Hawai‘i Natural Energy Institute

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SUPPLEMENTAL REPORT TO THE HAWAI‘I STATE LEGISLATURE IN ACCORDANCE HB1333

Policy Recommendations on Waste Management of Clean Energy Products in Hawai’i

Act 92, Session Laws of Hawai‘i 2021

December 2023

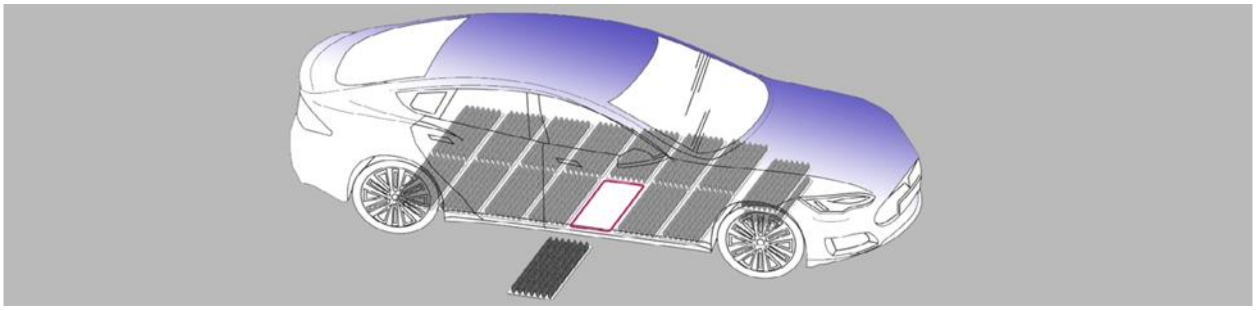
FOREWARD

The Hawaiʻi Natural Energy Institute at the University of Hawaiʻi at Mānoa was tasked by Act 92, Session Laws of Hawaiʻi 2021, to report on the best practices for disposal, recycling, or secondary use of clean energy materials resulting from our transition to renewable energy. That initial report was submitted in time for the first regular session of 2023. This document provides a supplement to that initial report, to be submitted in time for the convening of the first regular session of 2024.

The material contained herein is intended to add depth to policy recommendations for the disposal, recycling, or secondary use of clean energy materials (resulting from Hawaiʻi's transition to renewable energy) initially presented in the first report.

The scale of topics and stakeholders considered under Policy has been expanded. Specifically, costs and risks associated with storage and shipping PV panels and/or Li-ion batteries, as well as trends and actions of mainland counties or states have been included. 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 report, sources are referenced and notations are made when data has been approximated or translated to the Hawaiʻi context.



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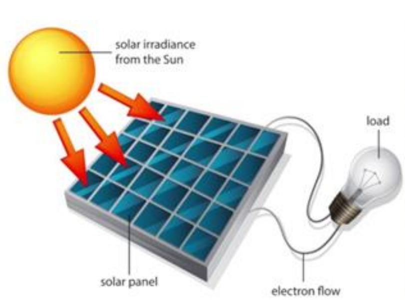
LIST OF ABBREVIATIONS

ADF	Advanced Disposal Fee	**HNEI**	Hawai‘i Natural Energy Institute
CalRecycle	California Department of Resources Recycling and Recovery	**HSEO**	Hawai‘i State Energy Office
CDTFA	California Department of Tax and Fee Administration	**IPP**	Independent Power Producer
CEW	Covered Electronic Waste	**LIB**	Li-ion Battery
DBC	Deposit Beverage Container	**NREL**	National Renewable Energy Laboratory
DTSC	California Department of Toxic Substances Control	**PC**	Propylene-Carbonate
DOH	Department of Health	**PPA**	Power Purchase Agreement
EOL	End of Life	**PV**	Photovoltaic
EMS	Environmental Management System	**RCRA**	Resource Conservation and Recovery Act
EPR	Extended Producer Responsibility	**TCLP**	Toxic Characteristic Leaching Procedure
ESS	Energy storage system	**WEEE**	Waste Electrical and Electronic Equipment
EV	Electric Vehicle	**WGR**	Waste Generator Responsibility



EXECUTIVE SUMMARY

The state of Hawaiʻi's thrust to become fully renewable by 2045 is an activity that transfers the responsibility for capital investment, insurance, maintenance, replacement, and end of life recycle of system components from a single large scale centralized energy provider (HECO) to a decentralized private sector of energy providers at multiple scales – residential, commercial, and utility. During this implementation the management and costs associated with environmentally sound disposal of all associated end of life (EOL) waste streams have been overlooked. Because of their classification as hazardous materials, relatively low concentration of recoverable metals, lack of simple low energy recycling processes, these costs will be high. Consequently, the recycling of PV panels and especially Li-ion batteries will always be a cost positive process.

To cover these costs a number of revenue-generating schemes were identified and reviewed. In particular waste generator responsibility, extended producer responsibility, state assisted recycle, state encouraged recycle were evaluated. Examples of their implementation in mainland states are detailed with summary analysis of their pros and cons. Results showed no single strategy could be used in Hawaiʻi but rather a stewardship program that could pursue many in parallel would be needed.

Finally, recommendations are given for future recommended work, including the execution of (i) a comprehensive technical assessment of deactivation processes as a function of scale, cost, and fit to shipping/logistics/recyclers, (ii) a feasibility study that recommends the best final design for Hawaiʻi and (iii) the design of a stewardship program that can manage the entire operation.

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 this supplemental report, we add depth to sections 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.

- 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.

CONSIDERATIONS FOR DISPOSAL OR RECYCLING

This section provides updated information to that provided in the original HB1333 report submitted to the 2023 Legislature. Specifically, it adds information and perspectives gained from participation in national recycling working groups, additional interviews of key island mainland players in the recycling and shipping industries, personnel from mainland stewardship programs, as well as insights gained from visits to mainland recycling plants and relevant state agencies.

Overview

While the technology and associated know how to recycle PV panels and Li-ion batteries does exist, these industries are relatively new, under development, and still evolving [1-3]. Principle reasons include that the recycling methods are relatively complex with substantial disadvantages [1, 4], and the downstream value of recovered components (i.e., precious metals) is marginal and even decreasing [5, 6]. When combined with high initial capital costs, these factors will require revenue streams to maintain profitability [5, 6]. For these reasons, the PV and Li-ion recycling industries should not be compared to other industries such as that for the lead-acid battery. The manufacturers that produce and distribute lead-acid batteries, for example, are established and stable, the manufacturing methods established, the underlying chemical compositions and physical structure simple and fixed, and their recycling methodologies uniform and low cost [7]. These factors help in the establishment of efficient take back programs (i.e., either are more easily funded with advanced disposal fees[1], application of EPR programs, revenue generated from metals recovery or some combination) that shift the cost of recycling away from the consumer and onto the manufacturers and/or recycle markets that purchase recovered materials (e.g., precious metals).

By contrast, the underlying chemistry, physical structure, and method of production of PV panels and Li-ion batteries are emerging, rapidly changing, and are not currently constructed in manner that supports simple and low-cost recycling [8, 9]. Moreover, the companies that produce these products are relatively new, unstable, weighted to foreign ownership, and in the case of Li-ion batteries, 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]. PV panels and Li-ion batteries are also dissimilar to small consumer products such as lead acid batteries. They have, for example, relatively long lifetimes (up to 25 years for PV panels, for example [10]), are classified as hazardous materials [11], are large, bulky and heavy, ill-suited to simple low-energy recycling technologies [12] and, in the case of Li-ion batteries, highly flammable and difficult if not impossible to extinguish using normal firefighting techniques [13].

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[1] Also known as “environmental fees”.
[2] Although sometimes the latter two steps are done in the same company.

In addition to the factors discussed above, there is also the issue of scale. Unlike typical consumer products covered upon traditional EPR agreements and county/city/state-managed take back programs, PV panels and their Li-ion battery storage systems are purchased and installed at residential, commercial, and utility scales, each of which possess a profoundly different type of owner. Residential home owners, especially those that purchase a home with panels already installed, may not be prepared to arrange off island shipment of a hazardous material or pay the cost required to ship their hazardous waste[3] to certified off-island recyclers. Moreover, even if less expensive landfilling options exist, these off-island landfill options will still incur shipping costs [14]. Larger commercial companies that lease PV panels to residential and commercial rooftops (e.g., Sunrun among others) could go bankrupt or be purchased by foreign companies that then try to orphan previously installed panels. And while utility scale operations operate under purchase power agreements that may require the independent power producer (IPP) to return the land to its original state, which presumably means they will bear the costs of off-island removal of all hazardous material, there is still the concern of what will happen in the case of a major hurricane or similar natural disaster that damages large fractions of PV panels and Li-ion batteries. Such an event would create a glut of these hazardous materials and in the case the ports are damaged, long storage times – if such storage is even available. Moreover, in the resulting confusion, potentially massive amounts of material will likely be orphaned or illegally dumped, a significant concern given their classification as hazardous materials of high flammability, explosivity, and/or toxicity.

Finally, there is the significant issue of logistics and shipping, especially with respect to Li-ion batteries. 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. With respect to Li-ion batteries, even more concerning is the emerging risk to shipping EV or energy storage system Li-ion batteries at EOL [15]. With respect to Li-ion batteries, those that are damaged, defective, recalled are subject to more stringent regulations; they are classified as Packaging Group 1 in the United Nations (UN) Manual of Tests and Criteria, indicating highest danger, and must be shipped in a UN-certified container [16]. Given that the shape and size of EV batteries vary by make and model, such containers must be custom ordered from dangerous goods manufacturers at higher costs [17]. Unlike standard alkaline batteries, Li-ion batteries manufactured today contain a chemical cocktail of incredibly high energy density that makes them hazardous to store and transport – particularly at EOL. Regardless of size or quantity, all lithium cells and the battery packs/modules that contain them are considered Class 9 Dangerous Goods by the U.S. Department of Transportation. Increasingly, the issue of on-board fires associated with

[3] Although PV panels and Li-ion batteries have been sub-classified as universal waste for the purpose of less restrictive shipping requirements, these materials are still hazardous waste and will therefore incur additional restrictions and shipping costs that typical goods.

EOL Li-ion batteries is a growing concern for both shipping companies and their insurers [15, 16] and this could potentially result in significantly increased restrictions for shipment of EOL or damaged/defective/recalled batteries [18]. The shipping industry and their insurers are grappling with the reality that they lack a simple mechanism to verify a given container packed with Li-ion battery does not contain one or more defective or damaged batteries. While tests do exist that test EOL for shipping stability, they require additional testing[4] and costs that will encourage some degree of evasion (Figure 1[5]).

In summary, the cost to recycle PV panels and Li-ion batteries will always be a net cost activity for Hawai‘i owing to the added costs of ocean shipping. Moreover, the cost of shipping EV and energy storage system Li-ion batteries is expected to increase with the emergence of required specialized shipping containers, enhanced surveillance, and fire suppression systems. Even more concerning is the chance that shipping companies and/or their insurers may begin to forgo shipping certain types Li-ion batteries as a means to mitigate risk of ship board fires[15]. 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[6]. The container shipping giant MSC now requires[7] (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 lithium batteries in an ocean container if they've been used or damaged[8].

Policy development should consider that the only long-term way to avoid this risk is to pretreat[9] Li-ion batteries in Hawai‘i to ensure safe shipment. Moreover, without the ability for local end users (at minimum residential and commercial scale) to turn in EOL PV panels and Li-ion batteries at low cost (if not free), and for local salvagers to be permitted to preprocess EOL PV panels and Li-ion batteries, 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 Li-ion batteries inappropriately shipped under the "reuse" label will increase [19], as will the risk of tragic fires that could further curtail access to shipping. This is not a risk Hawai‘i should take. A detailed breakdown of these points, along with a discussion of applicable waste management systems, across both PV panels and Li-ion batteries is now presented. Considerations for policy formulation are included in each section.

[4] For example, currently the only viable option is to set the batteries aside for a given amount of time (e.g., 27 days).
[5] Images either received from local recyclers or downloaded from the web (https://www.kitv.com/news/dead-batteries-from-electric-vehicles-in-hawaii-find-dead-ends/article_92426e58-3279-11ee-8f25-3b6dbd36030e.html3).
[6] https://www.cma-cgm.com/local/martinique/news/350/procedure-for-hybrides-and-electric-cars
[7] https://www.lithium-batterie-service.de/en/newsblog/shipping-company-msc-requires-declaration-for-sp-188-transports.
[8] 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.
[9] Generally expected to be deactivation followed by physical treatment to render the battery a non-battery.

Figure 1. Images of dumped or stored damaged, defective, or recalled Li-ion batteries.

PV Panels

Basic cost. As discussed previously, the price of disposing PV panels can vary dramatically with region and choice of treatment method [20]. Waste generators in Hawaiʻi can generally chose between a few off-island options: landfilling and various types of recycling. Current costs of landfilling PV panels on the mainland are around $1.38 per module while the average recycling cost is $28[10] per PV module [14]. Quotes from mainland recyclers, in California, for example, can be obtained for disposal by landfilling (cheaper option) or disposal by recycling (e.g., smelters) in, for example, Arizona or Asia. Most of these recyclers will offer certifications for varying levels of sustainability of “greenness” of the recycle option. In the event that off-island landfill options are ultimately banned (which should be considered a possibility), the waste generator in Hawaiʻi

[10] This excludes the cost of transport from Hawaiʻi to the mainland.

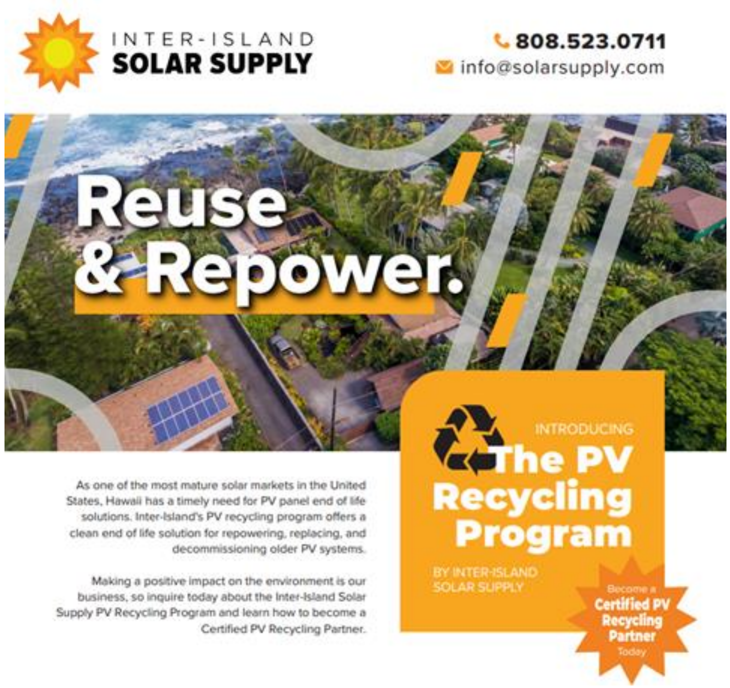
would then have no option but to bear the higher cost of recycling. These costs could be lowered if the frames of each PV panel could be removed before shipping. This would require, however, a hazardous waste processing permit and to date this is not possible although efforts to modify this requirement so as to allow this step of pre-processing are ongoing[11].

In our first report, the cost of shipping PV panels from Hawaiʻi to Reno (door to door) was estimated to be between $15 (40" HC) and $32 (20'Std) per panel depending upon the container selected [20]. When adding the cost of shipping to those recycling estimates [20], the cost of mainland recycling was estimated to be approximately $60 per module, not including the labor charge of the contractor/installer to remove the modules [20]. For the average size of a 20-panel installation, the cost of removal, transport, and recycle could reach as high as $3,200 (*including* the local costs of uninstalling a packing the PV panels)[12]. It was also noted in that report, however, that if landfill continued to accept PV panels in the U.S. or Asia, then the higher cost of recycling could be avoided and, under this scenario, the cost of transport and disposal a 20-panel installation could decrease to around $2,000. While recycling costs can be expected to decrease over time, the cost of transport can be expected to increase.

Recently, Inter-Island Solar Supply, a major distributor of panels into Hawaiʻi, and Hawaiʻi's first EPA-recognized handler and transporter of solar panels as universal waste, has introduced a PV recycling program (Figure 2). The program, which charges a fee around $49 per panel, covers all costs associated with sorting, packaging, shipping, and recycling of used solar modules. Lower costs are expected with increased scale. Other mainland operators can be found that offer cheaper landfilling options for Hawaiʻi-based operations; however, these options do not arrange for the collection in and transport from Hawaiʻi and their pricing also assumes a fully packed container. Inter-Island's program, although more costly, elects to recycle panels (while providing transport of materials in full containers). Feedback received during the writing of this reports suggests the program is well received and that its fee is acceptable and easily absorbed into the de-installation fee charged by contractors taking down or replacing PV panels.

[11] By the DOH which has signaled it may be approved this year.
[12] A high estimate of $2,000 to uninstall and take down modules plus 20x60$.

Figure 2. Brochure for Inter-Island Solar Supply noting their PV recycling program.



<u>*Considerations for policy development*</u>: The price gap between landfill and recycling options imposes an environmental dilemma regarding whether to support recycling at a higher cost to the consumer versus landfilling at a lower cost to the consumer. Obfuscating this environmental dilemma is the added fact that the landfills are on the mainland rather than in Hawaiʻi which can make it easier for residents of Hawaiʻi to select the less costly but environmentally worse landfill option. Although Inter-Island's recycle program is a promising start for affordable recycling, there is the possibility other programs will emerge that provide lower cost programs that use mainland landfill despite the higher environmental impacts [21] (although the extent of harm to landfills is still debated [22]). In any case, to avoid ownership of such negative environmental impacts, lawmakers would need to require that the disposal of PV panels must flow through certified recyclers (as opposed to mainland landfills[13]). While this could significantly lower the state's overall environmental footprint, it would impose higher costs on Hawaiʻi residents and businesses. These higher costs could be politically unpopular and could increase the occurrence of illegal dumping.

Waste generator responsibility. Under this scenario, also referred to as consumer responsibility laws, the state would require those responsible for generating the PV panel waste to both arrange for *and* bear the full cost of transportation and treatment of PV panels at off-island disposal/recycling centers. Although in practice the residential homeowner or commercial

[13] In terms of policy this can be accomplished by requiring "green receipts" for all PV panels disposed.

business would engage certified contractors to remove, transport, and arrange for the off-island landfill disposal or industrial recycling of their PV panels, the EOL costs will nonetheless be borne by the homeowner or residential business. If acting independently, these installers and contractors would also have to arrange for temporary storage of PV panels until sufficient amounts have been acquired to fill an entire container. Enforcement would need to focus on regulations and inspection of the independent contractors and their records for compliance. Alternatively, the state could require them to upload records of PV panel installations/deinstallations to online databases maintained and reviewed for compliance by a designated stewardship program. These records would also include reports on all PV panels decommissioned and information on where they were recycled with receipts.

At utility-scale, the Independent Power Producer (IPP) operates under Power Purchase Agreements (PPA) that generally include requirements that the IPP bear the full costs of deinstallation, transport, and off-island recycle of PV panels (and other system materials) at EOL. In application, the IPP would manage PV panel disposal on a day-to-day basis as needed for PV panels that have reached their EOL. Enforcement would focus on periodic site inspections and review of records. Alternatively, the state could require the IPP to upload records of PV panel installations/deinstallations to online databases maintained and reviewed for compliance by a designated state agency or stewardship program. These records would include reports on all PV panels decommissioned and information on where they were recycled with receipts. This type of management structure should be manageable at this scale – large IPPs should have the size and resources available to manage, in house, the long-term disposal of PV panels as they fail in real time.

Considerations for policy development: With respect to developing and implementing waste generator responsibility laws, policy development should consider *who* generates the waste. End users at residential, commercial, and utility scale all operate at vastly different economies of scale and business environments. Moreover, the *definition* of ownership should be considered, particularly with respect to leasing arrangements versus private ownership. Who, for example, actually owns the PV panels on the rooftop of a residential or commercial property and is therefore responsible for their off-island disposal? If the panels were purchased under loans, for example, do the banks ultimately own them and therefore final responsibility for their disposal? Or, by contrast, does the individual leasing the PV panels own them? What happens when homes or properties are placed into receivership? How will the presence of hazardous materials on the property affect its resale? From a policy development perspective, resolutions to these questions are important to consider when imposing laws that require the waste generator to bear the full responsibility for arrangement and payment of off-island recycling at EOL.

Policy development centered around waste generator responsibility laws should also consider that homeowners, local commercial businesses, and nonprofits will each approach the organization and financing of PV panel recycling much differently than larger commercial scale companies that lease thousands of PV panels across individual homeowners or commercial business. Moreover, at utility scale IPPs with national headquarters and operations across the U.S. will have even more options, like bonding insurance or ongoing operating budgets, to finance EOL management. In summary, *one policy will not fit all* – what works well for large commercial operators may not work well for individual homeowners and vice versa. It is recommended that waste generator responsibility laws, if used, should be tailored to each scale in order to remove inefficiencies that increase costs. For example, although mainland recyclers are available, it can be cost and time inefficient for local contractors to spend large amounts of time identifying them. While the DTSC website in California posts lists of mainland businesses that either "recycle" or "accept" PV panels, these companies can be unstable and difficult to establish long term relationships (with). They can also misrepresent their services[14]. Industry led efforts to organize PV paneling recycling across entities, such as the recent Inter-Island program should be championed.

At each scale, the following considerations are recommended:

1. A recent PV recycling working group[15] advised ***against*** waste generator responsibility laws/policies that ***require*** homeowners or small commercial businesses to directly pay for the recycling of their PV panels at EOL. Support for this point of view is evidenced by California's recent effort to reduce the number of illegally dumped or landfilled mattresses. Recognizing that waste generator responsibility laws generally promote the illegal dumping or excessive landfilling, California legislators signed the Used Mattress Recovery and Recycling Act (SB 254) into law in 2014. With the support of manufacturers, recyclers, business leaders, and environmental groups, SB 254 established an industry-run market-based mattress collection and recycling program wherein mattress end users can drop-off their old mattress at ***no-cost*** to participating collection sites or recycling facilities. In Hawai‘i, it should be considered that, analogous to mattress owners, individual or small business owners of PV panels faced with the direct cost of recycling PV panels will usually elect to illegally dump them.

2. At larger commercial scale, businesses possess more opportunities to directly finance EOL costs from ongoing operational budgets. Large commercial scale installations, for example, will typically have maintenance budgets to inspect and clean PV panels as well as to replace damaged or failing panels. If managed appropriately, these budgets could be

[14] A number of direct inquiries and visits, for example, revealed that many of those companies listed as recyclers on the DTSC website were actually no longer accepting PV panels or only accepting PV panels for subsequent shipment to out of state landfill disposal sites (generally in Nevada or Arizona) or recyclers (smelters in Arizona or South Korea).

[15] Convened by the National Stewardship Action Council the PV Panel Recycling Group contained a large variety of stakeholders from around the country that included participants from state agencies, recyclers, large and small installers, and nonprofits.

tapped to cover the cost of recycling PV panels at EOL. Similarly, leasing companies that distribute panels over large numbers of individual single residence homes or commercial buildings will possess operating budgets that can be similarly tapped. In states such as Minnesota, for example, the cost of recycling all PV panels installed is estimated to be roughly 5% of installation costs which, if spread out over the expected 20-to-25-year lifetime of the PV panels, comprises a small fraction of annual operating costs[16].

3. At utility scale most IPPs would prefer to similarly cover the cost of recycling PV panels from annual operating costs. In application the utility scale operator would post a "performance bond" that ensures the required recycling of all EOL PV panels but leaves the IPP company free to manage those outlays, on an annual basis, as the project progresses, using ongoing revenue streams and eventually cheaper options for disposal.

4. The burden of enforcement on state agencies to ensure panel owners at all scale have ensured sufficient resources are available (to them) to pay for EOL costs, especially in the event of large-scale disasters that both disrupt the port and generate a surge in PV panel waste, should be considered. Does, for example, the DOH Solid Waste Management Branch have sufficient staffing to meet this need?

5. The terms of all utility scale PPAs should be reviewed to ensure that the requirement of off-island disposal of PV panels is specified to the level that the state believes meets its goals of environmental stewardship.

6. As in recommendation 4 above, the burden of enforcement on local agencies, in case of default, should be reviewed as needed to ensure that they have sufficient resources available, especially in the event of large-scale disasters that disrupt entire installations. Does, for example, the DOH Solid Waste Management Branch have sufficient staffing to meet this need?

Extended producer responsibility (EPR). Under this scenario, the manufacturer, distributor, or equivalent as defined by law required to manage and bear full cost for EOL treatment of their PV panel product. Pioneered in Europe through the WEEE Directive, the EPR act requires producers of PV panels to ensure the take-back *and* recycling – including the related administration, reporting and financing – of their products within the countries of the EU [23]. In Europe, any violation of this WEEE rule may incur fines or an interdiction of commerce. Through this obligation, industry is expected to take greater responsibility for EOL recycling of its PV panels, presumably through up-front costs charged to the consumers. Finally, each EU Member state is left to define how PV panels will be covered in their state under their national WEEE law.

[16] Discussion with Amanda Cotton, PV Panel Recycling working group meeting.

In the U.S., there are a few mainland efforts moving in this direction. In 2017, the Washington Legislature passed Senate Bill 5939 to become the first state in the U.S. to pass a bill establishing an EPR program for PV panels[17] [24, 25]. In addition to promoting a sustainable, local renewable energy industry through modifying tax incentives, one portion of the bill created the *Photovoltaic Module Stewardship and Takeback Program*[18], which requires manufacturers of solar panels, also referred to as photovoltaic or "PV" panels, to provide the public a convenient and environmentally sound way to recycle all panels purchased after July 1, 2017. More specifically, the regulation in SB 5939 will require PV panel manufacturers, starting in July 2023, to finance the takeback and reuse or recycling of PV panels sold within or into the state, *after* July 1st, 2017, at *no cost* to the user. Under the law, the "manufacturer" of a PV panel covered by law, sold in or into Washington includes any entity that (i) has legal ownership of the brand name or co-brand of PV panel, (ii) imports a PV panel branded by a manufacturer that has no physical presence in the United States, (iii) sells at retail a PV panel acquired from an importer and chooses to take legal responsibility in place of the importer as the manufacturer of that product, (iv) chooses to take legal responsibility on behalf of a manufacturer as defined in (i) through (iii). However, the law also permits a product stewardship organization to act on behalf of a manufacturer or group of manufacturers to operate and implement a stewardship program. The Department of Ecology, Washington State, was directed to develop guidance for PV panel manufacturers on how to best create a stewardship plan for a self-directed PV panel collection and recycling program that ensures that the takeback plan offers a convenient collection system, and that the takeback and recycling of PV panels is done in a safe and environmentally sound manner.

Following Washington's lead, in 2021 the Niagara Country Legislature enacted a similar local law establishing solar panel recycling regulations. This law mandated that beginning August 1st, 2022 no manufacturer, distributor, retailer, or installer can sell or offer for sale a PV panel in or into their county unless the manufacturer of the PV panel is in full compliance with the EPR law[19]. Under this law, the manufacturer (or stewardship organization designated to act as an agent on behalf of the manufacturer) must present a stewardship plan that provides for the "*takeback of photovoltaic components and installation components at convenient locations within the County to minimize the release of hazardous substances into the environment and to maximize the recovery of other components, include rare earth elements and commercially valuable materials*". Moreover, every manufacturer or stewardship organization must prepare and submit a stewardship plan to the County for approval. The requirements of their stewardship plan are extensive and place full financial responsibility to finance the costs of collection and recycling on the manufacturer. In particular the law stipulates that no retailer may charge a fee to consumers that help to recoup these costs. While the law does not require that the manufacture take back any

[17] https://app.leg.wa.gov/billsummary?BillNumber=5939&Year=2017#documentSection
[18] Chapter 70A.510.010 of the Washington revised RCW.
[19] Local Law Filing Niagara County document.

panels other than those they manufacture, it does require the stewardship plan document how the take back plan will minimize the release of hazardous materials to the environment and to establish performance goals. Finally, the law requires the stewardship plan include a strategy to establish and maintain financial reserves to cover costs in the event of closure. The law also establishes the payment of fees to the Country that include a fixed one-time fee and an annual fee to cover the costs for County to administer the law.

In California in December of 2022, a bill (AB 2) was introduced to the 2023-2024 assembly to address PV recycling in California as an EPR policy approach. Specifically, to similarly require a manufacturer of solar photovoltaic panels sold or offered for sale in this state, or its agent, to develop an EOL management plan for the management and recycling of the solar photovoltaic panels it manufactured and the component materials [26]. If passed, the bill would have allowed the manufacture to designate an agent to act on behalf of the manufacturer to develop and EOL management plan under specific guidelines. The plan would be required to show (i) a plan to minimize the release of hazardous materials, (ii) a plan to maximize recovery of components, including rare earth metals, (iii) a plan for proper dismantling, transportation, and treatment of PV panels in a manner consistent with (i) and (ii), and (iv) performance goals for the rate of combined reuse and recycling of collected PV panels as a percentage of the total weight of soar PV panels collected, of which the rate will be no less than 85 percent. While the bill does *not* possess language that mandates the take back be at no cost to the end user, it does require the manufacturer to pay the department an administrative fee. Finally, while the bill does not possess language covering legacy or orphaned panels, it does specific a start date for the stewardship plan to be submitted by July 1, 2026 for any panels sold after that date.

Unfortunately, AB2 was amended June 22 and further amended June 28, 2023 to be a bill that is *no longer* an EPR approach. Moreover, the bill no longer gives the producers any financial reason to design for EOL management. While the California Senate Environmental Quality Committee will hear the bill again before it can continue in 2023, if passed as amended, the bill would set the precedent of no producer responsibility in California.

Considerations for policy development: With respect to policy development, there are several key issues unique to Hawaiʻi that should be considered. The first is that none of the EPR initiatives listed above address legacy PV panels. PV panels have a long lifetime of 20 to 25 years and the industry is still developing. As a consequence, many PV panels currently installed in Hawaiʻi have outlasted the companies that produced them. As such, policy development should consider a stewardship (e.g., transition) plan to address these orphaned (or legacy PV) panels as these companies, especially those overseas, will resist responsibility for their past products. Moreover, enforcement will be difficult given the difficulties pursuing remedies through international law.

The second is that passage of EPR laws, if done before larger markets such as California pass similar laws, could lead to PV panel manufacturers abandoning the Hawaiʻi market. As is currently the case in California, if EPR bills are passed that possess no EPR responsibility, then Hawaiʻi runs the risk of being boycotted by manufacturers of PV panels if it passes a law that goes further than California – as Hawaiʻi is a relatively small and isolated market with minimal power to enforce compliance on PV panel manufacturers. The influence of market size has already been observed by two small markets that have tried to implement EPR laws: Niagara County and Washington State. In both cases the EPR laws passed placed near total responsibility for take back on the manufacturer, including paying for all costs inclusive of county costs to administer the program. This has resulted in a steep decline of manufacturers willing to sell their panels in these locations. Moreover, the majority of PV panel manufacturers are based in countries outside the jurisdiction of U.S. law, complicating legal enforcement of EPR laws. Under this scenario, the most likely way for Hawaiʻi to enforce EPR compliance would be to disallow the purchase of PV panels from manufacturers that decline to participate. Given Hawaiʻi's small market size, this step would likely have little impact other than to limit the ability of installers and contractors to offer their clients the full range of price and product choice, leading to unreasonably high costs to the consumer. By contrast, it should be noted that Europe ***has*** pursued EPR across ***all*** its member nations, thereby dramatically increasing their ability to influence manufacturer compliance. Unfortunately, this is not the case for the U.S. market. For these reasons, the success of EPR laws in Hawaiʻi is tied to their concomitant implementation in mainland jurisdictions that have large market influence (such as California).

The long lifetime of PV panels further complicates reliance on EPR as a funding mechanism for recycling PV panels at EOL. The PV working group, for example, considered the complexity associated with the application of EPR laws to products that have lifetimes as long as 25 years. Typically, EPR is applied to consumer products with (i) lifetimes of 1 to 3 years, (ii) well established chemistries, and (iii) comparable recycling pathways across models. Policy development in Hawaiʻi will need to clearly address EPR responsibilities for products with 25-year lifetimes if it is to be a significant mechanism to fund EOL disposal of PV panels.

State assisted recycle. Under this scenario, the state would assist with the recycle of EOL PV panels through the appropriation of state raised and/or managed revenue to subsidize the cost of recycling PV panels[20]. In application, the funds would be dispersed to fund, for example, county programs that manage recycling programs[21] or to reimburse contractor/salvagers who arrange for and manage the collection, transport, and recycle of PV panels at mainland disposal or recycle sites[22]. Mechanisms to raise these funds include: (i) state tax income, (ii) fees or taxes applied to electricity bills, or (iii) through the assessment of a direct Advanced Disposal Fee (ADF) at the time of purchase. These are now discussed.

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[20] By a state managed recycle program in a manner, perhaps, similar to how the Hawaiʻi Energy program is funded.
[21] Similar to those that who contract salvagers to underwrite the cost of disposing abandoned cars.
[22] For example, Inter-Island Solar who has introduced a PV recycling program that does exactly this.

State income tax: The use of funds derived from state tax income to assist with recycle costs was not viewed favorably by the national PV recycling working group for various reasons. First, it was seen as inappropriate to use state general funds derived from various state taxes to fund out of state business/operations (i.e., out of state recyclers). Second, it was not seen as equitable given that some tax payers are not direct consumers of electricity generated by PV panels. Third, a significant fraction of PV panels in Hawaiʻi are owned by companies outside Hawaiʻi who operate lease agreements granting access to commercial and residential rooftops for income purposes. For example, the vast majority of solar panels are owned by some 100 companies nationwide, most of which have headquarters outside the State of Hawaiʻi. It could be seen as inequitable to use local tax revenue to support these out of state companies who have already benefited from state tax incentives[23].

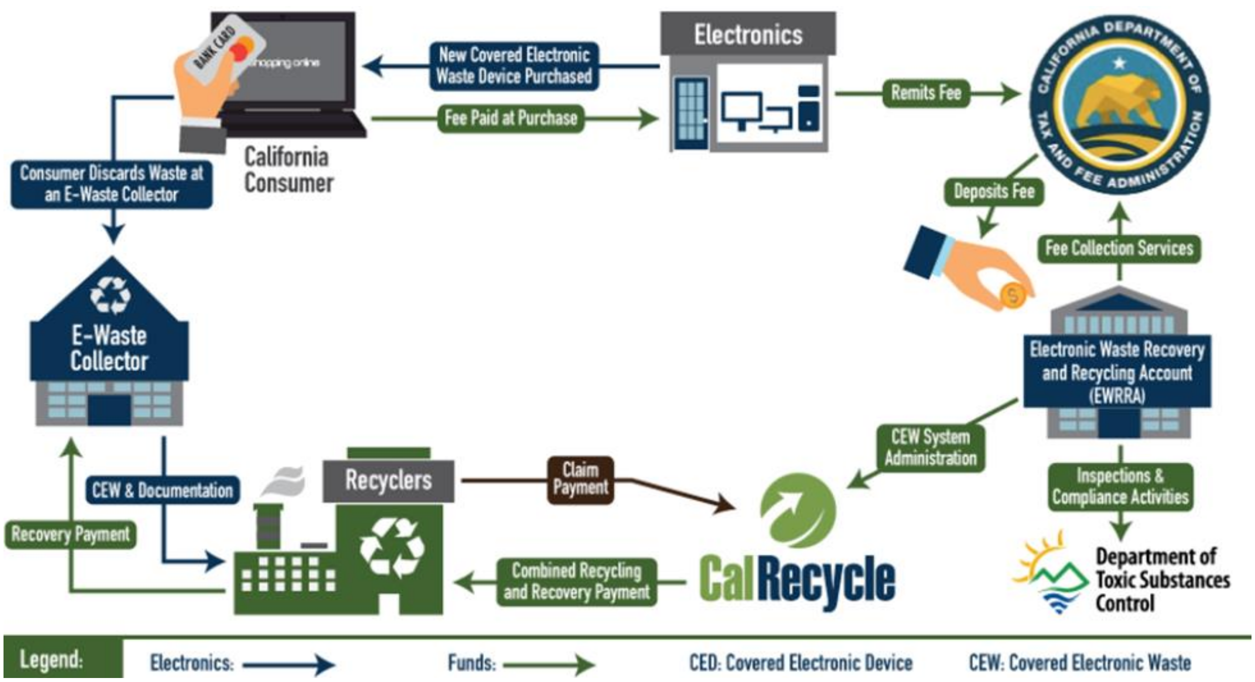
Fees or taxes applied to electricity bills: There is precedence for the use of fees or taxes applied to utility bills to raise revenue. For example, a tax is applied to electricity bills to fund the Hawaiʻi's energy rebate program. Also, a fee or tax is applied to vehicle registration to cover the cost of abandoned cars. Both are examples of fees/taxes applied at the point of the purchase of a product or service to fund state mandated projects that serve a community service or need. Similar to the use of state income tax terms of policy development, the PV recycling group noted that "environmental" fees added to electricity bills (to pay for recycle of EOL PV panels) could attract criticism on grounds of lack of inequity for either (i) rate payers who do not own PV panels or (ii) those who have already leased out their rooftops to leasing power companies. That being said, it was noted by the PV recycling group that if the ratepayers could be charged a fee that was on a percentage of consumption basis (as opposed to a flat fee), then this would be more equitable because only those directly benefiting from reduce electrical bills (owing to PV panels directly on their roof) would be charged.

Advanced disposal fee: The ADF option represents a pay-forward mechanism in which fees collected at the time of purchase are then used to cover the cost of recycle at EOL. Under this scenario, a Hawaiʻi based stewardship program would assist the recycle of PV panels through the management of ADF's collected at the time of purchase which would then be used to subsidize the cost of recycle. In application, the vendor would collect an ADF at the time of purchase and then transfer the collected funds to a fund managed by the state or state nominated stewardship program that would then reimburse those entities that arranged for the recycle of EOL PV panels[24]. In Hawaiʻi, one obvious example is the Deposit Beverage Container (DBC) program. The DBC program has assisted residents to recycle over 10 billion containers by managing a program that certifies independent recycling companies to operate Certified Redemption Centers (CRCs) statewide. In combination with stores that collect the fee at the time of purchase, these CRCs provide Hawaiʻi consumers with refunds of the 5¢ deposit fee that is paid for eligible containers.

[23] For example, past State and Federal rebates given out to spur installation.
[24] Again, see Inter-Island Solar's recent announcement of a fee-based PV recycling program.

In California, the mattress recycling program applies a "recycling charge" collected at the point of sale of each new or renovated mattress[25]. Also, the California Department of Resources Recycling and Recovery (CalRecycle) adopted recommendations that came out of the two-year Future of Electronic Waste Management in California project[26] whereby consumers pay an advanced recycling fee when they purchased new electronics. Termed the Covered Electronic Waste (CEW) Recycling Program, a fee is collected by retailers in California at the point-of sale of a covered electronic device which is then used to fund the collection and recycling of waste devices at end-of-life. The Act is implemented by CalRecycle, DTSC, and the California Department of Tax and Fee Administration (CDTFA) who collect the money and provides collection and processing payments to e-scrap companies handling covered devices, currently 49 cents a pound (Figure 3). In the case of PV panels, similar fees would be applied at the time of purchase of new panels and then used to subsidized the cost of recycling the PV panels.

Figure 3. Flowchart of material and fund within the State of California's covered electronic waste recycling program.



A significant issue to the ADF approach is what to charge for the fee. While the collected fee could be set to the current market price of recycling (including shipping cost) a PV panel, an alternative price structure would take advantage of imbalances between the number of panels being installed versus recycled, as well as expected reduction in recycling costs. While the former is typically used for recyclable products that have very short shelf lives, the latter takes advantage of

[25] SB 254 authorizes such in its law.
[26] https://resource-recycling.com/e-scrap/2018/05/24/california-plans-substantial-changes-to-its-state-program/.

the very long lifetimes of PV panels [14]. In one analysis by NREL scientists, for example, the authors assumed a national installation of 25 GW in 2021, a 25:1 ratio of newly installed to recycled panels, yielding an average panel rating of 350 W per panel, and a recycling cost of $18 per panel. Spreading the cost across the full 25 GW, the authors calculated a "fee" of 0.2 cents per watt or approximately $0.78 per 350 Watt residential/commercial scale PV panel and just over $1 per commercial scale PV panel. The authors further postulated that such a fee system would increase the cost of a 7 kW residential project by only $15; a commercial scale project by only a few hundred to a few thousand dollars; and a utility-scale project between tens of thousands to a million dollars for a gigawatt scale facility [14]. Finally, the authors pointed out that although the ratio of new panels being recycled will decrease with time, the cost of recycling panels in the U.S. would significantly decrease, thus offsetting the greater number of panels being recycled[27]. With time, as the number of PV panels to be disposed and recycled increases, the cost of recycling can be expected to decrease significantly [27]. While averaging the surcharge over the lifetime of the PV panel has the advantage of keeping the surcharge low while still ensuring that sufficient funds are raised to cover present recycling costs, in application, funds raised in any given year are used to pay costs of recycling EOL PV panels in the same year. In Hawai‘i, these savings are only for the recycling portion. Shipping and labor costs will have to be included.

Considerations for policy development: One advantage to consider with respect to state assisted recycle is that a fraction of upfront fee collected could be used to manage the large amount of legacy panels that have been orphaned by manufacturers that no longer operate in the market place. There is also evidence of consumer acceptance for state assisted recycle programs as evidenced by the Hawai‘i deposit beverage container program. Moreover, the PV recycling working group also noted the general acceptance by consumers of "environmental fees" tacked onto the cost of products in order to support their environmentally sound disposal (e.g., a fee charged at the time of purchase to cover to costs of properly disposing of car tires or lead acid batteries). Whether managed by the state – or privately-run stewardship programs, the larger public, therefore, is used to such programs and state agencies in Hawai‘i have experience managing or overseeing them.

If pursued, policy development should consider *who* pays the fee. In the case of ADF, the PV recycling group noted an accepted option is that the solar "permittee" pays. In Hawai‘i, this would mean the homeowner or commercial business would pay the fee as part of the installation cost. In practice, the fee would be paid on behalf of the homeowner or commercial business by the installer at the time of permit application. While this may work at residential or commercial scale, however, it has issues at utility scale. IPPs are generally resistant, at this scale, to provide large initial cash outlays. At utility and even very large commercial scale, for example, it does not necessarily make economic sense to tie up capital at the time of installation, especially when those upfront costs are

[27] This assumes the lower recycle costs is predicated on high participation in recycling and thus the production of sufficient volume of PV panels being recycled so as to support the learning curve of the U.S.-based recycling industry.

based on estimated recycling costs at market prices pegged to the time of installation and which could be considerably higher than future costs (i.e., 20 to 25 years later). At utility scale, any requirement to fund a deposit account at the time of installation that fully covers the estimated cost of recycling all installed PV panels at EOL would comprise a prohibitively significant fraction of overall capital outlays. Also, in many cases utility scale installations actively seek to replace functional but less efficient PV panels for which a reuse market may develop. Such reuse markets, if they develop, can also provide revenue as opposed to cost outlays. In summary, IPPs have resources and options available to permit their management of current EOL PV panels out of existing operating budgets that residential and commercial scale operators do not.

State encouraged recycle. Under this scenario, the state would pursue policy initiatives that reduce the *relative* cost of recycling. Examples include laws that ban the landfilling of PV panels, or laws that alter the hazardous waste classification of PV panels (or those that simplify the test of panels to achieve non-hazardous classification) so as to reduce the barriers to transporting and processing PV panels. Laws that declassify PV panels from hazardous to nonhazardous, or laws that ease processing of PV panels will decrease the cost of recycling. When pursued in collaboration with waste generator policies, this pathway can encourage the decision to recycle PV panels.

Other examples of state encouraged recycle include the development of templates for the collection/transportation and reuse/recycling infrastructure that are needed to recycle panels. The EOL management of PV panels is a regulatory market. Until the regulations are in place, the investment in their EOL pathways will not be made. When pursued in combination with efforts or laws regarding EPR, the ability to get manufacturer buy in to sell their panels in Hawaiʻi becomes greater because the burden of creating and managing stewardship plans is reduced. Finally, the provision of tax breaks/incentives to PV panel manufacturers in Hawaiʻi who participate in EPR and stewardship programs might also encourage their participation and mitigate the risk of isolation if stringent EPR laws are passed.

Clear regulatory policies and procedures for PV panels in Hawaiʻi could make recycling investments more viable, remove confusion of how to manage any given PV panel, and introduce long term stability in a local recycling market. California is currently evaluating a bill to require its DTSC to “develop alternative management standards for recycling PV panels that would, to the extent possible, reduce the regulatory burden on managing certain resources used for recycling the panels” during the California 2023-2024 regular session[28]. If adopted, the bill would impose a state-mandated local program.

Considerations for policy development: Policies that reduce the hazardous classification of panels will open up less expensive avenues for recycling PV panels – a key factor in encouraging end

[28] AB 1238 (Ward).

user participation. For example, processed scrap metal and shredded circuit boards that are recycled are specifically excluded from solid waste regulations and therefore are not subject to hazardous waste regulations, provided that the metal and circuit boards are stored in containers and free of mercury switches, mercury relays, and nickel-cadmium and lithium batteries[29]. Given that there is some evidence that the hazardous waste classification of PV panels may be overblown - a recent study by NREL scientists has shown show that toxicity characteristic leaching procedure (TCLP [28]) results for PV modules are highly variable, clouding the risk attributed to landfilling PV panels [24] – policy efforts could consider declassifying or reclassifying PV panels as nonhazardous waste in order to ensure easier less costly mechanisms of waste disposal[30]. Moreover, testing on PV panels have indicated that different varieties of PV panels have different metals present in the semiconductor and solder [20]. Consequently, some solar panels are considered hazardous waste while some are not, even within the same model and manufacturer.

In summary, policy development should address the entire EOL PV panel pathway in a uniform manner. For example, while the ban on land filling of PV panels in Hawaiʻi stops local recyclers from intaking and processing PV panels, it may encourage the occurrence of illegal dumping or the use of the household hazardous waste exclusion to dump smaller amounts of PV panels at transfer stations (and thus be landfilled without consideration of hazardous waste rules). Moreover, it has also had the negative effect of shifting the responsibility of EOL management of PV panels to a broad range of installers and contractors and increasing the number of contact points to regulate. Broad confusion on how to manage panels can encourage increased dumping or use of the hazardous waste exemption.

Li-ion Batteries

Basic costs. A recent study by the Electric Power Research Institute presented a cost of $1 per lb. ($2.20 per kg) to recycle Li-ion batteries [29]. This cost estimate included the batteries being delivered to the recycling facility, the labor cost of module disassembly as well as offsets for the value of the metals recovered from the recycling process. Although this study assumed that the revenue recovered from recycling the metal racks[31] (inherent to the battery packs/modules) was considered sufficient to offset the cost of their transport to a metal(s) recycler, it was not sufficient to significantly offset the added cost of recycling the battery. Moreover, the cost of recycling the battery management system unit was also neglected (e.g., the computer components that monitor and operate the battery modules along with the cable connectors that can be commonly recycled with the other electronic components in the system). Another report suggests that it costs $4.50

[29] Title 40, Code of Federal Regulations, 261.4(a)(13) and (14).
[30] In one example, the DOH is reviewing requests to permit the removal of the frames. This effort is seen as positive towards reducing the cost of the shipping portion of PV panels to mainland recyclers and can perhaps add a local revenue stream
[31] i.e., copper and steel.

per pound to recycle a Tesla battery [30]. If this number is used the cost to recycle a typical residential Tesla Powerwall battery (~ 250 lbs.) would be between approximately $250 and $1,000.

These numbers, however, will vary with price fluctuations in the metals market as well as with developments in the refurbish, reuse, and recycle market [31]. In many Li-ion batteries, for example, the concentrations of cobalt, nickel, lithium, and manganese exceed the concentrations in natural ores, making spent batteries akin to enriched ore [32]. However, routes to profitably recovering these metals are still unclear [33] even as new recycling methods are being developed [34]. Moreover, the widespread implementation of Li-ion battery recycling is hampered by recycling inefficiencies, environmental impacts, safety hazards, and logistical challenges such as collection and transportation [35]. A large variety of pack designs and battery chemistries further add to the complexity of recycling [36]. Finally, given the currently relatively low number of EOL EV Li-ion batteries, recycling costs are still high and profits low [37].

In Hawai‘i, the full cost of recycling will also need to account for the added cost of ocean transport. Estimates vary but a good rule of thumb is that shipping contributes roughly 40-60% to the overall cost of recycling [17, 38], with one review, reporting that estimates of costs for transport varied between $0.24 per kg to $5.51 per kg for a standard distance assumptions, yielding an average value of $1.54 per kg [17]. Reasons for the variation include regional differences in fuel and labor costs, as well as different calculation methods. Long term, the costs of recycling will likely decrease, in part because of classic market competition drivers[32], but also due to future improvements in the recycling industry and government regulatory sphere – both of which will provide downward pressure on the cost to recycle.

The costs for Hawai‘i, however, can be expected to remain in the higher part of this range owing to the requirement of ocean transport. As an estimate, the cost to ship Li-ion batteries from Hawai‘i to the mainland (e.g., Reno Nevada where Tesla’s Redwood Materials plant is located) could cost between $900 and $3,000 for a 44” x 48” x 48” size pallet[33]. For context, the Model S and Model X Tesla battery dimensions are 68.5 x 30 x 75 cm (L x W x H). This translates to a volume of 5.5 ft^3. The volume of the pallet above is 58.5 ft^3. If some loss of space is assumed just to shape issues, roughly 10 batteries per pallet can be shipped. As such, some savings could be achieved by bulk shipment as the price for one or multiple Li-ion batteries is comparable – the quotes are based on pallet size and not so much on weight. A typical Tesla car owner in Hawai‘i, for example, could expect to pay approximately $15,250[34] to have their used battery shipped and fully recycled. While, this number is only an estimate (e.g., the car battery weight is going to vary by the battery capacity and energy density both of which will vary with the manufacturer and car model), a local

[32] Competition between companies, advantages to scale, changing laws and other unknowns.
[33] Obtained from uShip (https://www.uship.com) which is an online service that facilitates quotes from multiple shippers.
[34] Based on an average vehicle weight of 3,500 pounds, a recycle cost of $4.50 per pound.

recycler entering the market of loose[35] Li-ion batteries has set a price of $14 per pound[36] to recycle Li-ion batteries. This price, on the upper end, incorporates high end shipping containers and packing material required to meet prescribed safety regulations. While these prices can be expected to decrease, through relationships developed with mainland stewardship programs[37], for example, it does highlight the difficulty local salvagers will have when working outside stewardship programs.

The cost calculations above are based on usual practices of pricing (e.g., $ per container or weight) and packing ($ per container of defined volumes) applied to ocean transport of shipped goods and ***does not account for future risk assessments***. Policy formulation should therefore consider that awareness of the risks of Li-ion battery fires on ships has risen and is now being analyzed as an emerging risk to the shipping industry [15]. The reality is that safety concerns will likely impact the logistics of shipping, both in terms of cost and access as shippers and their insurers continue to assess the risks associated with shipping EOL Li-ion batteries. Although Li-ion batteries would typically be shipped through established third-parties who are certified in hazardous material transportation, these parties are nonetheless responsible for ensuring that the batteries are packaged safely and shipped in compliance with DOT regulations. They will also bear responsibility for damage caused by fires during the storage, loading, transport (including ocean transport), and unloading of their Li-ion batteries. These hurdles, if properly addressed, will increase the cost of transport (e.g., packaging design, system design for fire surveillance and suppression) and insurance, both of which will be borne by the consumer at EOL.

One last consideration is decommissioning costs. While at the utility-scale the cost of decommissioning the installed batteries is the responsibility of the IPP[38], at residential and commercial scale installations the cost of decommissioning will be borne by the generator of the waste Li-ion battery, whether it be the car, home or business owner. While IPP's will have far greater awareness and resources to manage such decommissioning costs, your typical car, home or small business owner, may find the unexpected costs prohibitively high.

Considerations for policy development: While the recycling of Li-ion batteries may become profitable under the right circumstances [38], the cost of shipping Li-ion batteries will keep this from happening for Hawaiʻi. Moreover, the value of recovered metals will consistently fluctuate owing to continuous evolution of cathode chemistries as well as volatility in the metals market [20]. As such, the reality that the cost of recycling Li-ion batteries is both fluid and a moving target.

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[35] A term to indicate smaller replaceable batteries.
[36] Jason Gruber, E-opala Computer Recycling Center.
[37] Call2Recycle being one of the most established and significant with respect to Li-ion and other batteries.
[38] As required under the terms of power purchase agreements between the State and the power producer.

Figure 4. Recent cargo ship fires due to EVs containing EOL still activated Li-ion batteries. (A) the Fremantle Highway (2023); (B) the Felicity Ace (2022); and (C) the Hoegh Xiamen (2020). All fires resulted in a total loss of all cargo.

Perhaps most important is that insurance carriers are reassessing their policies and approaches to insuring storers, shippers, and recyclers of Li-ion batteries [15]. In particular, the risks of transporting Li-ion batteries are now well noted (Figure 4) and costly safety protocols are actively being researched by shippers, as well as the EPA and DOT. In its Shipping and Safety Review 2023, Allianz Global Corporate & Specialty reported that were 209 ship fires reported during 2022, of which, 13 occurred on car carriers. According to the Allianz report, the increasing the risk of fires at sea is due, in large part to new types of cargo such as electric vehicles (EVs) and the prevalence of lithium-ion (Li-ion) batteries which pose a growing risk for container shipping and car carriers.

Maritime safety agencies are also reassessing risks to shipping Li-ion batteries. In March 2023, the European Maritime Safety Agency (EMSA) published its CARGOSAFE study, which assessed the risks associated with fires on container ships and evaluated prevention, detection, firefighting, and containment measures. The study indicated that the main cargo types identified as responsible for a large share of cargo fire accidents included Li-ion batteries [39]. Some of the consequences of these fires are already being felt. The International Code Council (ICC) recently approved new lithium battery storage requirements for incorporation into the 2024 international fire and building code (IFC and IBC)[39]. Among other things, these new requirements restrict the amount of Li-ion battery that can be stored in a container as well as increase the amount of space that must occur between the containers. Both requirements can be expected to significantly increase the cost of storage and transport. While it can safely be assumed that the industry as a whole will move towards regulations and laws that support the overall uptake of Li-ion battery storage systems at all scales of society, it can also be expected that continued regulations will add significant cost to the storage, transport, and recycling of EOL batteries. Policy development in Hawai‘i should prepare for these costs and consumer response.

[39] See https://www.prba.org/areas-of-focus/fire-codes/

Waste generator responsibility. Under this scenario, those responsible for generating the Li-ion battery waste would be required to arrange for and pay, at EOL, the full cost of transporting and recycling of EOL Li-ion batteries at off-island disposal/recycling centers. For EVs, this would be the last owner of the vehicle (who presumably would work through a dealership or independent mechanic replacing the battery), car dealerships if acquired through the 2nd hand market, salvagers if purchased at auction, or the counties in the case of abandoned vehicle. In the case of energy storage system systems, this will likely be the residential or commercial owner (who presumably would work through a certified contractor) or, at utility scale, the independent power producer (who presumably would follow the terms of the PPA that governs their installation). In those situations where the IPP does not honor their contractual commitment to the PPA, either through insolvency or contractual disagreement, the state of Hawaiʻi would be financially responsible unless/until they could transfer these costs to the land owner[40].

Considerations for policy development: Recently, the Li-ion Battery Recycling Advisory Group from the California Environmental Protection Agency published a report recommending battery take-back at no cost to the consumer [38]. While this report was written for EVs, it is reasonable to expand their recommendations to residential homeowners and commercial businesses who own Li-ion batteries as part of energy storage systems. Specifically, the Li-ion battery Advisory Group ***did not recommend*** placing the cost of EOL recycling of Li-ion batteries onto the consumer in part because the costs are sufficiently high to encourage illegal dumping. Moreover, when faced with battery replacement costs that approach the price of a new car[41], for example, some car owners will sell their EVs onto the second-hand car market where they will ultimately end up as abandoned vehicles[42]. In Hawaiʻi, there is already concern for this at the county level [20].

Policy development should consider the reality that the success of waste generator (consumer) responsibility laws governing recycling lead acid batteries will not successfully cross over to Li-ion batteries. Lead acid batteries are far simpler to recycle, far more stable from a safety point of view, possess a highly standardized design across manufacturers, and contain large amounts of lead. This degree of product equivalence and overall amount of a valuable resource has permitted the growth of an established and reliable lead acid battery recycling industry[43], a reality that facilitates the outsourcing of responsibility for the collection, transport, and payment of lead acid batteries (to mainland recyclers) to a variety of local entities, some of whom may even offer gift cards to the generator of the battery[44]. This advantage, however, does not transfer to Li-ion

[40] For example, by placing a lien on the land.
[41] Costs to replace a battery will include the price of a new battery, the cost to recycle the old batter, and labor.
[42] It is assumed that second or third hand owners will avoid the cost of recycle and just pay the fine of illegal abandonment.
[43] See, for example, recycling lead-acid batteries is easy. Why is recycling lithium-ion batteries hard? By James Morton Turner. Https://cleantechnica.com/2022/07/24/recycling-lead-acid-batteries-is-easy-why-is-recycling-lithium-ion-batteries-hard/.
[44] See, for example, the following representative link: https://footprinthero.com/how-to-recycle-lead-acid-batteries.

batteries where similar product equivalency across makes and model has yet to materialize[45]. Only one automaker (Tesla) has announced an intention to take back and recycle their batteries while only a few others[46] propose to pursue refurbishing for reuse in energy storage system batteries [40]. Although promising, Redwood Material's under development recycling plant in Nevada is only recycling a fraction of Tesla's batteries [41]. It should be noted, however, that other recyclers are emerging. Li-Cycle[47], a Canadian based company is creating a spoke and hub model wherein spoke facilities are being built in mainland states such as Arizona. Also, Interco[48], a metaltronics recycler in St. Louis, Missouri has just come on line with a plant that can take in Li-ion batterie and recycle them to downstream product streams that can then be purchased by battery manufacturers. Both options, however, will charge to take in still active EOL Li-ion batteries and to this cost the cost of shipping has to be added.

While nickel-based batteries could potentially generate modest revenue with good logistics, Li-ion batteries do not possess sufficient precious metals to ensure their recycling is profitable without subsidies. Moreover, these revenues, if realized, would not overcome the cost of shipping. Realistically, only lead acid batteries can be recycled profitably but even in Hawai‘i, a modest fee at the time of purchase is still required. The costs of shipping and recycle of Li-ion batteries is higher and for this reason, the existing model used for the recycling of lead acid batteries will not readily transfer to the recycling of Li-ion batteries. This reality will undermine efforts to deploy waste generator laws and substantially increase the load of enforcement upon the state agencies. With respect to waste generator responsibility laws, policy development in Hawai‘i should consider the consequences of high EOL costs associated with recycling Li-ion batteries. Not only will high costs applied to the waste generator encourage selling to 2nd and 3rd hand markets and even abandonment (i.e., illegal dumping), they could also reduce consumer uptake of EVs or energy storage system batteries – both key factors that could undermine the state's goal to become fully renewable by 2045.

Expanded producer responsibility. Under this scenario, the battery supplier or manufacturer would be required to manage EOL treatment of their EV or energy system storage Li-ion batteries. Recently the Li-ion Battery Recycling Advisory Group from the California Environmental Protection Agency published a proposed policy around EPR for EV Li-ion batteries [38]. Given the similarity between the two systems, it is presumed that the recommendations of the Advisory Group for EV Li-ion batteries can be similarly applied to Li-ion batteries used in energy storage system systems. In their report, the Advisory Group presented two policies that, although different, fall under the EPR umbrella. Both policies were well received and promoted by the

[45] Materials used within a given brand of LIB, particularly with the chemistries of the cathode and electrolyte, as well as the structure and material used in the casing not only vary between manufacturers, but can vary between models of the same battery.
[46] Hyundai, Renault, BMW.
[47] https://li-cycle.com.
[48] https://intercotradingco.com.

report's Advisory Group. In the first policy, termed core exchange with vehicle backstop, the *EV battery supplier* is required to detail a core exchange program and in the second policy, termed producer take-back, the *EV vehicle manufacturer* is responsible to ensure proper repurposing, reuse, or recycling at EOL. With respect to Li-ion batteries in energy storage system systems, as late as July 2020 no U.S. federal policy directly addressed battery energy storage systems decommissioning, or mandated or incentivized reuse/recovery of Li-ion batteries [42, 43]. Also noted was the issue of orphaned batteries if the original equipment manufacturer (OEM) leaves the industry (or goes out of business). Additional key points made include:

- The Li-ion battery Advisory Group's core exchange with vehicle backstop policy defines responsibility for out-of-warranty batteries[49] for either (i) in service EVs or (ii) out of service EVs. For in service EVs the out-of-warranty battery pack (or modules or individual cells) are replaced under a core exchange program *detailed* by the manufacturer of the *new* EV battery (or modules or individual cells) and *accessed/used* by the entity removing the old battery and installing the new battery. In application the owner of the pre-existing battery purchases a new or refurbished Li-ion battery and turns in the old Li-ion battery for credit, the entity removing and installing the new battery ships the old battery to the manufacturer who then inspects the old battery to determine credit eligibility. If their battery was deemed eligible the owner receives the credit. For out of service vehicles the policy used depends upon whether (or not) the vehicle has been purchased by a dismantler/salvager. When the vehicle is purchased by a dismantler/salvager they become responsible to ensure the battery is properly reused, repurposed, or recycled. When the out of service vehicle is not purchased by a salvager/dismantler the vehicle manufacturer would become responsible to ensure the vehicle is properly dismantled and the battery is properly reused, repurposed, or recycle. The report did not, however, provide guidance on administrative structure.

- With respect to the Advisory Group's take-back policy, the auto manufacturer would be responsible for ensuring proper repurposing, reuse, or recycling of its EV batteries by a licensed facility at no cost to the consumer if and/or when the batteries are no longer wanted by the owner, and in the event no other entity has taken possession of the battery [38]. This responsibility would include arranging for the transport of the batteries to the repurposing or recycling hubs, being responsible for the recycling costs, and being responsible for the proper documentation of proper disposal of the battery. Moreover, the auto manufacturer's responsibility is initiated when the auto manufacturer has been notified that the EV battery has reached its EOL and is available to be reused, repurposed, or recycled. When repurposed the responsibility for the battery is then transferred to the repurposing company. Even though their recommendations targeted manufactures of EV batteries, it seems reasonable to assume that the same reasoning could apply to manufacturers of energy system batteries.

[49] For batteries under warranty, the vehicle manufacturer is presumably responsible for properly reusing, repurposing, or recycling the returned lithium-ion battery.

- The Li-ion battery Advisory Group compiled a list of advantages and disadvantages to both policies. Advantages to the take-back model include addressing those LI-ION BATTERYs that could potentially become abandoned, a necessary means of capturing batteries that are currently on the road and out of warranty, does not add an upfront fee at the time of purchase of the EV, and specifies terms of responsibility upon battery transfer. Advantages to the producer take-back policy include clear definition of responsibility, providing the option for EV owners to sell the battery at EOL or contacting the vehicle OEM to arrange for correct disposal. However, disadvantages to both include increased costs to the OEM and thus higher EV prices and lower market penetration, as well as the possibility of orphaned batteries if the OEM goes out of business.

While this report was being written, California passed two laws that overhauled its Li-ion battery EPR program. Both bills, however, left out EV (and energy system scale) Li-ion batteries while the above-mentioned report was being written. AB 2440[50] addressed loose household batteries only while SB 1215[51] addressed battery embedded products. AB 2440 created a singular EPR program for the state and will require battery producers to create or fund stewardship programs for collecting and recycling most batteries sold within California, beginning no later than April 1, 2027. SB 1215 broadened the Electronic Waste Recycling Act of 2003 definition of manufacturers requiring consumers to pay a fee at the point of sale for any new or refurbished product with an embedded battery. The law also expands the reporting requirements for manufacturers of all covered electronic devices. The point-of-sale fee will take effect beginning January 1, 2026, while the new reporting requirements will take effect beginning July 1, 2027. In terms of policy development, both bills could serve as a model for EPR bills addressing the recycling of household loose and product embedded Li-ion batteries in Hawai‘i.

With respect to larger Li-ion batteries used in EVs and energy storage systems, California is currently legislating a true EPR bill for EV Li-ion batteries based upon recommendations of the Li-ion Battery Recycling Advisory Group’s report. Introduced as SB 615[52], this bill is currently being revised and is expected to pass in 2024. In speaking with lobbyists from relevant stewardship programs in California, the general perception is that the bill’s authors initially went into too much detail regarding chain of custody and tracking the from the point of purchase. Current revisions are trending towards simpler requirement that the manufacture simply takes the batteries back and pay for it.

Considerations for policy development: Although a variety of states have regulations governing the recycling of lead-acid and other batteries of well-established chemistry that could ultimately be applied to Li-ion batteries [43], SB 615 should be used as a model to follow for EPR laws in Hawai‘i. Hawai‘i’s market share of EV and energy storage system batteries is small compared to

[50] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220AB2440.
[51] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB1215.
[52] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240SB615.

the U.S. or global market and attempts to pass EPR laws that extend to manufacturers based outside the reach of U.S. law, could result in their disengagement from Hawai‘i's market. Realistically, the passage of EPR laws in Hawai‘i should only follow similar efforts in California or the U.S. For example, California has lead-acid battery recycling regulations and EPR regulations for recycling of rechargeable batteries. Both California and New York require retailers to accept battery returns from customers and to recycle them [43]. Hawai‘i similarly requires retailers and wholesalers of lead-acid batteries to accept old batteries when new batteries are purchased (Chapter 342I, Hawai‘i Revised Statutes).

State assisted recycle. Under this scenario those entities who arrange for the collection and transport of Li-ion batteries to mainland recyclers would receive reimbursement[53]. The most functional point to collect fees would be at the point of purchase or fees applied to car registration or electric bills [20]. Fees assigned at the time of purchase would have the entities selling the Li-ion batteries assess the surcharge and then transfer these funds to the designated state agency or nonprofit managing the reimbursements. Fees applied to car registration or electric bills would be similarly collected (by the DMV or HECO) and transferred to the designated state agency or nonprofit managing the reimbursements.

Although mechanisms to reimburse the cost of recycling orphaned power tool size lithium batteries exist in Hawai‘i[54], these programs are not presently prepared to underwrite the cost of recycling the larger EV or energy storage system scale Li-ion batteries [20]. To manage these larger item waste streams, policy development should consider the use of state assisted recycle. Moreover, at the larger scale (EV and power systems) the collection and transfer of funds could be simpler to organize and administrate for EOL Li-ion batteries given the size and complexity of installation/deinstallation.

Considerations for policy development: Similar to PV panels, the mechanisms of how to raise the revenue is complicated by issues of equity and administrative practicality. In particular, the cost to recycle larger Li-ion batteries will be relatively high when including the cost of shipping. The cost to replace an EOL Tesla EV battery, for example, could add as much as $15,520 to the purchase price. Currently, county staff manage the small amounts of Li-ion batteries [20] entering the waste stream by dipping into revenues from vehicle registration fees. Concerns have been raised, however, with how to pay for these costs as the number of batteries increases with time [20]. That being said, upfront fees can be a great way to manage abandoned products. Such ADFs, for example, could also be used to sponsor amnesty programs that serve to bring in wastes that would otherwise be dumped[55].

[53] This could occur, for example, through the counties via their current interactions with salvagers and other processors of abandoned or discarded waste.
[54] Various recycling centers and chain stores such as Home Depot will take Li-ion batteries.
[55] See the following link that describes an amnesty program for mattress and box springs. https://yubanet.com/regional/wm-offers-free-mattress-and-box-spring-drop-off-at-mccourtney-road-transfer-station/.

State encouraged recycle. Under this scenario, the state would pursue policies that would reduce the relative cost of recycling. While this could include laws that ban landfilling, eliminate the household hazardous waste exclusion, or the application of significant fines for noncompliance, it could also include policies that facilitate the permitting of facilities that deactivate and break up EOL Li-ion batteries for safe off-island shipping. Several options currently exist. Li-Cycle is a Canadian company that markets a "Spoke and Hub" process in which "Spoke" facilities take in Li-ion batteries and using their proprietary process reduce the batteries to several recyclable streams including a black mass. Unfortunately, the design of their system is such that the "Spoke" plants are likely too large for Hawai‘i[56]. A more scalable process has been identified at Interco[57], a global recycling company headquartered on the Illinois side of St. Louis. Because Interco uses a process that shreds L-ion batteries under water, the process can be scaled to lower intake volumes that that required by Li-Cycles larger chemical and thermally intensive process. Moreover, Interco's process allows for the addition of additional unit operations that can further process the shredded battery scraps all the way to a black mass and associated metal and plastic streams, all of which could then be shipped safely to mainland refiners. A significant development is ongoing on Maui wherein specialists[58] from the EPA, Matson, and California fire departments are working out procedures to treat Li-ion batteries recovered form the fire zones of Lahaina. Research is ongoing as to the best practice to render the recovered and fire damaged batteries safe for shipping to mainland recyclers. The results from these tests can be used to evaluate and design a scale up facility (or facilities) in Hawai‘i. Finally, there is a small startup company[59] that is developing super-critical CO2 technology to deactivate Li-ion batteries. This technology can be driven around by trucks on a flat bed extension and parked outside stores or on relevant locations to deactivate loose or unattached Li-ion batteries on site. In time, the technology could conceivably be scaled up to larger EV batteries or to manage greater processing rates.

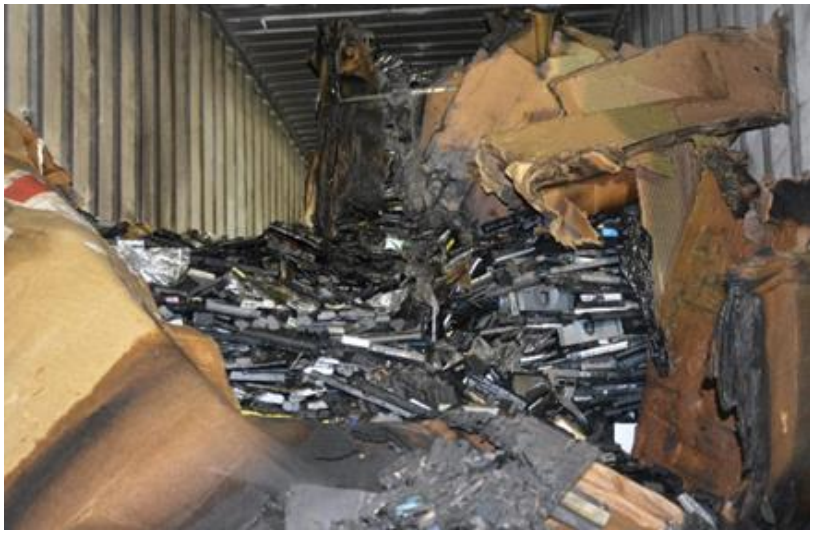
Figure 5. Burnt Li-ion batteries recovered from Maui fire. Photo courtesy of onsite team.

Considerations for policy development: Because of the risks to ocean shipping, policy development should consider on-island preprocessing of Li-ion batteries to a deactivated state. If

[56] One estimate by Eric Frederickson of Call2Recycle is that a typical Li-Cycle "Spoke" facility would require a minimum of 30,000 standard EV batteries per year.
[57] https://intercotradingco.com/about/
[58] Bryan Vassar, Greg Jenkins, and Robert Rezende.
[59] OnTo Technology LLC

done on island, however, this would involve the initial discharge of the high-voltage batteries followed by deactivation by various methods such as underwater shredding (or equivalent processes such as long-term submersion in salt solutions followed by crushing). Indeed, a recent marine safety alert highlighted the risk of loading and shipping EVs with damaged Li-ion batteries onto commercial vessels as well as highlighting the even greater risk of packing Li-ion batteries into containers[60]. This risk is even higher for damaged Li-ion batteries e.g., exposed to flooding with salt water) [44] – a likely risk, for example, in case of high storm surges in the event of a hurricane. In one event, a container illegally loaded with discarded Li-ion batteries caught fire while on travel to the Port of Virginia (Figure 5) [45]. In a typical instance, the bill of lading was listed “computer parts,” and not lithium batteries. The Coast Guard reported the incident could have been potentially catastrophic had the container caught fire after being loaded aboard the container ship. Policy development should consider that these types of events are likely to continue so long as the cost of shipping EOL Li-ion batteries is high to the end user. Moreover, accidents like these increase the risk to Hawai‘i of having access to ocean shipping of EOL Li-ion batteries removed by the shippers (or their insurers). As such, policy development should consider supporting the development of a Li-ion battery deactivation process facility in Hawai‘i.

Figure 6. Burned Li-ion batteries found in fiberboard boxes after the August 19, 2021 fire. Photo courtesy U.S. Coast Guard.



Summary and Recommendations

The new and emerging waste streams of PV panels and Li-ion batteries will begin to accelerate to significant levels in Hawai‘i during this decade [20]. Many stakeholders (e.g., relevant state government agencies, counties refuse divisions, local salvagers and recyclers) in Hawai‘i who will

[60] Marine Safety Alert 01-23.

have a role in the management, collection, disposal, and recycling of these new and emerging waste streams are neither prepared nor have the capacity to administrate them. Moreover, the generators of these waste streams are generally unaware of (or prepared to) bear the full costs of their EOL disposal. The risk to Hawaiʻi is that unless these hurdles are addressed, the threat of continued and increased unlawful dumping/storage of these materials in Hawaiʻi is high (and is already occurring).

There is time and opportunity, however, for stakeholders in Hawaiʻi to prepare for the surge in these new and emerging waste streams. Mainland efforts addressing effective EPR laws[61] as well as reliable recycling options that can be championed in Hawaiʻi law are progressing[62]. There is also good reason to assume that many of the proposed solutions will, when pursued collectively, prove effective. Moreover, as reuse and recycling pathways mature on the mainland, the cost of recycling should decrease. That being said, policy development should acknowledge that the costs associated with off-island shipping will increase such that the recycling of either waste stream will continue to be a net cost activity. To help navigate this uncertain and changing future, it is recommended to support the creation of 403B nonprofit stewardship programs.

Risks. There are several additional risks that threaten initiatives to recycle EOL PV panels and Li-ion batteries in Hawaiʻi. The reuse/refurbishing market, for example, requires testing and certification across all makes and brands, with only a few on the mainland operating successfully[63]. With respect to PV panels, the predicted fall in prices of new panels, coupled with increased efficiencies[64], will constrain demand (and thus revenue) for old panels. With respect to Li-ion batteries, there are a number of challenges to their reuse/repurposing that will restrict demand (and thus price). First, estimating remaining capacity will be challenging owing to the variety in the make of EV and energy system Li-ion batteries in terms of electrode chemistry, size, and format. Second, standards for second life battery quality and performance are still being developed. The absence of widely accepted standards can make potential buyers wary while their presence can reveal flaws that limit demand. Strict EPR laws will be difficult to pass and nearly impossible to enforce on legacy products abandoned by their manufacturers. Finally, 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 Li-ion batteries[65]. Finally, ocean shipping of EOL Li-ion batteries remains at risk.

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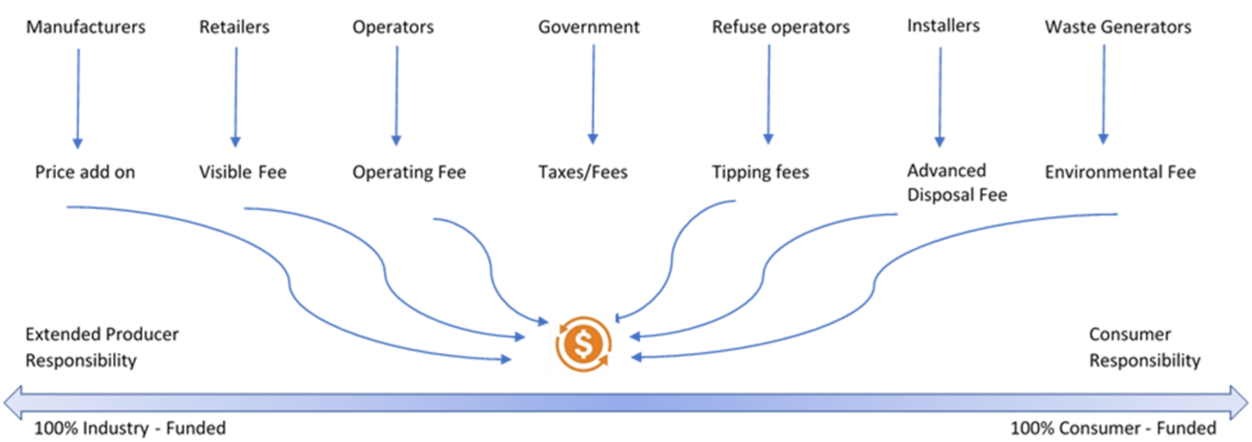
[61] See, for example, the following webinar addressing solar panel recycling and EPR at https://oregonrecyclers.org/events/webinar-solar-panel-recycling-epr.
[62] See, for example, the following webinar on battery recycling from Clean Energy States Alliance https://www.cesa.org/event/battery-decommissioning-recycling-and-reuse.
[63] See Bumblebee Battery Recycling which refurbishes Toyota and Honda LIB. https://bumblebeebatteries.com/.
[64] See, for example, https://www.cnet.com/home/energy-and-utilities/why-the-cost-of-solar-panels-will-likely-keep-falling/.
[65] See https://www.reuters.com/article/us-china-waste-imports/china-plans-to-cut-waste-imports-to-zero-by-next-year-official-idUSKCN1R90AQ.

Recommendations. Current options for disposal of EOL PV panel as well as EV or energy storage system Li-ion batteries will remain a positive cost activity in Hawaiʻi [20]. Both products require high-cost energy and chemically intensive unit operations to extract and purify relatively small amounts of precious metals per pound of material processed. Also, the cost of shipping out of Hawaiʻi, is particularly significant for Li-ion batteries and can equal or even surpass the cost of recycling. Specifically, 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.

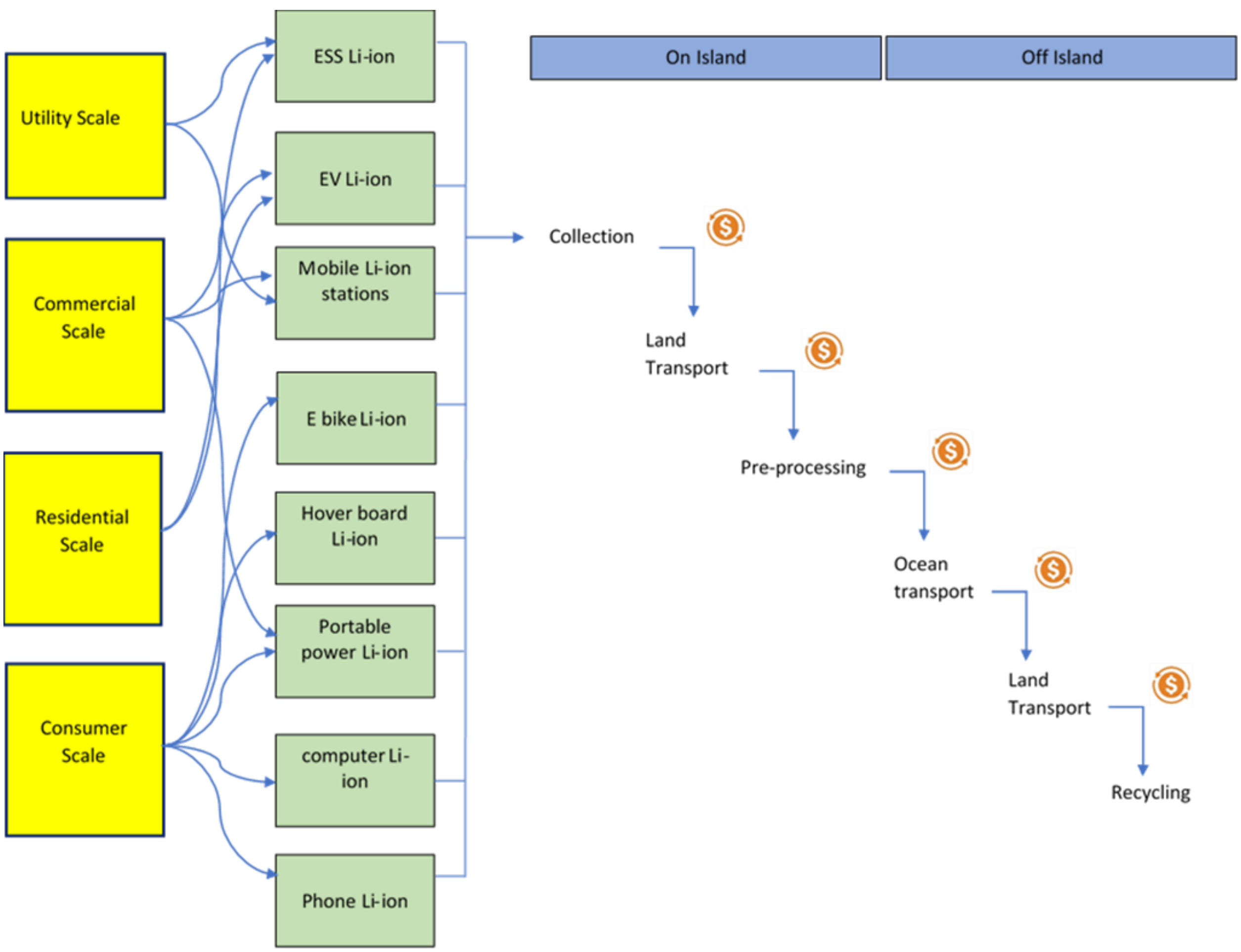
Revenue streams from PV panels and Li-ion batteries recycling will remain constrained in part because of low recovery yields – both inefficiencies in recovering operations but also to low concentrations per pound of material – but also because of production from the mining industry. For example, a recent discovery of high-grade lithium in Nevada bodes well for lithium production that places downward pressure on its market price [46]. For these reasons it is recommended that policy development consider the pursuit of additional revenue streams to supplement revenue from the sales of recovered precious metals. Figure 6 presents a potential list of revenue streams ranging from 100% industry funded to 100% consumer funded. While there are pros and cons to each stream, all of them are established methods used, one way or the other, in the recycling industry.

Figure 7. Potential range of revenue streams for stewardship program administrating recycling either PV panels or Li-ion batteries.



State-wide stewardship program. When considered in aggregate, these factors highlight the complexities associated with executing an effective state-wide recycling program that covers either PV panels and/or Li-ion batteries at EOL. Managing revenue streams, collections, storage, and transport logistics is complicated. For these reasons, policy development should consider the creation of stewardship programs that operate outside any one specific state agency, incorporates multiple revenue streams, pursues a package of complementary policies that spreads the cost and responsibility across multiple participants and reduce the risk of over reliance/burdening on any one actor. The advantage to stewardship programs is that they are comprehensive. They also take the burden off of state agencies. For these reasons, to achieve comprehensive and effective disposal and recycling of these waste streams, it is suggested that the stewardship program, in collaboration with specific laws, be charged to administrate the activities listed in Figure 6. The scope of activity covered by such a stewardship program applied to Li-ion batteries is outlined in Figure 6. The program would cover Li-ion batteries generated from all scales and products. It would also administer the batteries on-island collection, transport, and deactivation (i.e., the pre-processing step in Figure 6). It would also manage the logistics of transport and recycling. The revenue to manage the program would come from some combination of activities described in Figure 6. There are stewardship programs on the mainland that could help coordinate this in Hawai‘i. One such program, Call2Recycle, is highly recommended. One applied to PV panels could be built around Inter-Island’s program.

Figure 8. Scope of non-profit stewardship program as applied to the recycling of Li-ion batteries.



OTHER ISSUES TO CONSIDER FOR MANAGEMENT, RECYCLING, AND DISPOSAL

This section identifies additional issues to consider with respect to development the management, recycling, and disposal of clean energy systems that may be pertinent to policy development.

Stewardship Programs and Tracking EOL EV Li-ion Batteries

Many barriers exist to the recycling of Li-ion batteries that stem from the decentralized and unregulated nature of the vehicle afterlife market in the U.S. [38]. Retired EVs, for example, will end up being handled by several different parties who have unequal access to the resources and information necessary to manage EOL batteries properly. To that end, one key concern noted by the Li-ion battery Advisory Group was that once vehicles and/or their batteries are out of warranty, it becomes difficult to track them or control what happens to them. The same could be true for energy system batteries in residential/commercial scale installations. Under these conditions, the collection and return of EOL Li-ion batteries to a domestic reuse or recycling system will benefit from the presence of financial incentives for whoever is handling the battery at that time. Stewardship programs can efficiently manage unregulated and/or decentralized markets and ultimately reduce redundancy and increase efficiency.

Necessity of Transition Programs

Efforts to impose PV panel EPR laws in California have found significant resistance from manufacturers, in particular with respect to legacy and orphaned products produced by other manufacturers that have left the business. This has been seen in the recent gutting of proposed strict EPR laws in California with respect to PV panels. Given these realities, and the fact that no fees have been collected to date for previously installed products, transition programs should be considered for Hawaiʻi will be needed even if EPR laws are successfully implemented.

Consideration of Possible Shipping Restrictions

Policy formulation should consider the extreme situation where ocean shippers either decline to ship EOL Li-ion batteries outright or apply restrictions that are sufficiently strict so as to either restrict amounts that can be shipped at any given time (e.g., number of batteries per container, total weight per shipment, etc.) and/or impose high costs (i.e., make it very difficult and expensive to ship off island).

Extended Producer Responsibility

Although, extended producer responsibility (EPR) or similar models, whereby the manufacturer, reseller, or installer is responsible for the end-of-life management of PV panels, electronic items, and batteries, 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 out of sync with national trends. California, in fact, is perhaps the only state large enough to drive trends nationally. Currently, only two states[66] have pursued EPR policies for PV panels and Li-ion batteries and a third[67] has opted to pursue visible fees[68] (and not EPR) programs for both PV panels. Most important, however, is to recognize that all 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 batteries) 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[69].

The challenges to the EPR model, with respect to PV panels and energy storage system batteries, 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 batteries occurs through multiple layers of manufacturers of which many are outside the U.S.[70]. 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 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 Li-ion batteries going out of business before their products reach end of life is real and significant[71].

[66] Niagara Country and Washington State.
[67] California.
[68] Visible fees are similar to advance disposal fees or environmental fees that are (i) transparent and (ii) collected at the point of purchase.
[69] i.e., collection, storage, transport and recycling.
[70] 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.
[71] 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.

Power Purchase Agreements

Utility-scale installations should include, in the power purchase agreements (PPAs), provisions that place responsibility on the independent power producers (IPP) to cover the end-of-life disposal and/or treatment of clean energy materials. This will remove a significant burden on local waste disposal handlers as well as impacted state agencies and counties. Throughout the development of this report, several suggestions emerged to ensure effective PPAs.

The first is for the state to insert into the PPA a provision that requires IPPs to remove and transport *all* of the clean energy materials off the island at the end of the agreement. The advantage to this requirement is that the state bears no responsibility for processing the end-of-life treatment of utility-scale clean energy waste. The disadvantage to this option is that the state has no protection against bankruptcy of a given IPP.

To guard against this potentiality, the second option is to attach a fee or deposit requirement as part of the PPA that requires funds to be put away for the disposal of these materials at their end-of-life[72]. The advantage to this option is that state can collect the necessary funds at the start of the project and therefore does not bear the risk of a given IPP declaring bankruptcy and leaving behind clean energy materials. The disadvantages to this option are that the costs of end-of-life treatment are difficult to estimate accurately, the end of life can occur as many as twenty years later and the state will have to manage both the funds and the logistics of off-island transportation of all clean energy materials.

Landfill Ban

While universal waste and hazardous waste regulations generally prohibit the dumping of universal waste PV panels, electronic items, and Li-ion batteries into local municipal solid waste landfills (the State of Hawaiʻi does not have any hazardous waste landfills), there is currently an exclusion for household hazardous waste. Unless the Department of Health's Hazardous Waste Program makes a clear determination that solar PV panels removed from residential structures do not meet the conditions of this exclusion[73], this allows residential PV panels to be landfilled. Moreover, PV panels are currently landfilled in many states in the U.S. at relatively low cost. However, concerns about landfilling PV panels are increasing. As such, full landfill bans may become a reality. In this case, recycling, with its higher costs, will become the only remaining option and the challenges of high transport costs to recycle previously discussed will become paramount. In this case, the state may need to charge sufficient fees (e.g., Advanced Disposal Fee)

[72] This is similar to the decommissioning fee that all nuclear reactors pay.

[73] See subsection "Best Practices for Collection, Disposal, and Recycling of Clean Energy Materials: PV modules – disposal" in HNEI's 2022 Final Report on House Bill 1333: Recommendations on Waste Management of Clean Energy Products in Hawai'i.

to supplement the cost of disposal at residential and commercial scale and, at utility-scale, require the placement of deposits in the absence of enforceable PPAs.

Handling Issues Associated with Li-ion Batteries

Li-ion batteries, as currently designed, present a real threat of fires and extreme challenges to firefighters. It may take several generations of battery modifications by manufacturers to lessen the hazard of fires at recycling plants. In a recent publication, for example, the existential threat of Li-ion battery fires to the recycling industry in California was emphasized.

“Every (Materials Recycling Facility) MRF, pretty much, in California is experiencing fires, if not on a daily basis, on a weekly basis….We're on the fringe of losing our recycling infrastructure that we've built over several decades to try and recycle this stuff” [47].

This growing hazard serves to emphasize the risk to storage and transport of Li-ion batteries at local and regional recycling centers. It also raises concerns around their ocean transport from Hawai‘i. In the case of an extreme weather event that causes damage to large numbers of residential, commercial, or utility-scale Li-ion batteries, this increases the chance of Li-ion batteries being damaged to the point of increased threat of flammability and explosion. Given these risks, procedures should be put in place to manage the collection, storage, and transport of a large number of damaged EV or energy storage system Li-ion batteries. This could be through the deactivation of Li-ion batteries on island prior to their transport, pathways to test EOL batteries to secure certifications of their being safe to transport, or some combination of the two.

Household Hazardous Waste Exclusion

Currently, the household waste exclusion permits the landfilling of hazardous waste generated by households. The Hawai‘i Department of Health’s Hazardous Waste Program has not yet taken a position on whether solar PV panels removed from residential structures meet the conditions of this exclusion. If solar PV panels from household residences are excluded from the household waste exclusion, residential waste generators[74] will be exposed to unexpectedly high end-of-life treatment costs. These types of unexpected cost “shocks” often lead to and promote the kind of illegal dumping that is difficult to monitor and regulate.

[74] Or the contractor they seek for quotes.

RECOMMENDATIONS

This report has highlighted the unexpectedly high costs that will be associated with disposal of Li-ion batteries in Hawai‘i. Moreover, there is a high risk to shipping Li-ion batteries 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 Li-ion batteries shipped under misleading manifests, which can take up a month before igniting, Li-ion batteries 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 Li-ion batteries, poses an existential threat to Hawai‘i’s initiative to become fully renewable. To manage this threat, a comprehensive technical assessment that analyzes a number of Li-ion battery deactivation processes, the requirement and logistics of collection, transport and storage prior to deactivation, as well estimated costs and infrastructure requirements should be executed. Such as 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 Hawaii’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 Hawaii military bases, private nonprofit recycling groups, installers/contractors, professional associations and others.

Finally, 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 Li-ion batteries - inclusive of revenue collection, storage, on-island transport and processing of both PV panels and Li-ion batteries, tracking from point of purchase to recycle, off-island transport of pre-processed PV panels and Li-ion batteries to mainland recyclers, and payments to all participating participants – could 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 Li-ion batteries. Because of structural differences, separate stewardship programs for PV panels and Li-ion batteries 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. Divya, A., et al., *Review on recycling of solar modules/panels.* Solar Energy Materials and Solar Cells 2023. **253**: p. 112151.
2. Dobó, Z., T. Dinh, and T. Kulcsár, *A review on recycling of spent lithium-ion batteries.* Energy Reports, 2023. **9**: p. 6362 - 6395.
3. Majewski, P., et al., *Recycling of solar PV panels- product stewardship and regulatory approaches.* Energy Policy, 2021. **149**: p. 112062.
4. Blomeke, S., et al., *Material and energy flow analysis for environmental and economic impact assessment of industrial recycling routes for lithium-ion traction batteries* Journal of Cleaner Production, 2022. **37**(1): p. 134344.
5. Granata, G., et al., *Recycling of solar photovoltaic panels: Techno-economic assessment in waste management perspective* Journal of Cleaner Production, 2022. **363**: p. 132384.
6. Lander, L., et al., *Financial viability of electric vehicle lithium-ion battery recycling.* iScience, 2021. **24**: p. 102787.
7. Yu, J., et al., *Emergy based sustainability evaluation of spent lead acid batteries recycling.* Journal of Cleaner Production, 2020. **250**: p. 119467.
8. Liu, Y., et al., *Current and future lithium-ion battery manufacturing.* iScience, 2021. **24**: p. 102332.
9. Seo, B., J.Y. Kim, and J. Chung, *Overview of global status and challenges for end-of-life crystalline silicon photovoltaic panels: A focus on environmental impacts.* Waste Management, 2021. **128**: p. 45-51.
10. Sodhi, M., et al., *Economic Lifetimes of Solar Panels.* Procedia CIRP, 2022. **105**: p. 782-787.
11. Tammaroa, M., et al., *Experimental investigation to evaluate the potential environmental hazards of photovoltaic panels.* Journal of Hazardous Materials, 2016. **306**: p. 395-405.
12. 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.
13. Yuan, S., et al., *A review of fire-extinguishing agent on suppressing lithium-ion batteries fire.* Journal of Energy Chemistry, 2021. **62**: p. 262-280.
14. 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.
15. 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.
16. Huo, H., et al., *Safety requirements for transportation of lithium batteries.* Energies, 2017. **10**(6): p. 793.
17. Slattery, M., J. Dunn, and A. Kendall, *Transportation of electric vehicle lithium-ion batteries at end-of-life: A literature review.* Resources, Conservation & Recycling, 2021. **174**: p. 105755.
18. Diaz, L.B., et al., *Review—Meta-Review of Fire Safety of Lithium-Ion Batteries: Industry Challenges and Research Contributions.* Journal of The Electrochemical Society,, 2020. **167**(9): p. 090559.
19. Allianz, *Safety and Shipping Review 2023*. 2023, Allianz Global Corporate & Speciality. p. 1-44.

20. 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.
21. Lunardi, M.M., et al., *Comparative Life Cycle Assessment of End-of-Life Silicon Solar Photovoltaic Modules.* Applied Sciences, 2018. **8**: p. 1396.
22. Sinha, P., et al., *Human Health Risk Assessment Methods for PV Part 3: Module Disposal Risks*. 2020, International Energy Agency (IEA) PVPS Task 12, Report T12-16:2020
23. *DIRECTIVE 2012/19/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2012 on waste electrical and electronic equipment (WEEE).* Official Journal of the European Union, 2012. **L 197/38**: p. 1-34.
24. 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.
25. Ericksen, D. and G. Palumbo, *romoting a sustainable, local renewable energy industry through modifying renewable energy system tax incentives and providing guidance for renewable energy system component recycling*. 2017.
26. Ward, C.M., *Recycling: solar photovoltaic modules*. 2023.
27. Weaver, J., *Recycling solar panels: Making the numbers work*, in *PV magazine*. 2021.
28. EPA, *Method 1311: Toxicity Characteristic Leaching Procedure*, in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*. 1992, U.S. Environmental Protection Agency Washington, DC.
29. *Recycling and Disposal of Battery-Based Grid Energy Storage Systems: A Preliminary Investigation*. 2017, EPRI: Palo Alto, CA.
30. Redding, C., *Can Tesla Batteries Be Recycled?*, in *CarShtuff*. 2022.
31. Garole, D.J., et al., *Recycle, Recover and Repurpose Strategy of Spent Li-ion Batteries and Catalysts: Current Status and Future Opportunitie.* ChemSusChem, 2020. **13**: p. 3079 – 3100.
32. Jacoby, M., *It's Time to Recycle Lithium-Ion Batteries.* Chemical & Engineering News, 2019. **97**(28): p. 28-32.
33. Lander, L., et al., *Financial viability of electric vehicle lithium-ion battery recycling.* iScience, 2021. **24**: p. 102787.
34. EPA, *An Analysis of Lithium-ion Battery Fires in Waste Management and Recycling*, O.o.R.C.a. Recovery, Editor. 2021, Environmental Protection Agency.
35. Gaines, L., K. Richa, and J. Spangenberger, *Key issues for Li-ion battery recycling.* MRS Energy Sustainability, 2018. **5**: p. E14.
36. Chitre, A., et al., *Towards a More Sustainable Lithium-Ion Battery Future: Recycling LIBs from Electric Vehicles.* Batteries & Supercaps, 2020. **3**(11): p. 1126 - 1136.
37. Heelan, J., et al., *Current and Prospective Li-Ion Battery Recycling and Recovery Processes.* JOM, 2016. **68**: p. pages 2632–2638.
38. CalEPA, *Lithium-ion Car Battery Recycling Advisory Group Final Report*. 2022, California Environmental Protection Agency: Sacramento California.
39. Wilkens, K., et al., *Study investigating cost-efficient measures for reducing the risk of cargo fires on container vessels (CARGOSAFE)*, in *CargoSafe Report*. 2023, European Maritime Safety Agency.
40. Lambert, F., *Tesla is developing a 'unique battery recycling system'*, in *electrek*. 2019.

41. Lienert, P., *Ex-Tesla exec Straubel aims to build world's top battery recycler*. 2020, Reuters.
42. *Pathways To Achieve New Circular Vision for Lithium-Ion Batteries*. 2021, NREL.
43. *The Regulatory Environment for Lithium-Ion Battery Recycling.* ACS Energy Letters, 2022. **7**: p. 736-740.
44. USCG, *Saltwater Instrusion Causes Damage to Electric Vehicle Batteries*, in *Marine Safety Alert*, I.a.C. Directorate, Editor. 2023, United States Coast Guard: Washington DC.
45. USCG, *Lithium Battery Fire*, in *Marine Safety Alert*, I.a.C. Directorate, Editor. 2022, United States Coast Guard: Washington, DC.
46. Benson, T.R., M.A. Coble, and J.H. Dilles, *Hydrothermal enrichment of lithium in intracaldera illite-bearing claystones.* Science Advances, 2023. **9**(35).
47. Carleton, A., *Lithium Battery Fires Are Threatening Recycling as We Know It*, in *Motherboard Tech by Vice*. 2022.