Reuse of Solar Photovoltaic Systems for Social and Economic Benefit

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Abstract

Photovoltaic modules, inverters and mounting hardware are getting deinstalled as systems age, owners seek to upgrade to more efficient use of rooftop space, buildings undergo major remodeling and other factors. Recycling of modules and other components to recover valued raw materials currently lacks economic processes with the capacity to responsibly deal with the volume of equipment being taken offline. Sending inverters to overseas electronic recycling locations and the modules and mounting systems to landfills has become a default path for many. While incentives for middle- and upper-income buyers have been instrumental in driving lower system costs over the past decades, low- and moderate-income (LMI) households who are most burdened with energy costs have been excluded from this green revolution. Much of this decommissioned equipment still retains many years of energy generation potential and reinstalling these systems to benefit previously excluded populations presents significant opportunity to fill the social equity gap in the triple bottom line of solar energy while delaying ecological impacts until recycling processes can be developed to meet economic and throughput requirements for a sustainable business model. This paper presents the framework for foundational research of the multiple facets of culture, social equity, ecology, policy, technology and sustainable business to create a movement that repurposes high-value equipment away from waste streams and towards a more equitable society.

Keywords: Reuse solar PV, social benefit, ecological benefit, energy burden, policy, sustainable business.

1. Introduction

As solar photovoltaic (PV) systems reach the 20- to 25-year expiration of module warranties, system owners begin to consider replacement using newer technology with significantly higher efficiencies for the same footprint and features not previously available with their original systems. Some PV array owners are upgrading their systems well before the end of their warranty period for similar reasons. Rather than disposing of these legacy systems in a landfill or in raw material reclaim, there is potential for a second life – possibly as long as a second 20 to 25 years.

While federal and state incentives have played a large role in increasing the demand for solar PV systems which, combined with other programs have greatly reduced the per watt installed cost, most incentives have only been available to middle and upper income households and businesses (Heeter *et al.*, 2018). Because low-income households typically lack the income levels or home ownership to participate in tax credit programs, disparities in social equity have increased in the triple bottom line of solar energy. These disparities have created an ever-widening social equity gap that impacts energy-burdened households to a greater extent. (Figure 1)

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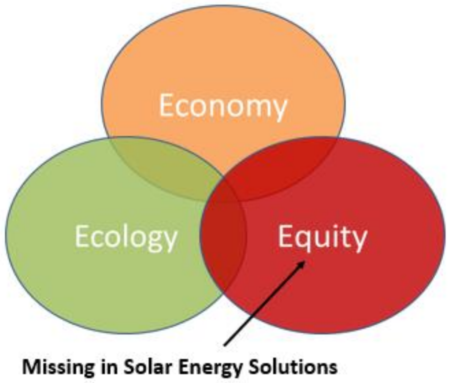

Fig. 1: Social equity gap in commercial and residential PV systems.

Equitable Solar Solutions™ (ESS™) was founded in January 2018 by the author and five undergraduate capstone students at Western Colorado University's Clark Family School of Environment and Sustainability with the intent to take used solar photovoltaic equipment otherwise destined for the landfill or reclaim and reinstall for the benefit of low-income households. By April 2018, ESS™ had become a key program of Coldharbour Institute, a 501c3 nonprofit that promotes regenerative living practices. Under this business structure, equipment donors receive a tax donation letter that allows for a deduction on their taxable income in addition to any tax credit they may qualify for in purchasing a new PV system.

Two years later, ESS™ has received donations of around 600 PV modules totaling 83 kilowatts of nameplate capacity and more than 55 kilowatts of grid-tie inverters along with various mounting hardware. Age of donated equipment ranges from as old as 20 years in service to systems that have only operated for 12 years, 8 years and one 2-year-old residential system from a home that had been purchased with the intent of tearing it down to build condominiums. Primary focus of the ESS™ program is to ensure that all reinstalled equipment is not only operational but will be reliable over the proposed 20-year lifetime of future projects. This is critical so that recipients are assured of getting PV systems of the highest quality rather than being a disposal site for unwanted waste. The secondary focus encompasses project development by working with partner agencies to identify qualifying households and provide funding for the balance of installation costs.

Projections for volumes of decommissioned solar PV systems can be estimated from historical installed capacity numbers and assumptions of 20- or 25-year system lifetimes. While some commercial and residential system owners may upgrade early, utility-scale generating systems are typically operated under a fixed 20- to 25-year power purchase agreement with less likelihood of early decommissioning. Assuming a 20-year system lifetime and yearly installed capacity in the U.S. (Table 1), as much as 4 megawatts (MW) of solar PV equipment may be retiring at the time of this publication, rising to 10 or 11 MW over the following year.

Tab. 1: U.S. PV Installations, 2000-2012 GTM Research & SEIA (*U.S. Solar Market Insight 2012 Year in Review*, 2013)).

Installations (MWdc)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Residential	1	5	11	15	24	27	38	58	82	164	246	302	488
Non-Residential	2	3	9	27	32	51	67	93	200	213	336	826	1,043
Utility	0	3	2	3	2	1	0	9	16	58	267	760	1,781
Total Installations	4	11	23	45	58	79	105	160	298	435	848	1,887	3,313

Absent other options, much of the decommissioned PV modules will be sent to landfills with inverters shipped to overseas electronics recyclers. Rails and mounting hardware can easily be sent to regional metal recycling centers. While landfill disposal of silicon-based PV modules comes with low environmental risks, the mounting volumes of waste on the horizon can have a significant impact on municipal landfill capacities causing accelerated need to plan, construct and finance new landfill space. These impacts carry a risk of eroding the solar industry's social license to operate. In addition to a lack of industry capacity to recycle current volumes of PV modules, the present average processing cost of $20 per module well exceeds the ~$2 market value of recoverable raw materials (Sandoval, 2021). Reuse of solar PV systems presently offers the most economic option until future PV module recycling processes can be developed to extract raw materials at a cost lower than the market value of those materials (Tao *et al.*, 2020).

Two years after inception, the Equitable Solar Solutions™ model has successfully demonstrated proof of concept through installed pilot projects and eagerness of equipment owners and installers to donate equipment with only minimal advertising and solicitation. The challenge moving forward is to understand what barriers exist and which paths provide the most sustainable business models to proliferate solar PV reuse. These factors extend beyond just the technical and financial realm to encompass cultural/social, ecological and political considerations. Included within these primary frameworks exist numerous subfactors that must be understood and addressed to develop successful roadmaps. (Figure 2) Further exploration has revealed that even these subfactors break down more into critical details that inform root cause analysis and solution options. These frameworks comprise the structure being used for doctoral research in reuse of solar PV systems for social and ecological benefit.

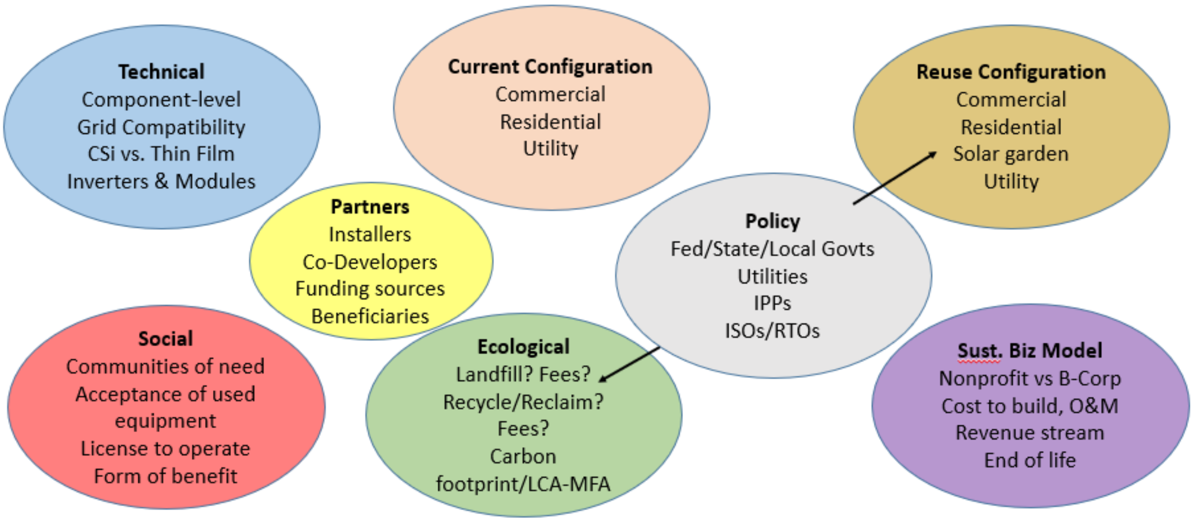

Fig. 2: Primary and secondary focus areas for researching reuse of solar PV equipment for social and ecological benefit.

2. Methods

2.1 Technical

Assessing the quality and degradation of donated equipment is essential to the ESS™ program. The inventory of currently-installed PV systems spans several decades during which components, materials and manufacturing processes have evolved. While not commonplace, product recalls have occurred – most notably certain BP Solar modules manufactured between 1999 and 2007 (www.bpsolarsettlement.com, 2016), all REC modules sold in 2008 ('REC to Recall All of Its Solar Panels From 2008', 2009) and one model of Bosch solar modules from 2011 through 2013 (Pickerel, 2017). Manufacturing changes between and within manufacturers can impact degradation rates and failure modes (Jordan and Kurtz, 2013a). Absent a well-documented characterization across all surplus equipment, testing methods must be developed to screen out non-functioning and lower-quality inverters, modules and other system components.

PV modules degrade over time from exposure to UV light, ambient heat and high humidity (Jordan and Kurtz, 2013b). Module power output degradation rates range from near zero to more than 3 percent, but median degradation rates are around 0.5 percent per year and average rates of 0.7 to 0.8 percent per year. It should be noted that thin-film modules have a higher annual degradation rate than silicon technologies (Jordan and Kurtz, 2013a).

Osterwald et al. has found an initial rapid degradation rate of PV modules due to oxygen recombination in the bulk crystalline structure. Long-term degradation is dominated by exposure to ultraviolet (UV) light. Encapsulant browning is not thought to result in long-term performance losses (Osterwald *et al.*, 2002). Wohlgemuth and Petersen found that hard failures were commonly caused by corrosion and breaks in the interconnections between cells (Wohlgemuth and Petersen, 1993).

While manufacturers and laboratories have equipment capable of detailed cell and module characterization, “outdoor field testing has played a vital role in quantifying long-term behavior and lifetime for at least two reasons: it is the typical operating environment for PV systems, and it is the only way to correlate indoor accelerated testing to outdoor results to forecast field performance.” (Jordan and Kurtz, 2013a) Legacy systems still in operation can be assessed for the presence of failed inverters and modules using power analyzers or PV curve tracers such as the Solmetric PVA-1000S. Characterizing performance degradation though can be challenging if all modules are not oriented in the same direction and if access to measuring backside module temperature is impeded. This method produces a useful aggregated result across the entire array or string but backside thermal imaging offers the ability to detect certain failure modes while the PV array is operating (Chattopadhyay *et al.*, 2018). DC optimizers allow for isolation of bad modules while larger systems can be evaluated string by string.

ESS™ personnel adopted a module characterization and test flow consisting of: 1) cleaning any frontside debris/dust; 2) temperature stabilization in the sun of each module for a minimum of 20 minutes; 3) visual inspection of the frame, junction box, cables, frontside (discoloration, metal defects, burn marks, corrosion) and backside film (bubbles, tears, cracks, burn marks, bad vibes); 4) measuring open circuit voltage and short circuit current coincident with backside temperature and plane of array solar irradiance; and 5) thermal imaging of the module backside under short-circuit conditions. (Figure 3) Throughput for full characterization is around six modules per hour for a team of two people. ESS™ has since increased throughput to 35 modules per hour by selecting 10 modules out of each donated batch for complete degradation analysis with the remaining modules receiving a visual inspection, measuring short circuit current independent of module temperature and solar irradiance and backside thermal imaging. ESS™ has plans to build a test array that will provide a platform for testing inverters.

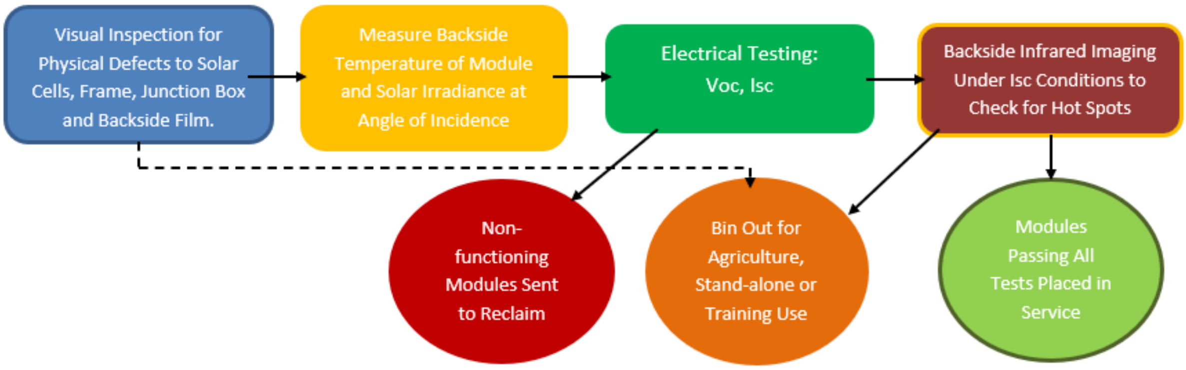

Fig. 3: PV module test flow.

ESS™ has been operating under the assumption that visual defects such as 1) discoloration of the frontside encapsulant, 2) corrosion/delamination within the frontside encapsulant not associated with any burn marks or breach of the backside film or 3) cracks/holes in the backside film not associated with any infrared thermal hot spots should be considered as potential future failure modes rather than merely cosmetic defects (Figures 4a and 4b). Subsequent literature review has caused ESS™ to consider that some of these defects may in fact accelerate year-over-year degradation or cause complete product failure in the future (Jordan and Kurtz, 2013a). ESS™ will be setting up a long-term monitoring configuration in which modules are connected to DC loads to produce maximum power so that specific solar cells representative of various visual defect types can be studied year by year.

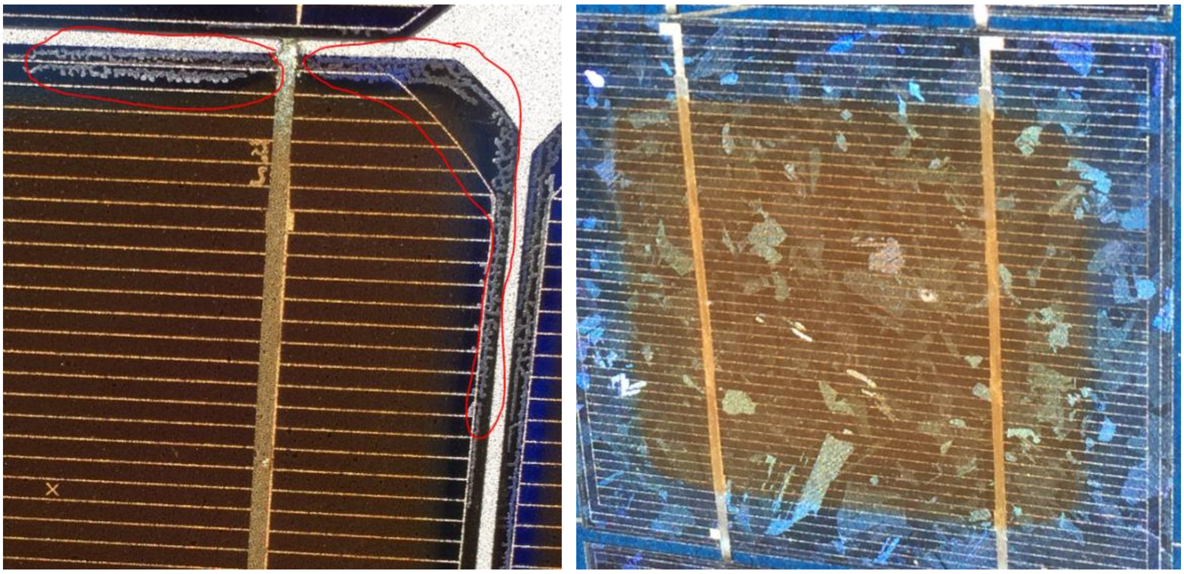

Fig. 4a and 4b: Cell corrosion/delamination and encapsulant browning/discoloration.

All 600 modules acquired by the ESS™ program have been silicon-based technology which has dominated 80 to 95 percent of the PV module market over the past decade. Thin film technologies such as cadmium-telluride (CdTe) rigid modules and copper indium gallium di-selenide (CIGS) flexible modules account for the present remaining five percent of the current work market (Philipps *et al.*, 2021). Any thin film module donations will be considered for evaluation purposes only until sufficient data exists to support a long-term redeployment as the flexible modules are offered with a 5-year limited power warranty versus the 20- to 25-year warranty typical with silicon-based rigid modules ('SunPower Flexible Solar Panels | SPR-E-Flex-110', 2018).

DC to AC inverters offer more challenges for reuse than PV modules. Extended warranties are available but most manufacturers offer a standard 10-year product warranty (Svarc, 2021). This reduced warranty may correlate to greater long-term risk for PV array operation. Some inverter suppliers offer replacement circuit boards that can be swapped out by trained personnel but availability of those replacement parts cannot be assured 30 years after the original manufacturing date. Longer-term inverter reliability will be a key focus of this research both in the field and at the planned test array. It may be possible to detect early indicators of inverter failure that could allow for proactive replacement in the field or even screening at the time of donation.

In addition to a focus on inverter reliability, electrical code compliance and grid compatibility will be considered. Once an older inverter is removed from a particular installation, it may no longer meet electrical code requirements for rapid disconnect (NEC 690.12). In some cases, ancillary components may be available to bring the new system up to compliance although the upgrade cost may come close to that of a new inverter. Future code changes could create new challenges with reuse of grid-tie inverters. Larger utility-scale PV arrays and community solar gardens must be compatible with inverter-based resource connectivity/disconnectivity requirements, low voltage ride-through and essential reliability services at time of re-commissioning (Ropp, 2019).

2.2 Cultural and Social

Redeploying equipment that is not capable of operating for an additional 20-year economic life cycle can erode public opinion of the product quality and their perception of the ESS™ model. Testing of all donated equipment is essential to build customer confidence in the product and the service that it offers. If new owners received un-tested reuse PV systems with early failures, this could create a perception of receiving a lower value asset and others within their community may become resistant to participating in the program. Lower-income communities might rightly claim that they are a dumping ground for society's electronic waste. Further, deploying substandard systems can erode the social license to operate enjoyed by all renewable energy technologies. Ensuring that customers receive quality and reliable systems is paramount to a reuse business model and social movement.

The vision statement of the ESS™ program is "reusing solar PV systems to create the greatest value for those with the greatest need." Determining who has greater and lesser need and where the greatest benefit will be possible is achieved using a defined hierarchy of needs (Table 2) to assess where customers land within that hierarchy. People living without any electricity have the highest need followed closely by those with no available grid connection who must run small gas-powered generators. A 2014 report from RMI points out that 14 percent of homes on tribal lands are not connected to an electric grid (*Native Energy: Rural Electrification on Tribal Lands*, 2014). A major factor driving these households isolated from electrical infrastructure is the existence of disperse homesites on large areas of land that make the cost of extending the local distribution grid to each home prohibitive compared with costs in denser urban and suburban locations. The ESS™ program has discussed potential projects with tribes and there is a unique benefit in partnership that would allow tribal governments to leverage the value of reuse equipment as cost-share on federal grants.

Tab. 2: Hierarchy of needs.

Priority	✓ All That Apply
Greater Need	People Living Without Electricity
↓	People Struggling to Pay Energy Bills
	People Living in Low-Efficiency Housing with Inability to Pay for Improvements
	Underserved/Underrepresented Groups
	Habitat Homeowners
	Landlords Serving Lower-Income Populations
	Educational Opportunities
	Nonprofits
	Agricultural Users
	Government Buildings
	For-Profit
Lesser Need	Other Installations/Homeowners

The U.S. Dept. of Energy defines energy burden as "the percentage of gross household income spent on energy costs."(*Low-Income Community Energy Solutions*, no date) In the U.S. low-income households can experience as much as three times the energy burden of higher income families. The factors driving this include: greater prevalence of electric heating systems, high air conditioning load and older homes with fewer (if any) energy efficiency features (*Low-Income Household Energy Burden Varies Among States — Efficiency Can Help In All of Them*, 2018). A pilot partnership developed with the Gunnison Valley Regional Housing Authority (GVRHA) uses the energy savings from a reuse solar PV array on a city-owned building and redirects those savings to fund energy efficiency upgrades in low-income households through an already-existing program run by GVRHA. Because of the ongoing benefits of energy efficiency measures, this approach results in more than twice the economic benefit over the lifetime of the project than had the money been spent on monthly energy bill assistance.

Other pilot configurations developed include bundling solar PV arrays with energy efficiency upgrades through the State of Colorado's Weatherization Assistance Program where previous attempts to install brand new systems were not economical and partnering with Habitat for Humanity builders and homeowners such that system costs can be rolled in with the home financing. The result of the latter is that the total monthly cost of ownership including mortgage payment and utilities is less than building the home without a reuse solar PV array.

One of the more challenging populations in need are low-income rental households because of minimal incentive to upgrade buildings occupied by someone other than the owner. Low-income apartments do not provide an equal distribution of solar-compatible roof space for all units. Even where those rooftops provide good solar gain, agreements must be structured so that the financial benefit goes to the renter rather than merely allowing a landlord to charge higher rent. Apartments that lack individually-metered units also propose challenges with respect to apportionment of any energy savings. In 2017, the Government Accounting Office listed 48 percent of renting households as energy burdened (*Housing Cost Burden for Low-Income Renters Has Increased Significantly in Last Two Decades*, 2020).

One option being explored is the development of community solar gardens dedicated solely to low-income renters. Such a structure would guarantee lower monthly energy bills for the renter and subscription programs can be structured without down payments while meeting the needs of a more transient population (Heeter *et al.*, 2018). Qualification or eligibility can be tied to the Low-Income Home Energy Assistance Program (LIHEAP) or other public assistance programs.

Tenants in HUD housing do not presently have an opportunity to benefit from a reuse solar array or participation in low-income community solar gardens as those tenants are charged a fixed combined monthly rent and utilities payment calculated as 30 percent of their income. Any installed solar array could reduce costs for the HUD program but tenants might expect to see a drop in monthly bills that will not materialize due to this fixed 30-percent calculation. Creating such a false impression could have a negative impact on the ESS™ program.

LIHEAP participants pay a monthly utility bill and thus are a potential beneficiary of reuse solar arrays. Government partnerships similar to the City of Gunnison diverting energy savings from an array on a city building to the GVRHA energy efficiency program could also be structured to divert energy savings to LIHEAP-qualifying households or the LIHEAP program itself. Partnerships with commercial businesses can be structured to share the energy savings between the commercial partner and LIHEAP programs. In the future, transferring ownership of a utility-scale solar PV array for management of the ESS™ program could be used to cover program costs while providing assistance to LIHEAP participants.

Other target populations include small, minority-owned businesses and people with disabilities. ESS™ recently built a prototype mobile solar charging station for a motorized wheelchair user and is building a permanent charging station on the Western Colorado University campus for motorized wheelchairs and E-Bikes.

Historically marginalized communities can be skeptical of new programs, especially in light of past environmental injustices (Masten *et al.*, 2021). There will be significant research focused on building social movements, collaboration with local communities on needs assessments and involving local community members for training, employment and buy-in. ESS™ believes in starting with small pilot projects to lay the groundwork for long-term partnerships based on trust built over time as single-shot large projects have increased risk and can raise suspicions of profiteering. An ancillary concern for these pilot projects will be whether energy savings from subsidized or discounted PV arrays will trigger any energy use rebound effects akin to Jevons Paradox (Jevons, 1865; Foster, Clark and York, 2010).

The agricultural community plays a key role as recipients of second tier equipment that is not suitable for a 20-year rooftop installation. Electrically-functioning equipment with scratches and other visual defects can be placed on farms and ranches at heavily discounted costs where damage from livestock or the environment is less impactful from a financial perspective. Supporting the agricultural community has the added benefit of strengthening food security through lower energy costs.

A key goal of the ESS™ program is to build a social movement to drive awareness and adoption through institutionalized methods such as engaging legislatures, regulatory bodies and industry groups along with noninstitutionalized approaches like partnering with community and grassroots organizations within the target groups of those in need of energy assistance (Staggenborg, 2016). The long-term goal is to develop modular approaches and methods that can be replicated region by region across the country (Tarrow, 2011) to create an increased social license to operate through greater reach and benefit across populations who might have previously had no vested interest.

2.3 Ecological

In quantifying the life cycle carbon intensity of photovoltaic modules, Jean, et al. assume a 20- to 30-year operating life cycle before system decommissioning (Jean *et al.*, 2015). This is consistent with the 20- and 25-year operating warranty offered by most PV module manufacturers that guarantees at least 80-percent of original power output specification at that time. From their analysis of the carbon intensity of electricity in the US and in China, Jean et al. calculate "the median carbon intensity of [crystalline-silicon] PV modules manufactured in the U.S. and deployed in the U.S. [is] 36–65 g CO2-eq/kWh … [and] the carbon intensity of PV modules manufactured in China and deployed in the U.S. [is] 61–111 g CO2-eq/kWh." This range is representative of the PV modules that are donated to the Equitable Solar Solutions™ program and compares favorably to the much higher carbon intensities of natural gas (~500 g CO2-eq/kWh) and coal (~1000 g CO2-eq/kWh) (Trancik and Cross-Call, 2013). Jean et al concludes that "if our goal is to reduce emissions, it is far less important where the PV is made…than where it is used…and most important whether it is used at all.(Jean et al. 2015) Reusing solar equipment for an additional 20 years further reduces the carbon intensity over the lifetime of the modules by 43.78 percent assuming a consistent annual degradation rate or from 36-111 g down to 20–62 g CO2-eq/kWh depending on where the modules were manufactured.

Some equipment does not meet ESS™' rigorous standards and must be downgraded in the applications for reuse, sent to a capable recycling facility or disposed of in a landfill. Eventually though, the reinstalled equipment has a finite lifetime and responsible end-of-life product management must occur.

While recent research shows that silicon-based PV modules can be safely disposed of in landfills (Sinha et al. 2020) despite the presence of lead solder and other trace materials, such disposal will eventually add significant volumes of material to those landfills. Further, this assumption of safety is based on the continued integrity of each landfill's leachate liner in perpetuity. Any breach of that liner or disposal in non-regulated landfills creates risk to human health and the environment as heavy metals leach into the groundwater and soil (Hernandez et al. 2014). Conversely, the aluminum frames of modules are easily removed/recycled and the silicon cells can be recycled with less energy and lower cost than mining and processing new silicon (Choi and Fthenakis 2010).

Factors driving volumes of PV waste in the U.S. include modules broken in handling, severe weather (high winds, hurricanes, large hail) and residents/businesses upgrading their systems after several decades to newer, more efficient technology. Early failure due to quality and reliability defects are rare in the U.S. In the future, volumes of PV waste are expected to increase dramatically as the first utility-scale solar farms of 1 megawatt and larger in size approach the end of their negotiated 20- and 25-year power purchase agreements (PPAs) with utility or large industrial power off-takers (*U.S. Solar Market Insight 2012 Year in Review*, 2013) The ESS™ model helps to buy time for industry to develop cost-effective recycling processes that can meet future volumes of PV modules as they meet their true end of life.

Current ease and low cost of disposing of solar PV modules in a landfill are a disincentive for system owners to pursue options that divert waste from landfills. Cheap disposal fees create environmental externalities that prevent development of cost-effective module recycling processes and business models (Eshet, Ayalon and Shechter, 2005). Policies that discourage landfill disposal would better incentivize reuse and recycling pathways. Siting of existing fossil fuel infrastructure as well as expanded waste disposal sites disproportionately impacts the public health of low-income and other marginalized communities (US EPA, 2014).

2.4 Policy

Policy and regulations impacting new and reuse solar PV systems exist across federal, state and local jurisdictions as well as within independent system operators (ISOs), utilities and independent power producers (IPPs). National Electrical Code and local government or utility interpretation can affect whether earlier modules and inverters can still be reused once removed from their original installation. They may also specify system modifications to meet new code requirements at the time of re-installation.

Current Colorado, Connecticut, Hawaii, Maryland, and Oregon statutes for participation in solar gardens provide for a small percentage of these cooperative installations to be "carved out" to benefit low-income energy users but some utilities interpret statute to prohibit construction of a solar garden that would target a specific low-income group of subscribers. Xcel Energy requires use of all new PV equipment to participate in their Solar*Rewards® program with involves renewable energy credits and a 20-year contract (*Solar*Rewards | Xcel Energy*, no date) but also offers a basic net-metering plan that would be compatible with used equipment and does not require a long-term contract (*Net Energy Metering | Xcel Energy*, no date),

Generation and Transmission companies often restrict their member electrical cooperatives from generating more than five percent of total community load while some local utilities self-impose limits on renewable energy systems. In 2020, Tri-State Generation and Transmission Association raised this limit for member cooperatives to 10 percent with certain restrictions (*Tri-State members advance greater contract flexibility, starting by increasing member self-generation opportunities by an additional 10% of system demand*, 2020).

Policies will be explored surrounding municipal waste disposal that could provide incentives for reuse or recycling of solar PV system components. These could exist in the form of volume limits or disposal fees that are either fixed or escalating. Incentives could be offered for raw materials such as recycled aluminum and glass that are easier to recover while funding could be appropriated for research and development of more efficient recycling processes and infrastructure. Other forms of incentive could provide municipal solid waste bill credits for system owners who donate old PV systems for reuse instead of disposing.

2.5 Finance and Sustainable Business

Local, state, federal and private grants have been beneficial in funding pilot projects and program development. These will continue to have a critical impact on program development and seeding new initiatives. Other forms of project financing will be needed to meet the expected volumes of decommissioned solar PV equipment in the coming decade.

For individual homeowners and business owners, federal and state tax incentives have been instrumental in increasing market demand that drives down the average costs of solar arrays, these tax credit approaches can only benefit those with high enough incomes to qualify for a $5,000 or greater credit on their annual income taxes. Low-income households have fewer affordable financing options. Greater use of property-assessed clean energy financing can provide another option beyond home equity loans or other conventional financing. Pay as-you-go options tied to utility bills that remain with the meter and are transferrable to new residents offer an alternative to loans (Heeter *et al.*, 2018; *Pay-as-you-go models: Innovation Landscape Brief*, 2020)

Alaska Native and Native American tribes can compete for special energy grants, but these programs are underfunded and the most energy-burdened tribes struggle to meet the 50-percent cost match requirements. Partnerships between tribes and ESS™ programs allow for valuation of the donated equipment towards these federal cost match requirements.

Additional grants combining funds from energy and environmental agencies could provide additional sources of funding that address both agencies' goals.

The ESS™ program is exploring split cost and split benefit structures in which a commercial business supports the vision of ESS™ to reuse solar PV systems to create the greatest value for those with the greatest need but also wishes to enjoy the benefits of renewable energy systems. Under such an arrangement, the value of the donated equipment is combined with the remaining cost of installation and the resulting percentage of commercial contribution determines how much of the monthly energy savings is retained by the business owner. The remaining funds are then distributed to a local social benefit program for energy, food, housing or other assistance under a memorandum of understanding (MOU).

As mentioned earlier, solar gardens could be developed specifically to benefit low-income households. In fact, this is ESS™' preferred option for providing energy assistance to renters who make up the largest category of low-income households and are most challenged with housing and energy costs (*Housing Cost Burden for Low-Income Renters Has Increased Significantly in Last Two Decades*, 2020). Funding for these low-income solar gardens could come in the form of targeted grants or could be financed with funding already allocated for assisting these populations. Both California and New York have used portions of their federal LIHEAP funds to finance rooftop solar PV arrays for LMI homes (Heeter *et al.*, 2018). The rationale for this approach is that these are ongoing appropriations and that the impact and payback are more beneficial than simple monthly energy bill assistance. Funding of low-income community solar gardens offers another path for state-managed LIHEAP programs to assist renters at an improved benefit-cost ratio compared with monthly bill assistance. These community solar gardens offer the added benefit to ESS™ of reduced project development time as future equipment donations can be used to expand existing solar garden arrays.

As first-generation utility-scale solar arrays reach the end of their power sales agreements, there may be tax benefits to the current IPPs or investor-owned utilities to donate these assets in place to a nonprofit ESS™ program who will then operate the facility throughout its second life and direct revenues after expenses to social programs. Lastly, various business structures (501c3 vs. benefit corporation vs. other) will be explored to determine which offer optimal use of donated equipment and available funds.

3. Results and Conclusions

From the donated equipment tested to date, nearly two-thirds of PV modules meet Tier 1 testing criteria and are suitable for redeployment on rooftop systems with an expected 20-year future life (Figure 5). Second tier modules have been deployed to ground-based and agriculture uses with third-tier modules being restricted to training purposes or short-term applications. Pilot projects have been completed and monitoring of array outputs indicate systems are meeting or exceeding projections. As awareness of the ESS™ program grows, donations have increased to more than keep up with the present rate of project development. Additional development of wheelchair charging stations, USB device chargers and eBike charging stations in the public square and golf cart charging allows for other deployments beyond conventional solar arrays.

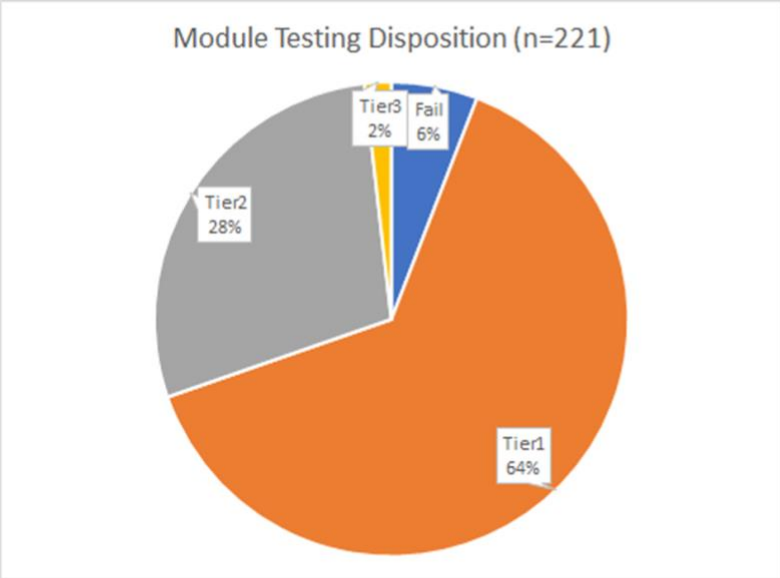

Fig. 5: Testing results from first batch of donated modules. Tier1 modules are approved for all uses.

The scope of this work is larger than a single doctoral degree and the advisory committee will be challenged to set appropriate sidebars on the degree plan that are separate from the longer-term focus of ESS™ program development and research that will continue beyond graduation. Post doctoral degree completion, opportunities exist for partnerships with agencies and industry consortia to further develop methods that divert future volumes of high-value assets from our waste streams to reuse applications that produce greater public benefit.

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