meaning the majority are simply going to waste [28].

Revenue streams from LIBs recycling is and will remain constrained in part because of low recovery yields – both inefficiencies in recovering operations but also to low concentrations per pound of material, but also because of production from the mining industry [29]. For example, a recent discovery of high-grade lithium in Nevada bodes well for lithium production that places downward pressure on its market price [30]. For these reasons, EOL treatment of LIBs will always be a cost positive proposition that will require the pursuit of additional revenue streams to supplement revenue from the sales of recovered precious metals [1].

Summary. Current options for disposal of EOL PV panels as well as EV or energy storage system LIBs will remain a positive cost activity in Hawai‘i [6]. Also, the cost of shipping out of Hawai‘i is particularly significant for LIBs and will surpass the cost of recycling. Moreover, federal agencies, shipping companies, and their insurers can be expected to impose increasingly strict transport regulations to counter the risk of explosions and fire which will, at best, increase cost or, at worst, forbid transport.

[35]https://www.sustainabilitybynumbers.com/p/lithium-electric-vehicles

RISKS

Overview

Due to strict regulations, EOL PV panels and LIBs cannot be preprocessed in Hawai‘i. Because of their classification as universal waste, facilities can collect, package, and ship these materials off island with extensive permitting but with the exception removing frames from PV panels, the ability to crush, shred, or otherwise treat these materials is not currently permitted. This requires that EOL PV panels and LIBs only be shipped off-island for treatment and disposal. The working group identifies several risks associated with this situation.

EPR laws

Rather than pursue pathways to preprocess LIBs to non-flammable and non-explosive fragments that are safe to ship, Hawai‘i legislators proposed Bill 2311 in 2024. The idea behind this bill was to put the entire responsibility of management of EOL LIBs onto manufacturers. Had it passed, however, Bill 2311 would have presented significant risks for Hawai‘i with respect whether, or not, manufacturers would continue to import LIBs into Hawai‘i. The working group discussed these risks and identified two main concerns.

Manufacturer response. One challenge to the EPR model, with respect to PV panels and energy storage system LIBs, is the difficulty in identifying and gaining compliance from the responsible manufacturer. In addition to a general ongoing resistance of these manufactures to take on these burdens, the production of PV panels and energy systems LIBs occurs through multiple layers of manufacturers of which many are outside the U.S.[36]. As a consequence, it can be difficult to identify which manufacturer is responsible. Moreover, if that producer is outside the U.S., it can be more difficult, if not impossible, to enforce compliance (on them). Finally, as both recycle and reuse industries are fluid and developing, the risk of a given manufacturer of PV panels or LIBs going out of business before their products reach end of life is real and significant[37].

In Hawai‘i, heavy reliance on EPR laws is a relevant concern because two previously passed laws with heavy EPR requirements for PV panels in Washington State[38] and Niagara county[39] resulted in PV manufacturers declining to import PV panels into these regions [6]. With respect to LIBs,

[36] In the case of PV panels, the solar cells may be produced by one manufacturer while the PV module itself may be assembled by a second. In the case of batteries, the battery cell is manufactured by one producer and assembled into a battery pack or module by another.
[37] See for example the following press release announcing LG is leaving the PV module production business. https://www.lg.com/us/press-release/lg-to-exit-global-solar-panel-business.
[38]https://ecology.wa.gov/waste-toxics/reducing-recycling-waste/our-recycling-programs/solar-panels#:~:text=In%202017%2C%20the%20Washington%20Legislature,while%20solutions%20are%20being%20developed.
[39]https://www.niagaracounty.gov/government/county_information/niagara_county_solar_panel_recycling_local_law.php#:~:text=NIAGARA%20COUNTY%20SOLAR%20PANEL%20RECYCLING%20LOCAL%20LAW,-NIAGARA%20COUNTY%20SOLAR&text=Beginning%20August%201%2C%202022%2C%20no,4.

the situation is not much better. While California[40] and Washington[41] have enacted extended producer responsibility (EPR) laws specifically for LIBs, which shifts the responsibility for battery recycling from consumers to manufacturers, these laws are limited in scope. More, the patchwork of state policy and regulations related to battery recycling reflects the complex and inconsistent approach to handling LIBs in the electric mobility industry[42]. The working group noted that such conditions do not create a favorable environment for the implementation and resilience of demanding EPR laws in Hawai‘i, rather they pose a significant risk in terms of manufacturers willingness to import them into the state.

Market size. Although, extended producer responsibility (EPR) or similar models, whereby the manufacturer, reseller, or installer is responsible for the EOL management of PV panels, electronic items, and LIBs, is conceptually attractive, policy development should consider the fact that Hawai‘i is too small of a market to adopt/implement/enforce policies that are overly aggressive compared to national trends. California, in fact, is perhaps one of only a few states that are large enough to drive trends nationally. Currently, only two states[43] have pursued EPR policies for PV panels and LIBs and a third[44] has opted to pursue visible fees[45] (and not EPR) programs for both PV panels. Each of these efforts have faced varying degrees of implementation issues, including pushback from (i) state agencies that aggressively restrict any type of in-state pre (or full) processing of these materials, (ii) manufacturers eager to restrict their responsibility to only those materials manufactured by them and, in particular, only those installed going forward (i.e. avoid responsibility for legacy products), and (iii) installers of solar systems (PV panels or PV panels with LIBs) who wish to avoid adding any fees associated with EOL treatment. All of these efforts have also suffered a lack of funding to support those entities (whether it be state agencies or private nonprofit stewardship organizations) charged with overseeing/managing the EOL process as defined in law[46].

Insurance

Transportation of EOL LIBs incur a double hit of high costs and low packing density associated with “safe packaging” designed to meet DOT regulations and mitigate fire risks. These costs are often overlooked in terms of their ability to encourage several undesired outcomes: (i) the use improper manifest labeling, (ii) concealing EOL LIBs in mixed cargo shipments, and (iii) low capture rates followed by improper storage/dumping of EOL LIBs in Hawai‘i. These impact the ability of businesses to secure the insurance needed to run their businesses.

[40] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB1215
[41] https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Senate%20Passed%20Legislature/5144-S2.PL.pdf#page=1
[42] https://archive.legmt.gov/content/Committees/Interim/2023-2024/Transportation/Meetings/September-2024/11.3summit-fact-sheet.policymakers.pdf.
[43] Niagara Country and Washington State.
[44] California.
[45] Visible fees are similar to advance disposal fees or environmental fees that are (i) transparent and (ii) collected at the point of purchase.
[46] i.e., collection, storage, transport and recycling.

Land transport. Because LIBs can ignite during transport, the U.S. DOT has put in place significant restrictions for their transportation[47]. Because of this, it is becoming significantly more difficult to obtain insurance for garbage trucks due to the increasing number of fires caused by improperly disposed lithium-ion batteries, leading to higher premiums and stricter coverage limitations for waste management companies – essentially making insurance for garbage trucks more expensive and harder to acquire[48]. In view of this, the working group noted that in the absence of a stewardship program (or NGO equivalent) that has high success organizing the collection and transport of EOL LIBs, and in a manner that is sufficiently transparent and satisfactory to insurance underwriters, the ability of local and state businesses that either collect or transport waste streams that can obtain improperly dumped or labeled EOL LIBs to obtain insurance will increase significantly.

Ocean transport. The working group noted that Hawai‘i exists in a very unique space compared to states on the mainland because of the added requirement of ocean transport. Hawai‘i’s reliance on ocean shipping and the costs and availability of insurance of posing significant risks to Hawai‘i. The use of ocean transport brings on additional costs and requirements of insurance coverage that mainland states do not have to address. Moreover, even if EPR laws are passed in California that could be emulated in Hawai‘i, there remains the significant and unique risk to ocean shipping EOL LIBs [31]. Specifically, the risk of fires generated by EOL LIBs during shipment is increasing and of particular concern to insurance underwriters[49]. In addition, operators in Hawai‘i have no control over the response of mainland port authorities, international ocean shipping companies and the insurance agencies that insure them. The working group highlighted the threat to the local economy, as well as the state’s goal of achieving full renewable power by 2045, if ocean transport was to become severely curtailed due to an inability to procure affordable insurance.

Even more concerning is the chance that shipping companies and/or their insurers may begin to decline shipping certain types LIBs as a means to mitigate risk of ship board fires [31]. To some extent, this is already happening. Recently, CAM CGM made the decision to refuse to ship hybrid and electric cars older than 7 years[50]. The container shipping giant MSC now requires[51] (i) UN38.3 Battery Test Summary (BTS), (ii) Material Safety Data Sheet (MSDS), and (iii) Certificate Of Compliance with IMDG Code SP188 for any Li-ion battery booking as well as outright refusing to ship LIBs in an ocean container if they’ve been used or damaged[52].

Municipal waste processing facilities and transfer stations. Lithium-ion batteries are a growing threat to waste management facilities, including municipal waste transfer stations [32], and the

[47] https://www.phmsa.dot.gov/lithiumbatteries.
[48]https://axaxl.com/-/media/axaxl/files/pdfs/fff/2023/7784_env_risk-bulletin--lithium-batteries_hot-loads_vehicle-fires.pdf?sc_lang=en&hash=B632F97C13C337412A5C8583847A5AAA
[49]Private conversations with underwriters from Atlas insurance.
[50] https://www.cma-cgm.com/local/martinique/news/350/procedure-for-hybrides-and-electric-cars
[51] https://www.lithium-batterie-service.de/en/newsblog/shipping-company-msc-requires-declaration-for-sp-188-transports.
[52] https://www.icetransport.com/blog/can-i-ship-lithium-batteries-in-an-ocean-container#:~:text=Container%20shipping%20giant%20MSC%20recently,ve%20been%20used%20or%20damaged.

cost of insuring against fires caused by them is increasing[53]. According to a new report from the National Waste & Recycling Association[54], more than 5,000 fires are estimated to occur annually at recycling facilities[55]. The increased risk of LIB fires has driven up the cost of insuring these facilities, according to the report. Ultimately, the financial strain could make its way back to the ratepayers if municipal wastes management facilities are forced to raise rates to cover higher insurance and other costs. The working group noted that even transfer stations are having increased coverage issues[56] and that as fewer insurers underwrite the risk, those that do are becoming far more selective[57]. The working group noted that as municipal waste processing facilities in Hawai‘i face increased financial pressure and difficulty getting insurance due to LIB fires the threat to their closure, whether short or long term[58], due to lack of insurance is real.

[53]https://wasterecycling.org/press_releases/nwra-and-rrs-release-report-on-threat-of-lithium-batteries-to-waste-and-recycling-infrastructure/#:~:text=The%20rate%20of%20catastrophic%20losses,of%20fires%20were%20small%20events.%E2%80%9D
[54] Arlington, Virginia, and Resource Recycling Systems, an Ann Arbor, Michigan- based environmental consulting firm
[55] https://wasterecycling.org/press_releases/nwra-and-rrs-release-report-on-threat-of-lithium-batteries-to-waste-and-recycling-infrastructure/
[56]https://www.businessinsurance.com/lithium-batteries-fuel-fires-at-waste-facilities/#:~:text=Waste%20and%20recycling%20businesses%20are,%2Dion%20batteries%2C%20sources%20say.
[57]https://www.businessinsurance.com/lithium-batteries-fuel-fires-at-waste-facilities/#:~:text=Common%20household%20items%20containing%20lithium,Caron%20said.
[58] https://resource-recycling.com/recycling/2021/08/31/mrfs-face-brunt-of-the-negative-impact-from-battery-fires/#:~:text=The%20most%20common%20devices%20that,Solid%20Waste%20in%20Appleton%2C%20Wis.

OTHER ISSUES TO CONSIDER

This section identifies additional issues to consider with respect to the management of EOL PV panels and LIBs.

Jobs

The cost of safely transporting, storing, and shipping hazardous waste, even under the universal waste label, will be significant for residents of Hawai‘i. In the case of PV panels, even modest efforts to reduce these costs of shipping (e.g., the prior removal of frames in Hawai‘i to increase the packing density of panels per container) require a hazardous waste processing permit. Policies that ban the preprocessing of PV panels and LIBs in Hawai‘i, and instead require they only be packaged and shipped to off-island recyclers ignore the cost to the local economy. As stated in this and previous reports, the costs associated with shipping untreated PV panels and LIBs is a cost incurring activity and, in the case of LIBs, one that is very expensive [1, 6]. The working group noted that policies that favor the direct shipment of EOL PV panels and LIBs as opposed to managing their pre-processing in Hawai‘i represents a transfer of jobs and money from Hawai‘i’s economy to those in mainland states. Given the real risk that the ability to directly ship EOL LIBs may be severely restricted by the shipping companies and their insurers, it makes good sense to invest in the development of an industry in Hawai‘i that can collect and pre-process EOL PV panels and LIBs (rather than paying other states to do it).

Catchment

Without the ability for local end users (at minimum residential and commercial scale) to turn in EOL PV panels and LIBs at no cost, and for local salvagers to be permitted to preprocess EOL PV panels and LIBs, the quantity dumped in Hawai‘i (whether it be to landfill or otherwise) should be expected to increase in volume. Also, the incidence of damaged, defective, recalled LIBs inappropriately shipped under the “reuse” label will increase [33], as will the risk of on board fires that could further curtail access to shipping. This is not a risk Hawai‘i should take. A detailed breakdown of these points is now presented.

Stewardship programs

Managing collections, storage, and transport logistics is complicated. For these reasons, policy development should consider the creation of a stewardship program that operates outside any one specific state agency, incorporates multiple revenue streams [1], pursues a package of preprocessing pathways that mitigates the risks and costs of ocean transport, reduces the reliance/burdening on an array of local businesses to self-organize, and brings a degree of transparency to the processing of EOL PV panels and LIBs. The working group noted that the

presence of such a stewardship program that guided and tracked local participation in the processing of EOL PV panels and LIBs, would go a long way to help local businesses address the concerns of the underwriters associated with their insurance companies. Also, EOL LIBs, as currently designed, present a real threat of fires and other challenges to first responders (during fires). A well-run stewardship program would be able to standardize collection, transport, and pre-processing facilities in conjunction with first responders.

External factors

There is also the concern of unpredictable regulatory policies. China, for example, has already stopped the importation of electronic waste, opening up the possibility that same will be applied PV panels and/or LIBs[59].

Refurbishing

As with reuse, the working group noted that the advantages to establishing a refurbishing industry in Hawai‘i that could address one part of the EOL LIB stream. Junkyards in Hawai‘i are filled with dozens of perfectly salvageable hybrid electric vehicles that will be crushed. These are extremely valuable resources that are being squandered. Rebuilding batteries as a means of economically rebuilding these cars would minimize waste. In particular, the ability for individuals and independent repair shops to have access to the information, tools, and parts necessary to repair and maintain their own electronic devices without legal or technical restrictions[60].

[59] See https://www.reuters.com/article/us-china-waste-imports/china-plans-to-cut-waste-imports-to-zero-by-next-year-official-idUSKCN1R90AQ.
[60]https://www.no-burn.org/wp-content/uploads/2024/06/03-Battery-Infosheet-The-Right-to-Repair-of-Electric-Vehicle-Batteries.pdf

RECOMMENDATIONS

This report has highlighted the unexpectedly high costs that will be associated with disposal of LIBs in Hawai‘i. Moreover, there is a high risk of shipping LIBs owing to their capacity to ignite explosive hot fires that release toxic gasses and are difficult to extinguish. In addition to the issue of pre-damaged LIBs shipped under misleading manifests, which can take up a month before igniting, LIBs may be exposed during transit to high temperatures or jolting movements that damage them. Such conditions can trigger thermal runaway reactions that lead to extremely high heat fires that are nearly impossible to extinguish – especially on-board ships.

Because of these issues, the cost of shipping, as well as the possibility of enhanced restrictions and even outright banning of ocean shipping of EOL LIBs, poses an existential threat to Hawai‘i’s initiative to become fully renewable. To manage this threat, the state needs to approach a comprehensive plan to address the collection, transport, and on island processing of LIBs to end products that are both safe to ship and accepted at recycling centers. Without such a delineation, the planning of both a stewardship program to run it, as well as the placement of an on-island processing facility cannot be created.

As such, the working group acknowledge that efforts to pass EPR laws in Hawai‘i that impose extensive administration requirements (i.e., collection, transport, tracking, and managing the off-island recycling of EOL LIBs) onto the manufacturers of LIBs, should consider both waiting for and then following EPR laws passed in larger markets such as California.

Objective

The objective of this work is to detail the requirements of (i) insurance underwriters who insure all aspects to the movement, storage, and treatment of EOL LIBs and (ii) multiple methods of disposal for EOL LIBs (EOL LIB). In each case, the requirements for each pathway (e.g., land, utilities and materials, collection, transportation, human resources[61], infrastructure[62], legislative[63], insurance) will be detailed with as much specificity as possible.

Deliverables

To execute the objective, the following tasks will be completed:

Task 1. Define the requirements of the insurance industry with respect to underwriter’s requirements for coverage with respect to entities collecting, transporting, and process LIBs. All

[61]Inclusive of first responders, state agency oversight (inspectors and auditors), compliance enforcement
[62]Inclusive of collection vessels, roadways, buildings
[63]Inclusive of legislative laws and agency guidelines

options for disposal of EOL LIBs will be dictated by the requirements of the insurance industry. Every person in the pathway of collection, transport, and processing of these EOL LIBs will have to acquire insurance. To obtain insurance each player will have to provide specific details to their insurance underwriters. Knowing those requirements, along with trends to the future, will help influence the evaluation of the most effect disposal options defined in Tasks 2 through 4.

Task 2. Define the requirements for the pre-processing of EOL LIBs for crude end products (i.e., crude shred) or to fine end products (plastics, metals, and black mass) that are safe to ship (i.e., broken down into smaller nonflammable and ignitable parts). The end products of both crude and fine processing of EOL LIBs are suitable as inputs to recycling plants (where they are further refined to raw materials that are suitable as feedstocks for battery manufacturing). This includes a crude shed to shippable products as well as full shred to plastic, metals, and black mass streams. Because both end products are safe to ship, defining the requirements of both processes is needed.

Task 3. Defining the requirements for the full neutralization of EOL LIBs to end products that are safe to ship (i.e., LIBs left intact but rendered nonflammable and ignitable) and that are suitable as inputs to recycling plants (where they are further broken down and refined to raw materials that are suitable as feedstocks for battery manufacturing). This process does not require physically altering the EOL LIBs but, rather, simply deactivating them by use of high pressure super critical CO_2 to chemically bind all reactive products within the LIBs and, in the process, poisoning any chance for thermal runaway reactions to initiate. Because the end product is safe to ship, and because this can be conceptually a desirable non-intrusive approach, it is worth considering.

Task 4. Defining the requirements for a ship only system wherein the EOL LIBs are not rendered nonflammable and ignitable but, rather, simply collected, packaged, and transported to full compliance to relevant U.S. Code of Federal Regulations. The straight shipment of EOL LIBs without any processing, using explosion proof and flammability proof packing materials, is the preferred pathway of the DOH’s Solid and Hazardous Waste Branch. Because of this and the fact that it is a viable process, defining its requirements is also important.

***Task 5*.** Define the requirements of reuse/repair/rebuild of EOL LIBs (i.e., at scale of energy storage systems and EVs) as a means to reduce the fraction of EVs that are totaled when their LIBs are replaced. Part of any state wide process to manage the disposal of EOL LIBs should take into account the possibility to include the repair and reuse of a smaller fraction of the LIBs within larger EOL LIB battery packs. There is a burgeoning industry in Hawai‘i that rebuilds used EVs whose battery pack has reached its end of use. Because the ability to reuse and repair these battery packs will decrease the number of EVs that are currently being crushed when their LIBs are removed, understanding the requirements of how this pathway will help create room for this pathway to handle of fraction of EOL LIBs.

Task 5. In addition, a strength, weakness, and risk analysis for each pathway discussed in Tasks 1 through 4 will be performed, with each metric scored on a common scale and the results plotted in the form of radar plots that permit cross comparison. A final cross comparative analysis of all pathways considered in Task 2 through 4 (packaging, partial shred, full shred, neutralizing) will be conducted to create a relative ranking of the most to least preferred, with a list of pros and cons completed for each. This is important to due to support a final recommendation.

Assessment of the requirements of multiple should be executed. Such an assessment would support the execution of a feasibility study that would design the most optimal state wide processing pathway (e.g., do we have one central plant or a series of smaller facilities distributed across the islands). Conducted over a one-year period, the technical assessment would review current industry options for deactivation as a function of scale and fit for the unique context of Hawai‘i’s location and shipping requirements. Conducted over a three-to-four-year span, the follow-on feasibility study would execute assessment of deactivation processes in real time at demonstration scale at appropriate locations throughout the state. Both efforts would be conducted with the support and collaboration from stakeholders (as relevant) representing the shipping industry, international maritime insurance industry, U.S. Environmental Protection Industry, local salvaging and recycling industry, state agencies, U.S. Department of Defense and Hawai‘i military bases, private nonprofit recycling groups, installers/contractors, professional associations, and others.

With the information from the technical assessment and feasibility study, the design/creation of stewardship programs that manage the overall process of recycling PV panels and LIBs - inclusive of revenue collection, storage, on-island transport and processing of both PV panels and LIBs, tracking from point of purchase to recycle, off-island transport of pre-processed PV panels and LIBs to mainland recyclers, and payments to all participating participants – can begin. Non-profit 403B stewardship programs are recommended as a “best practice” means to manage the overall system of safe and environmentally sound treatment of waste PV panels and LIBs. Because of structural differences, separate stewardship programs for PV panels and LIBs should be adopted. As part of this effort, the state legislature can design laws that create the stewardship program, organize extended producer responsibility and other revenue generating fees, as well as audit/review committees that both review and report on the stewardship program.

REFERENCES

1. Cooney, M.J., *SUPPLEMENTAL REPORT TO THE HAWAI‘I STATE LEGISLATURE IN ACCORDANCE HB1333: Policy Recommendations on Waste Management of Clean Energy Products in Hawai’i*. 2022, Hawai‘i Natural Energy Institute: University of Hawai‘i at Mānoa. p. 49.
2. Divya, A., et al. *Review on recycling of solar modules/panels.* Solar Energy Materials and Solar Cells 2023. **253**: p. 112151.
3. Dobó, Z., T. Dinh, and T. Kulcsár. *A review on recycling of spent lithium-ion batteries.* Energy Reports, 2023. **9**: p. 6362 - 6395.
4. Majewski, P., et al. *Recycling of solar PV panels- product stewardship and regulatory approaches.* Energy Policy, 2021. **149**: p. 112062.
5. HAR. *Hazardous Waste Management: Standards for Universal Waste Management*. DOH. Title 11 §273.1, 2021
6. Cooney, M.J., *Recommendations on Waste Management of Clean Energy Products in Hawai’i*, in *Annual Report from the Hawai‘i Natural Energy Insitute*, R. Rocheleau, Editor. 2022, Hawai‘i Natural Energy Institute.
7. U.N. *Recommendations on the Transport of Dangerous Goods: Manual of Tests and Criteria. Sixth Edition*. 2015. United Nations, Geneva, 38.3, 424 - 435.
8. Walzberg, J., A. Carpenter, and G.A. Heath. *Role of the social factors in success of solar photovoltaic reuse and recycle programmes.* Nature Energy, 2021. **6**: p. 913-924.
9. Al Zaabi, B. and A. Ghosh. *Managing photovoltaic Waste: Sustainable solutions and global challenges.* Solar Energy, 2024. **283**(15): p. 112985.
10. Oteng, D., J. Zuo, and E. Sharifi. *A scientometric review of trends in solar photovoltaic waste management research.* Solar Energy, 2021. **224**: p. 545-562.
11. Wang, X., et al. *A review of end-of-life crystalline silicon solar photovoltaic panel recycling technology.* Solar Energy Materials and Solar Cells, 2022. **248**: p. 111976.
12. Granata, G., et al. *Recycling of solar photovoltaic panels: Techno-economic assessment in waste management perspective* Journal of Cleaner Production, 2022. **363**: p. 132384.
13. Ndalloka, Z.N., et al. *Solar photovoltaic recycling strategies.* Solar Energy, 2024. **270**: p. 112379.
14. Granata, G., et al. *Recycling of photovoltaic panels by physical operations.* Solar Enegy Materials & Solar Cells, 2014. **123**: p. 239 - 248.
15. Peplow, M., *Solar panels face recycling challenge*, in *Chemical & Engineering News*. 2022, American Chemical Society.
16. Tao, M., et al. *Major challenges and opportunities in silicon solar module recycling.* Progress in Photovoltaics, 2020. **28**(10): p. 1077 - 1088.
17. Cheema, H.A., et al. *Comprehensive review of the global trends and future perspectives for recycling of decommissioned photovoltaic panels.* Waste Management, 2024. **174**: p. 187 - 202.
18. Kilgo, M.K., et al. *Metal leaching from Lithium-ion and Nickel-metal hydride batteries and photovoltaic modules in simulated landfill leachates and municipal solid waste materials.* Chemical Engineering Journal, 2022. **431**: p. 133825.
19. Curtis, T.L., et al., *Solar Photovoltaic Module Recycling: A Survey of U.S. Policies and Initiatives*. 2021, National Renewable Energy Laboratory: Golden, CO. p. 1-78.

20. Slattery, M., J. Dunn, and A. Kendall. *Charting the electric vehicle battery reuse and recycling network in North America.* Waste Management, 2024. **174**: p. 76-87.
21. Pang, H., et al. *Accurate capacity and remaining useful life prediction of lithium-ion batteries based on improved particle swarm optimization and particle filter.* Energy, 2024. **293**: p. 130555.
22. Börner, M.F., et al. *Challenges of second-life concepts for retired electric vehicle batteries.* Cell Reports Physical Science, 2022. **3**(10): p. 101095.
23. Khan, N., et al. *A critical review of battery cell balancing techniques, optimal design, converter topologies, and performance evaluation for optimizing storage system in electric vehicles.* Energy Reports, 2024. **11**: p. 4999-5032.
24. Juliane Seika and M. Kubli. *Repurpose or recycle? Simulating end-of-life scenarios for electric vehicle batteries under the EU battery regulation.* Sustainable Production and Consumption, 2024. **51**: p. 644-656.
25. Rallo, H., et al. *Lithium-ion battery 2nd life used as a stationary energy storage system: Ageing and economic analysis in two real cases.* Journal of Cleaner Production, 2020. **272**: p. 122584.
26. Pagliaro, M. and F. Meneguzzo. *Lithium battery reusing and recycling: A circular economy insight.* Heliyon, 2019. **5**(6): p. e01866.
27. Dobó, Z., T. Dinh, and T. Kulcsár. *A review on recycling of spent lithium-ion batteries.* Energy Reports, 2023. **9**: p. 6362-6395.
28. Hirschlag, A. *Lithium batteries' big unanswered question*. BBC, 2022. DOI: https://www.bbc.com/future/article/20220105-lithium-batteries-big-unanswered-question.
29. Vinayak, A.K., et al. *Circular economies for lithium-ion batteries and challenges to their implementation.* Next Materials, 2024. **5**: p. 100231.
30. Benson, T.R., M.A. Coble, and J.H. Dilles. *Hydrothermal enrichment of lithium in intracaldera illite-bearing claystones.* Science Advances, 2023. **9**(35).
31. Lund, R., Kersey, J., Herrera, M., *Lithium-ion batteries: Fire risks and loss prevention measures in shipping*, in *Allianz Risk Consulting bulletin*. 2022, Allianz Global Corporate & Speciality.
32. EPA, *An Analysis of Lithium-ion Battery Fires in Waste Management and Recycling*, O.o.R.C.a. Recovery, Editor. 2021, United States Environmental Protection Agency. p. 1-79.
33. Allianz, *Safety and Shipping Review 2023*. 2023, Allianz Global Corporate & Speciality. p. 1-44.