WHEN SOLAR GOES DARK: AN ANALYSIS OF SOLAR PANEL WASTE MANAGEMENT POLICIES

A Culminating Project Presented to the Department of Public Policy and Administration at California State University, Sacramento in Fulfillment of the Requirements for the Degree of

MASTER OF PUBLIC POLICY AND ADMINISTRATION

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Executive Summary

Solar panels, a popular source of alternative energy in California, were made with no plan for what to do with them once they have been used. Used solar panels pose a challenge for California to responsibly manage since they are bulky, hard to deconstruct, and contain potentially hazardous materials. This policy report provides the Legislature with a high-level understanding of the current environment of used solar panel management, as well as policy alternatives to address the problem and support California's progress toward a more circular economy.

In this report, I use rational policy analysis to determine which policy alternative may address the problem by defining the problem, identifying policy alternatives and criteria with which to analyze the alternatives, and making a final recommendation. I identify three criteria, cost efficiency, equity, and administrability, to analyze the following three policy alternatives against the status quo:

1. Establish an extended producer responsibility (EPR) program for used solar panels.
2. Add used solar panels to California's electronic waste program.
3. Enact labeling requirements for new solar panels.

Based on my analysis, I recommend that the Legislature combine the first and third policy alternatives to enact an EPR law for used solar panels that includes a labeling requirement for new solar panels sold in or into the state. Together, these policies would create a convenient, cost-effective system for collecting and safely managing used solar panels and would address many of the barriers currently present

in the solar panel reuse and recycling market. These policies would also provide flexibility as solar panels continue to gain popularity and evolve as technology improves.

In Section I, I provide a background of the problem, including a description of solar panels, problems associated with used solar panel management, and rationale explaining why government intervention is necessary. In Section II, I further explore common themes related to used solar panel management in recent literature, including key players involved in the lifecycle of a solar panel, barriers to solar panel reuse and recycling, and recent developments in federal, state, and local policies. In Section III, I describe rational policy analysis and identify criteria with which to analyze the policy alternatives. In Section IV, I analyze policy alternatives that solve one or more problems associated with used solar panel management and, in Section V, I propose a recommendation for policymakers. Section VI concludes with a summary of the report and key takeaways.

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First and foremost, thank you to my family who has always supported me in everything I do and has endured the past three years of me saying, “I can’t, I have a paper that I need to write.”

Thank you to my professional colleagues and mentors who warmly welcomed me into the world of recycling and product management and have given me wonderful opportunities to dive deeper into the world of public policy and administration and apply my new knowledge.

Finally, thank you to my professors and classmates who taught me so much and often left me pondering long after class was over. Because of you, I got to spend the past three years engaging in two of my main passions, public policy and administration and learning.

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Section I. Introduction

Solar panels, a popular source of alternative energy in California, have fallen into the same trap to which many products are victim – they were made with no plan for what to do with them once they have been used. Even today, consumer guides, like California Public Utilities Commission's (CPUC) California Solar Consumer Protection Guide (2022), educate consumers on the costs and logistics of installing new solar panels but fail to address the costs and logistics of managing used solar panels. Used solar panels pose a challenge for California to responsibly manage since they are bulky and durable and contain potentially hazardous materials. Additionally, the used solar panel reuse and recycling market is new and does not yet exist on a commercial scale.

Solar panels that were installed in the early 2000s will begin to flood California's waste stream over the next few years as they are removed from buildings and other installations. At the same time, California is trying to meet its recycling goals and move toward a circular economy in which materials from products are reused again in new products, replacing virgin materials. Barring sudden development of a thriving used solar panel reuse and recycling market, California will need to produce a plan to handle the growing number of used solar panels, and soon.

A. What are solar panels?

Most Californians are likely familiar with the solar panels that they see on the roofs of houses and other buildings, on top of parking structures, or in solar farms, without knowing what is in a solar panel. A solar panel, also called a photovoltaic module or photovoltaic panel, consists of many small solar cells that absorb energy from sunlight and transfer that energy into electrical energy that can be used to power

homes and businesses (DOE, n.d.-b). There are several different types of solar cells that can be used to make solar panels today, especially as solar technologies continue to develop, but silicon solar cells are the most prevalent in the solar panel market.

Silicon solar cells are made by creating a crystalline lattice of individual silicon atoms, which is the second most abundant element on Earth behind oxygen (DOE, n.d.-b). A silicon solar panel is made by connecting many silicon cells with copper wire and sandwiching those cells between layers of polymers and glass and sealing it all in an aluminum frame with adhesives to protect the solar cells, as shown in Figure 1 (US EPA, 2023-b). Silicon solar panels account for approximately 95 percent of the solar panel market today because they are very efficient at generating electricity from sunlight, relatively inexpensive, and last around 25 years (DOE, n.d.-b; Woodworth et al., 2016). Even after their first use, silicon solar panels have the potential to be reused because they still produce about 80 percent of their original amount of energy. While most solar panels, and therefore, used solar panels, are silicon solar panels, this policy report addresses all used solar panels and recognizes that technology may change over time.

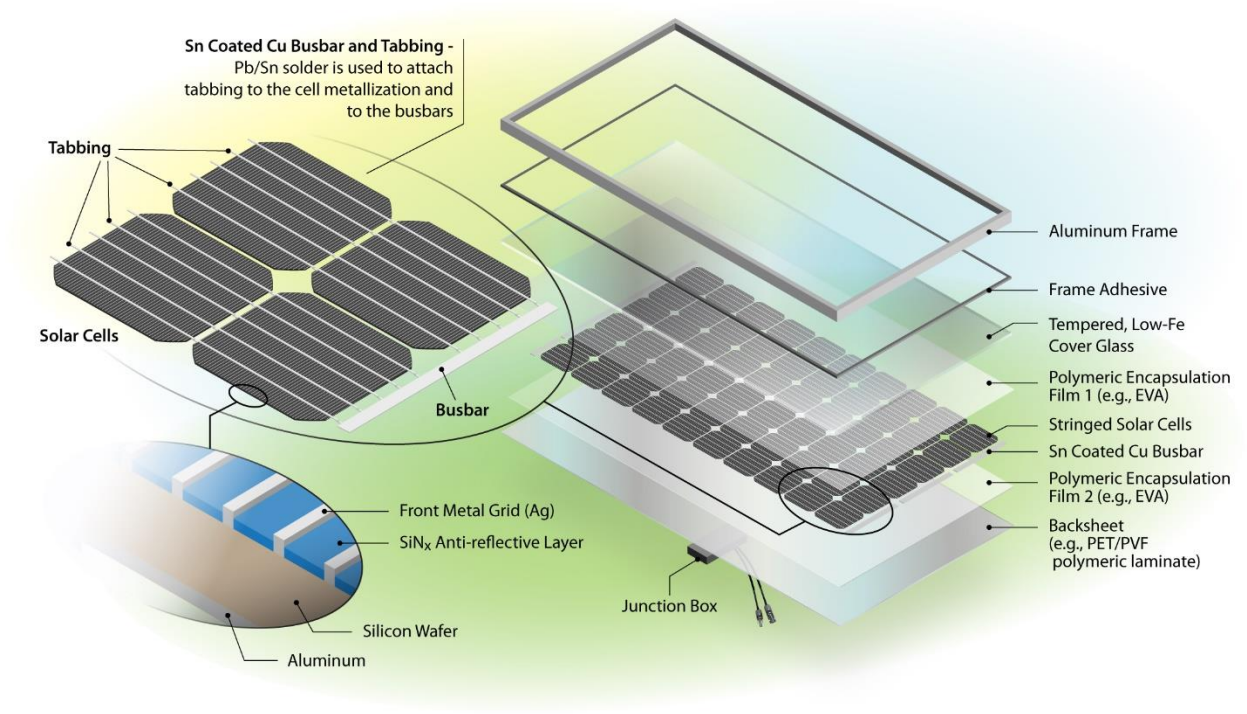

Figure 1. Diagram of the layers of a silicon solar panel (National Renewable Energy Laboratory via US EPA, 2023-b.).

B. Why are solar panels challenging to responsibly manage?

Used solar panels are difficult to responsibly manage because they may contain hazardous materials and are very bulky. Products that contain materials that are classified as hazardous waste face more stringent regulations than non-hazardous wastes to reduce potential negative impacts from these materials on public and environmental health. The federal Resource Conservation and Recovery Act (RCRA), which governs waste management in the US, classifies most waste as either hazardous or non-hazardous and requires more rigorous transportation and disposal practices for hazardous waste than non-hazardous waste (US EPA, 2024). For example, hazardous waste can only be disposed of at a hazardous waste landfill, not a regular landfill, of

which California has two (DTSC, n.d.-a). Although many solar panels do not contain hazardous materials, some solar panels meet RCRA's definition of hazardous waste because they contain heavy metals that meet characteristics of toxicity, such as lead used to weld solar panels frames and chromium used in coatings (DTSC, n.d.-c; US EPA, 2023-b).

Some waste falls into a special designation between the hazardous and non-hazardous classifications called universal waste. Universal waste, like hazardous waste, cannot be disposed of in regular landfills, but the requirements for handling universal waste are less rigorous (DTSC, n.d.-d). The US Environmental Protection Agency's (US EPA) federal universal waste regulations currently only apply to five types of products - batteries, pesticides, mercury-containing equipment, lamps, and aerosol cans (US EPA, 2023-c). However, the California Department of Toxic Substances Control (DTSC) received a waiver from the US EPA that allows used solar panels in California to be managed as universal wastes, which became effective on January 1, 2021.

Used solar panels that are free of hazardous materials could be disposed of with other solid wastes in normal landfills, but it is not always easy to make this determination. If people or businesses with used solar panels cannot confirm that the used solar panels are free of hazardous materials, then they must either pay for expensive lab tests for each panel or treat the panels as hazardous waste by default (CALSSA, 2022). Once people or businesses with used solar panels determine that solar panels are free of hazardous materials, either from manufacturer information or through testing, then the used solar panels could be transported to a landfill.

While used solar panels that are free of hazardous materials could be disposed of in landfills, solar panels are bulky, and disposal would not be consistent with California's policy goals. Because solar panels are bulky, they are difficult to transport and would take up valuable space in California's landfills, especially as large quantities of solar panels start to enter the waste stream. Disposal would also directly conflict with California's goals to reduce landfill disposal and develop a circular economy where materials are used again in new products. Other management options that would keep used solar panels out of landfills, such as reuse or recycling, are better aligned with the state's goals. Often, solar panels are still functional at the end of their first life after about 25 years of use but lose enough efficiency that consumers elect to replace their old solar panels with new ones (CALSSA, 2022). Solar panels could possibly be reused, and those that are broken, damaged, or no longer efficient enough for reuse can be recycled.

C. Why does California need to do something?

Government intervention in the used solar panel market is necessary to correct a market failure and plan for an impending wave of used solar panels. Solar panels contain valuable materials and, while components of the recycling processes exist, recycling processes are still in the early stages and do not exist on a commercial scale (US EPA, 2023-b). As a result, the public will increasingly bear the costs of managing solar panels, regardless of whether they own solar panels or not, through rising waste management rates.

Businesses often do not incorporate the cost of managing used products into the price the new goods they produce, which is a failure of a market's efficiency that

requires government intervention (Munger, 2000). A business may be aware of its marginal private cost, the cost for it to produce one extra unit of a good, but it typically does not account for the costs imposed on society, or negative externalities (Hill & Myatt, 2010). The true marginal cost for the business and society, the marginal social cost, includes the marginal private cost of the business and the external cost created by the good. The cost to manage goods, especially those that are bulky and difficult to manage, like used solar panels, is a negative externality because it imposes additional costs that were not covered in the price of the good. Businesses supply too many solar panels at a lower price than if these negative externalities were factored into the price. Therefore, the government should intervene to ensure that businesses consider the marginal social cost of solar panels, not just their marginal private cost.

Additionally, government intervention is necessary to plan for the upcoming surge in the number of solar panels entering the waste stream. Solar panels started to gain popularity as an alternative energy source in the early 2000s, and more continue to be installed each year. As of the end of 2023, solar panels had been installed in over 1.8 million solar projects, including California homes, schools, and small businesses (Energy Solutions, 2024), and the number of new installations continues to increase (see Figure 1). The average American home requires between 15 to 30 solar panels to power their homes (Solar Reviews, 2024; DOE, 2019), which means that California has at least 27 million solar panels. This is likely an underestimate because it does not account for schools and small businesses that may have more than 15 to 30 solar panels each, large solar projects (e.g., solar farms), and solar panels that are damaged and need to be replaced sooner.

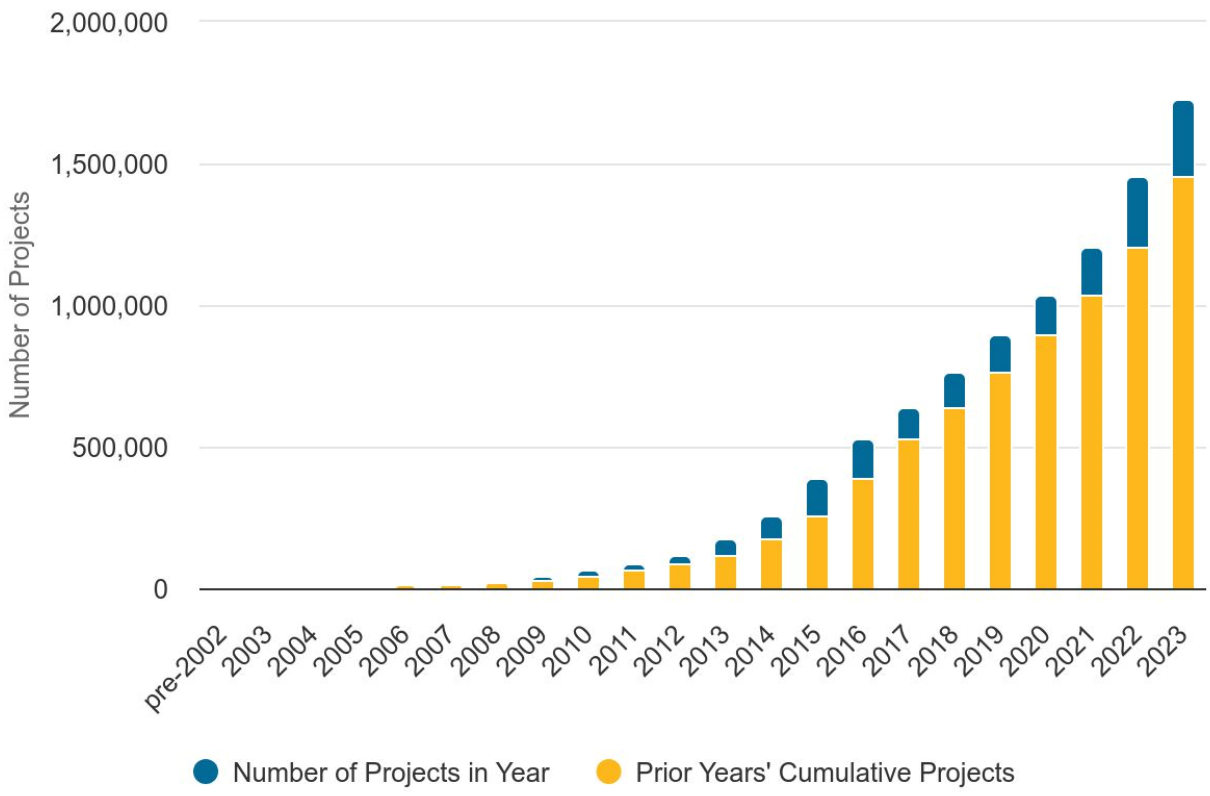

Figure 2. The number of solar projects in California from 2002 to 2023 (Energy Solutions, 2024).

Solar panels last an average of 25 to 30 years (IRENA, 2016), so solar panels that were installed in the early 2000s are will likely start to be removed in the next few years and will increase in volume around 2025 (BIO Intelligence Service, 2011). The magnitude of solar panels that will start to enter the waste stream over the next few years, along with the impacts associated with trying to manage solar panels without a plan or reuse and recycling infrastructure, provides members of the California State Legislature (Legislature) with a window of opportunity to address solar panel management.

D. Overview

This policy report is intended to provide members and staff in the Legislature with a high-level understanding of the current environment of used solar panel management, as well as policy alternatives to address the problem and support California's progress toward a more circular economy. Section I provided a background of the problem, including a description of solar panels, problems associated with used solar panel management, and rationale explaining why government intervention is necessary. Section II further explores common themes related to used solar panel management in recent literature, including key players involved in the lifecycle of a solar panel, barriers to solar panel reuse and recycling, and recent developments in federal, state, and local policies. Section III describes rational policy analysis and identifies criteria with which to analyze the policy alternatives. Section IV describes and analyzes policy alternatives that solve one or more problems associated with used solar panel management and Section V ultimately proposes a recommendation for policymakers. Section VI concludes with a summary of the report and key takeaways.

Section II. Literature Review

While the literature associated with solar panel technology and installation is diverse and well-developed based on decades of experience, the literature on used solar panel management has been slowly developing over the past few years and introduces more questions than answers. The literature focuses on the current regulatory landscape, potential recycling technologies, and a variety of challenges associated with used solar panel management. This section explores some common themes in the literature that are particularly relevant to determining how to address California's impending used solar panel management problem, including the key players in the lifecycle of a solar panel, barriers to solar panel reuse and recycling, and recent developments in federal, state, and local policies, as well as industry standards.

A. The key players in the lifecycle of a solar panel

Understanding the key players in the lifecycle of a solar panel helps to illustrate the chain of custody of solar panels and determine who needs to be involved in, and may be potentially impacted by, any policy that the Legislature develops.

1. Manufacturers

For the purposes of this policy report, manufacturers of solar panels include businesses that make the solar panels, and do not include other businesses in the materials chain, such as those that supply raw materials or make other parts used in conjunction with solar panels. There are currently fewer than 20 solar panel manufacturers in the US (DOE, n.d.-a) and there may be as many as 350 solar panel manufacturers in the world (The Renewable Energy Hub, 2023). Solar panel

manufacturers may be represented by industry organizations, such as the Solar Energy Industries Association (SEIA).

2. Regulatory Agencies

Agencies that regulate solar panel installation and used solar panel management are involved at multiple points in the lifecycle of a solar panel. For example, in California, CPUC regulates energy rates that utilities can charge, the California Energy Commission (CEC) monitors data and conducts research, local agencies oversee installation permits, and the California Department of Toxic Substances Control (DTSC) regulates solar panel disposal (SEIA, 2024; DTSC, n.d.-c).

3. Solar Panel Owners

Solar panels can either be owned by the person whose property the solar panels are installed on, such as homeowners or solar farms, or can be leased to the property owners by solar companies (SEIA, 2023-a). Ownership is not fixed and may change over the course of a solar panel's life. For example, solar companies can sell solar panels to homeowners through lease-to-own plans, old homeowners may transfer ownership of solar panels to a new homeowner, or a solar company may purchase solar panels that are currently installed and leased from another solar company that has gone out of business.

4. Used Solar Panel Generators

For the purposes of this policy report, used solar panel generators are people or businesses who remove used solar panels and need to determine how to properly

manage the used solar panels. Used solar panels generators are likely the owners of the solar panel but could be a different person or business.

5. **Used Solar Panel Handlers and Recyclers**

Used solar panel handlers transport used solar panels to landfills or recycling facilities, and used solar panel recyclers take solar panels apart and break them down into materials that may be used in new products. There are currently 57 handlers and 7 recyclers in California (DTSC, n.d.-b).

6. **Landfill Operators**

Landfill operators receive, track, and ensure that used solar panels are responsibly managed. Solid waste landfills are regulated by the California Department of Resources Recycling and Recovery (CalRecycle) and hazardous waste landfills are regulated by DTSC.

B. Barriers to solar panel reuse and recycling

In addition to outlining the key players in a solar panel's lifecycle, the existing literature also identifies barriers that prevent the used solar panel reuse and recycling market from thriving. These barriers include the limitations of current reuse and recycling technologies and infrastructure, the economics of recycling used solar panels, and general regulatory barriers associated with reuse and recycling (Curtis et al., 2021).

1. **Used Solar Panel Reuse and Recycling Technologies and Infrastructure**

As a relatively new concept, the used solar panel reuse and recycling markets require substantial growth in technologies and infrastructure before they can begin to process large volumes of used solar panels on a commercial scale. Solar panel

recycling technology needs to account for the fact that solar panels are durable products that must withstand decades of weather. Not only are the solar cells encased in large amounts of durable materials, such as glass and aluminum, but the layers of solar panels are also sealed together with strong adhesives to prevent water from getting in between layers (US Department of Energy (DOE), n.d.-c). The current technology to separate used solar panel components is rudimentary and involves treating used solar panels with high heat to loosen the adhesives (US EPA, 2023-b). Once recyclers loosen the adhesives, they can separate the used solar panels into their component parts, which consist of about 76 percent glass, 10 percent polymer, 8 percent aluminum, 5 percent silicon, 1 percent copper, and less than 0.1 percent silver and other metals (Dominish et al., 2019). Of those, glass, aluminum, and copper are the easiest components to recycle, while the more valuable components, like silver and other metals, are harder to recycle (US EPA, 2023-b). The current recycling process is labor and resource intensive, which will continue to inhibit the economic viability of solar panel recycling until more efficient technology develops.

Additionally, used solar panel reuse and recycling infrastructure in the US has not developed enough to meet the upcoming demands of the commercial market. There is a small collection of businesses in the US, as well as some non-profits, like Habitat for Humanity, that collect and resell used solar panels (CALSSA, 2022). However, these businesses are not common and may face regulatory barriers to operate on a greater scale. Similarly, there are a limited number of businesses that collect or recycle used solar panels in California, with 57 handlers and 7 recyclers as of 2024 (DTSC, n.d.-b).

Further, it is unclear whether any of these businesses will be able to scale up to meet upcoming demands.

2. The Economics of Recycling Used Solar Panels

Economic barriers to recycling used solar panels include the expense of recycling compared to landfilling used solar panels and the existing markets for recycled materials. First, generators of used solar panels may be more inclined to landfill, not recycle, their solar panels because landfills will often charge a lower cost for solar panels than recyclers. For example, it costs about $1 to dispose of a solar panel at a non-hazardous waste landfill in the US, and up to about $5 per solar panel at a hazardous waste landfill (Curtis et al., 2021; Hurdle, 2023). The costs to dispose of used solar panels in landfills in California are likely higher because the state's median landfill tipping fees are about twice those identified by Curtis et al. (2021) and Hurdle (2023). These estimates also do not account for transportation costs, which may vary throughout the state, or costs of laboratory testing needed to determine whether a used solar panel contains hazardous materials (CalRecycle, 2015; CALSSA, 2022). However, landfilling used solar panels is likely still cheaper than recycling solar panels in California, which may cost between $15 and $45 per solar panel in the US (Curtis et al., 2021). As a result, generators may opt to landfill solar panels, unless they place a higher value on the other benefits of recycling, such as environmental benefits, or the lower information costs associated with recycling, instead of searching for a landfill that will accept their solar panels (Hurdle, 2023).

The limited profits that recyclers may be able to make from recycled solar panels at this time also presents a potential barrier to solar panel recycling. Recycling markets

for some of the common materials found in used solar panels, such as aluminum or glass, are typically quite strong, and may benefit from larger volumes as recycling ramps up to meet the needs of more profitable markets. For example, SolarCycle, a prominent solar panel recycler, noted that it currently makes a couple of cents per pound of glass when selling to manufacturers that use the glass to make new bottles, but expects to be able to make a higher profit in the future when it has the volume needed to allow it to sell back recycled glass back into the used solar panel market (Hurdle, 2023). Other materials like silver and other metals in solar panels take more resources to recycle with current technology, though, and are therefore cost prohibitive until better technology develops.

3. Regulatory Barriers to Solar Panel Reuse and Recycling

Some aspects of the current regulatory landscape in California and the US present barriers to solar panel reuse and recycling, including regulations that make it difficult to transport and collect used solar panels for reuse and recycling. For example, household hazardous waste (HHW) facilities can accept some universal waste, such as paint, and may be convenient locations for residential generators like homeowners to bring used solar panels for reuse and recycling. However, it may be impractical for these facilities to become collection locations because regulations in the US limit the amount of HHW someone can transport without a permit to between 50 to 220 pounds and an average residential solar panel weighs around 40 pounds (DTSC, n.d.-c; Dametto, 2024). As such, it would not make sense for a homeowner to be limited to transporting one to three solar panels at a time if they are potentially removing a system of 15 or more solar panels.

Additionally, while California regulates solar panels that are hazardous or potentially hazardous as universal waste, solar panels that cross state lines are subject to the general requirements of RCRA or any specific regulations that state may have. This can make transporting solar panels for reuse or recycling out of the state more complicated (DTSC, n.d.-c). A portion of used solar panels generated in the state would likely need to be transported to businesses out of state because California has a limited number of solar panel reuse and recycling businesses, so the used solar panels transporters would be subject to the regulations of each state they pass through.

Beyond regulations that impede used solar panel collection and transportation, existing regulations will make it difficult to reuse solar panels. First, state regulations regarding interconnection to the electrical grid may not consider how reused solar panels could be interconnected. Additionally, there may be other state and local regulations related to fire, building, and electrical codes that may pose a challenge for reusing solar panels (US EPA, 2023-b). If there are no changes to remove these regulatory barriers, then the regulatory barriers, as well as the used solar panel reuse and recycling technology, infrastructure, and economic barriers, will limit the used solar panel management options available in California as more used solar panels start to enter the waste stream.

C. Recent developments in solar panel policies and standards

While barriers currently make it difficult to reuse and recycle used solar panels, recent developments in policies and standards may help move the solar panel industry closer to a circular economy. These developments also present an opportunity for the Legislature to introduce policies that build upon the momentum.

1. Developments in Federal Policy

At the federal level, the US EPA has proposed regulations to classify all solar panels that contain hazardous materials as universal waste, like the RCRA waiver that DTSC obtained (US EPA, n.d.). This could reduce barriers to used solar panel transportation, handling, and recycling, especially when the used solar panels cross state lines. Depending on the final regulations, this harmonization of regulations across the US could also bring attention to the costly laboratory testing that is currently required to determine whether a solar panel contains hazardous materials, and potentially spur innovation to develop a better way to make this determination.

2. Developments in State and Local Policy

At the state and local level, Washington State and Niagara County, New York, enacted a type of policy called extended producer responsibility (EPR) as a way to improve solar panel management, which has also been discussed in California. The general premise of EPR policies is that they hold manufacturers responsible for the product they make throughout that product's lifecycle (CalRecycle, n.d.-b). These policies typically require manufacturers, either individually or through a producer responsibility organization, to create and fund a plan for collecting, transporting, and managing (e.g., reusing, recycling, or properly disposing) the products, which shifts the financial burden and responsibility away from other entities, such as local governments or ratepayers.

Washington State passed a law in 2017 that requires manufacturers to create and fund a take-back program for solar panels sold into the state after July 1, 2017, that will begin no later than July 1, 2025 (Washington State Department of Ecology, 2020).

Washington State Department of Ecology developed guidelines for take-back programs that include critical characteristics of EPR policies. For example, operators of take-back programs must implement an outreach plan, provide collection opportunities at no additional cost, describe how used solar panels will be safely transported from collection locations to processing facilities, and reuse and recycle at least 85 percent of the solar panels collected. These programs may be developed and implemented by a producer responsibility organization on behalf of one or more manufacturers.

Starting in August 2022, a local law in Niagara County, New York, required solar panel manufacturers to form and join producer responsibility organizations and submit plans that describe how they will manage the solar panels they make (Niagara County, n.d.). Like Washington, Niagara County requires producer responsibility organizations to provide collection opportunities at no additional cost. Niagara County's local law also prohibits the sale of new solar panels from manufacturers that are not covered under an approved plan. As of October 2023, Niagara County reported that only one manufacturer, LG Electronics, out of the 55 it identified as selling into the county was in compliance with the ordinance.

In California, Assemblymember Ward introduced Assembly Bill (AB) 2 at the start of the Legislature's 2023-24 session. When AB 2 was introduced, it closely modeled the language of Washington State's EPR law but did not have the requirements or enforcement provisions like those in California's existing EPR programs. By the end of the first year of the legislative session, AB 2 had been amended to split used solar panels into two categories, "customer-owned" and "not customer-owned," and proposed managing the categories through two different policy mechanisms. Used solar panels

that are “customer-owned,” such as those owned by homeowners, would be managed through the electronic waste program that CalRecycle implements. In this program, a fee would be charged at the point of sale of a new solar panel, and the used solar panels would be brought to electronic waste collection locations to be managed. Used solar panels that do not fall under the umbrella of “customer-owned,” such as those owned by solar companies and leased to property-owners, would be covered by an EPR program in which an entity identified by the law would develop a plan to manage those solar panels. AB 2 was made a two-year bill by the Senate Committee on Appropriations in 2023 and, at the time of writing this report, was still active but had not moved in 2024.

3. Developments in Industry Standards

Industry standards related to used solar panel recycling and disposal best practices currently exist, but the solar panel industry has identified a need for additional standards to make it possible for more industry participants to obtain certification and operate responsibly. Currently, the NSF/ANSI 457 Sustainability Leadership Standard for Photovoltaic Modules and Photovoltaic Inverters (2019) requires manufacturers to provide nationwide take-back services to receive certification. However, SEIA announced in 2023 that the American National Standards Institute approved its proposal to develop 11 new solar and energy standards, including standards to guide equipment decommissioning, used solar panel recycling, and end-of-life management (SEIA, 2023-b). Although these standards are still under development, the underlying principles of the standards may help develop the solar panel manufacturing and recycling industries and remove some of the barriers to used solar panel management.

Section III. Methodology

This report uses rational policy analysis to determine which policy alternative, or alternatives, may address the problem. This section provides an overview of rational policy analysis, outlines the key problems that a viable policy alternative would need to address, and identifies the criteria by which the policy alternatives will be measured.

A. An overview of rational policy analysis

Rational policy analysis describes a category of frameworks that can be used to define a policy problem and analyze the policy alternatives. This report uses a specific rational policy analysis framework, Meltzer and Schwartz's (2019) Five-Step Approach, which outlines steps to define the problem, identify policy alternatives and criteria, analyze the alternatives, and make a final recommendation.

Rational policy analysis is an appropriate approach for this topic area because it requires careful analysis of the underlying problem before methodically analyzing potential solutions. It is difficult to develop policy alternatives that might address the underlying problem without careful analysis, and policy alternatives that are developed without this step will likely only address symptoms of the problem. Further, this method transparently explains how policy alternatives are analyzed, which allows policymakers to either support the recommendation or draw independent conclusions based on their own values.

B. Key problems related to solar panel management

Policy alternatives must effectively address the central problem, the upcoming influx of used solar panels in the waste management stream. Additionally, policy

alternatives should support a circular economy for solar panels by addressing one or more of the barriers to used solar panel reuse and recycling discussed in Section II, including barriers in solar panel reuse and recycling technologies, infrastructure, recycling markets, and the regulatory environment.

C. Criteria for policy alternatives analysis

I identified three criteria, cost efficiency, equity, and administrability, to use in analyzing the policy alternatives against the status quo. The status quo is the baseline against which the policy alternatives are compared when analyzing how well they meet each criterion. For this report, the status quo is a future where the government does not intervene, and the used solar panel reuse and recycling market is left to develop without outside assistance. In this section, I describe each criterion and discuss the quantitative scores that inform my final recommendation.

1. Cost Efficiency

The first criterion, cost efficiency, measures how much each implementing each policy alternative would cost relative to how effectively it would support a circular economy for used solar panels. I determine implementation cost by estimating the direct expenses needed to implement the policy compared to the status quo and include indirect costs incurred by other key players, as appropriate. I determine effectiveness by estimating the outcomes of the policy alternatives compared to the status quo. A score of a 5 means that the policy has low costs and is highly effective, while a score of 1 means that the policy has high costs and is not very effective. Since cost efficiency is an important consideration for government interventions, I assigned a weight of 0.40 to the cost efficiency score.

2. Equity

The second criterion, equity, measures the distribution of benefits across key players affected by the policy (Wassmer, 2017), including manufacturers, consumers, generators, and people living near disposal or recycling facilities. A score of a 5 means that the policy distributes benefits across the key players evenly and makes most groups better off compared to the status quo, while a score of 1 means that the policy impacts groups differently and makes some groups worse off than the status quo. Equity is also an important aspect for policymakers to consider, especially since Californians living near disposal or recycling facilities have been made worse off by past waste management and local zoning policies and impacted communities have been disproportionately low income communities or communities of color (CalEPA, 2021), so I assigned a weight of 0.35 to the equity score.

3. Administrability

The third criterion, administrability, measures how feasibly the government would be able to administer the policy. Administrability considers the additional staff and other resources that may be necessary for successful administration, and how easy it would be to make future improvements to the policy. A score of a 5 means that the policy can be administered using existing resources with minimal disruption to ongoing projects and can be easily changed if future improvements are needed. A score of 1 means that the policy will require many additional resources and is difficult to easily change as future improvements are needed. Administrability is important because a policy that is difficult to implement will likely not be as effective, so I assigned a weight of 0.25 to the administrability score.

Table 1. Criteria and Scoring Rubric with Weights

Criteria	Score: 1	Score: 5	Weight
Cost Efficiency How much does the policy cost to implement? How effective is it at improving used solar panel management?	The policy has high implementation costs and low levels of effectiveness.	The policy has low implementation costs and high levels of effectiveness.	0.40
Equity How well are the benefits distributed across key players (e.g., manufacturers, consumers, generators, and people living near disposal or recycling facilities)?	The policy impacts groups differently. Some groups are made worse off than the status quo.	The policy distributes benefits across the key groups evenly. Most groups are made better off compared to the status quo.	0.35
Administrability What is the level of administrative burden? Does the policy provide flexibility for future improvement?	Implementation will require major administrative restructuring. The policy will be costly and difficult to manage effectively. Policy elements are fixed once the program has been implemented, not flexible.	Implementation could be achieved within the existing administrative structure. Policy elements are flexible and amenable to periodic change.	0.25

Section IV. Policy Alternatives & Analysis

There are several policy alternatives that could improve used solar panel management, but I chose to focus on three key policy alternatives in this report. I selected these policy alternatives out of the viable options because they address more than one barrier to solar panel reuse and recycling and can be enacted through California's legislative process, instead of relying on the federal or local governments to make changes first.

A. Policy Alternative #1: Establish EPR for Solar Panels

The first policy alternative is a statewide EPR law that would require manufacturers to create and implement a stewardship program to fund, collect, and responsibly manage solar panels. I modeled this alternative after the solar panel EPR laws that Washington State and Niagara County, New York, passed, and incorporated lessons from California's existing EPR laws for carpet, paint, mattresses, pharmaceuticals, sharps, single-use plastic and packaging, and loose batteries. Though some components of the EPR law should be negotiated between industry representatives and the Legislature, I recommend including the following critical components of EPR laws at a minimum to develop an implementable program.

- **Producer responsibility organization (PRO):** The law must define PRO, which is an entity that develops and implements a stewardship program for used solar panels. A PRO could be an individual manufacturer or an organization that creates and implements a stewardship program on behalf of one or more manufacturers. The law should limit the number of PROs that can submit a plan, at least for the first several years, like Senate Bill (SB) 54 (Allen, Chapter 75,

Statutes of 2022). Limiting the number of PROs would reduce implementation costs, such as the government's ongoing oversight and enforcement costs. Limiting the number of PROs would also reduce confusion about the options provided by the PRO for used solar panel management or how to join a PRO, which would subsequently improve program performance.

- **Covered products:** The law must clearly define which solar panels are covered by the law. For example, the law could use the definition in Washington's law as a starting point for negotiation, which covers solar panels that are on or integrated with buildings, as well as those in smaller installations, such as streetlights and water pump stations. All stewardship programs must be designed to accept all solar panels to reduce confusion about which products are covered by the program.
- **Performance standards:** The law must establish performance standards that measure the success and convenience of a stewardship program (e.g., recycling, convenience, and collection standards). Performance standards are a critical tool that the government can use to ensure that the program's outcomes are consistent with the purpose of the law and leverage enforcement tools if PROs are not meeting performance standards.
- **Stewardship plans:** The law must require PROs to describe how it will implement its stewardship program through a stewardship plan that the state government reviews and approves. Critical components of a stewardship plan include descriptions of how the PRO will meet the performance standards, collect and manage solar panels, ensure all aspects of its program comply with federal,

state, and local laws, and educate people and businesses that interact with its program. The law should require a PRO to review its stewardship plan and determine whether updates are needed every five years to ensure stewardship plans reflect current practices and laws.

- **Funding mechanism:** The law must specify how the program will be funded. The law should require a PRO to divide the costs of implementing the stewardship program between the manufacturers that participate in its program. This is often called cost-internalization and allows manufacturers to react more nimbly to market changes and other potential impacts than cost-externalization, such as set fees at the point of sale, because the state government does not need to approve changes to the funding structure. The law must also require a PRO to cover the state government's costs associated with oversight and enforcement.
- **Annual reports:** The law must require a PRO to submit to the state government each year a report that describes how it implemented its program for the previous calendar year and achieved the performance standards.
- **Enforcement:** The law must include enforcement provisions to hold PROs and manufacturers accountable to meeting the requirements of the law. These provisions could include penalties and other enforcement mechanisms, as well as requirements for participating entities to retain records for inspections.

1. Analysis of Policy Alternative #1: Cost Efficiency

I expect that a new EPR program for used solar panels would have likely have moderate costs and high effectiveness compared to the status quo based on the cost

efficiency of existing EPR programs in California, so I assigned it a score of four. In the status quo, local governments and ratepayers would incur increasing costs to manage solar panels, so an EPR law would shift these costs to solar panel manufacturers instead. For example, PaintCare, the PRO that implements the paint stewardship program in California and several other states, reported saving local governments' HHW programs an average of $151,905 annually (PSI, 2016). Manufacturers' costs would depend on the activities included in a PRO's stewardship plan and how the costs are split between the manufacturers under that PRO and could range from $10 to $50 million per year split between manufacturers.

The state government's costs would include staff and other resources for one or more agencies to oversee and enforce the law and would also likely be moderate, depending on the scope of products and how the law is structured. For example, CalRecycle requested 18 new staff over two budget years and just under $3 million per year to implement AB 2440 (Irwin, Chapter 351, Statutes of 2022), the new loose battery EPR law (CalRecycle, 2023-a). However, CalRecycle's costs to oversee and enforce an established program, like the paint stewardship program, are lower and cost less than $500,000 in the 2022 to 2023 budget year (CalRecycle, 2023-b).

Based on the success of existing EPR programs in California, an EPR program would likely be highly effective at managing solar panels and increasing the number of solar panels that are reused and recycled. For example, existing EPR programs in California have collected 34 million gallons of paint, 9.6 million mattress, and 1.2 billion pounds of carpet to be recycled or otherwise safely managed (CalRecycle, 2024).

2. Analysis of Policy Alternative #1: Equity

An EPR law would be moderately equitable compared to the status quo, and could be designed to further improve equity, so I assigned it a score of four. Manufacturers would incur the most costs for an EPR program, while other groups such as local governments, ratepayers, and generators would see benefits through covered costs and increased access to collection. Recycling and solid waste operations have historically impacted areas with greater concentrations of low-income individuals and people of color, but the Legislature can determine how the used solar panel recycling industry develops to avoid these types of impacts through provisions it includes in the EPR program, such as requirements for engagement in specified communities.

3. Analysis of Policy Alternative #1: Administrability

An EPR policy would require minor restructuring within an agency and would be moderately flexible if policy changes are needed, so I assigned it a score of three. If the law limits the number of PROs and clearly defines the scope of covered products, then a state agency may need 15 to 20 new staff to oversee and enforce the law, like AB 2440 (CalRecycle, 2023-a). However, if the number of SOs increases, the number of staff and other resources needed for oversight and implementation will also increase. EPR laws are typically developed with a high level of flexibility for SOs to make changes to their programs (e.g., adding or removing recyclers or collection locations, modifying education and outreach strategies, etc.) within the scope of the law, but any changes to statute or regulations would be less flexible.

B. Policy Alternative #2: Add Used Solar Panels to California's E-waste Law

The second policy alternative would add all solar panels to the covered electronic waste (e-waste) recycling program that CalRecycle manages. This approach is like SB 1215 (Newman, Chapter 370, Statutes of 2023), which added battery-embedded products to the e-waste program. A fee is charged at the point of sale for each covered product, remitted to the California Department of Tax and Fee Administration (CDTFA), and used by CalRecycle to pay businesses that recycle e-waste, as well as by DTSC for enforcement activities (CalRecycle, n.d.-a). Manufacturers must inform generators of e-waste about where and how to return, recycle, and dispose of their e-waste, and must also submit an annual report to CalRecycle. Adding used solar panels to the e-waste program would improve collection convenience and would decrease the cost of recycling compared to landfilling, a key barrier to market growth that the literature identified, due to the program's recycling payments.

The law would need to clearly state which solar panels are included and at what point the fee would be charged. For products currently covered by the e-waste law, like televisions, retailers can easily determine what products require consumers to pay the e-waste fee. Solar panels, on the other hand, may be owned by solar companies or consumers that use the solar panel, and that ownership may change over the life of the solar panel, so it may be more difficult to determine who needs to pay the fee and which entities need to remit the fee to CDTFA.

1. Analysis of Policy Alternative #2: Cost Efficiency

Adding solar panels to the existing e-waste program would add moderate costs with a high level of effectiveness, so I assigned it a score of four. Adding solar panels to

the e-waste program would shift costs away from local governments and ratepayers like the first policy alternative. Instead, people or businesses that purchase solar panels would incur most of the costs of the program, and manufacturers and state agencies would incur a smaller share of the costs. The additional oversight necessary to determine which entities need to remit fees would increase state agencies' costs related to the program. This policy alternative would be highly effective compared to the status quo since it would offer convenient collection, incentivize recycling, and provide education to consumers, all of which have increased recycling for the existing products covered by the e-waste program.

2. Analysis of Policy Alternative #2: Equity

Adding solar panels to the e-waste program is moderately equitable compared to the status quo, so I assigned it a score of three. The benefits are spread across consumers and key players in the solar panel industry, but most of the burden would be incurred by used solar panel generators. This policy would also increase the burden on entities that must collect and remit the fees. The e-waste law does not currently contain provisions that require regulators or recyclers to consider environmental justice aspects, so those living near existing or new recycling or solid waste facilities may be disproportionately impacted. As a result, this policy would only be moderately equitable.

3. Analysis of Policy Alternative #2: Administrability

Adding solar panels to the e-waste program would likely require minimal restructuring within the participating state agencies and future policy changes would be moderately flexible, so I assigned it a score of three. The number of entities regulated by the e-waste law would increase with the addition of solar panels, subsequently

increasing program administration and enforcement activities. Additional staff and resources would be needed for CalRecycle to review requests for payment and periodically update the fee and for DTSC to inspect and enforce against a larger universe of e-waste manufacturers and recyclers. CalRecycle currently handles policy changes through the rulemaking process for the e-waste program, but substantive policy changes would require statutory updates, which makes this policy only moderately flexible.

C. Policy Alternative #3: Enact Labeling Requirements for New Solar Panels

The third policy alternative that I identified is a requirement for manufacturers to label new solar panels they sell in or into California that lists the materials that each solar panel contains. This is similar to a requirement in AB 2440, the loose battery EPR law, which requires labels for different battery chemistries to improve battery collection and recycling. This requirement, as codified in statute, must establish standardization across labels and describe the kind of information that labels would contain. Further, the label would need to be durable enough to withstand 20 to 30 years of the elements, but not so durable that it impacts recycling, and still relevant at the time solar panels are taken off. For example, if the law allows a manufacturer to design their own label and a manufacturer chooses to use a QR code, then consideration must be given as to whether QR code technology will still be relevant in 20 to 30 years.

Labels would reduce the barriers that solar panel generators currently face in California. As discussed in Section II, DTSC currently requires solar panel generators to determine whether a solar panel is hazardous or non-hazardous, and doing so requires information from the manufacturer or expensive laboratory testing. If all solar panels

were labeled with the materials they contain, then solar panel generators would be able to easily determine whether their solar panels contain hazardous materials. Additionally, solar panel recyclers would benefit from being able to quickly determine which materials each solar panel contains and at what amount, which will be increasingly useful as solar panel technologies evolve.

1. **Analysis of Policy Alternative #3: Cost Efficiency**

Establishing a labeling requirement would have a low cost with moderate levels of effectiveness, so I assigned it a score of two. Manufacutrers would need to modify their manufacturing systems to add labels, so manufacturers would incur some initial implementation costs, and state agencies would also incur low initial costs to clarify and enforce the law, as needed. Although the requirement would reduce barriers to solar panel reuse and recycling, this policy would not address short-term needs and the earliest benefits would be seen would be in a couple decades when the first solar panels with labels are removed from buildings and other installations.

2. **Analysis of Policy Alternative #3: Equity**

A labeling requirement would be moderately equitable compared to the status quo, so I assigned it a score of three. Manufacturers would primarily incur costs to meet the requirements of the new law, while other key players, including solar companies, used solar panel generators, recyclers, and local governments, would benefit from the policy in the long-term. This policy would likely neither burden nor benefit people living near disposal or recycling facilities compared to the status quo.

3. Analysis of Policy Alternative #3: Administrability

Establishing a labeling requirement would not require any restructuring within state agencies and would be moderately flexible to changes, so I assigned it a score of four. The state agency tasked with ensuring that solar panel manufacturers meet this requirement would likely be able to carry out initial rulemaking and ongoing enforcement tasks with one to two new staff. If changes to the labeling requirement are needed, the state agency could possibly make policy changes via regulations if the change is possible within the scope of the statute.

Table 2. Solar Panel Management Policies Criteria-Alternatives Matrix

Policy Alternative	**Cost Efficiency** Weight: 0.40	**Equity** Weight: 0.30	**Administrability** Weight: 0.25	**Total**
1. Establish an EPR program	4 (1.60)	4 (1.20)	3 (0.75)	3.55
2. Add to e-waste program	4 (1.60)	3 (0.90)	3 (0.75)	3.25
3. Enact labeling requirements	2 (0.80)	3 (0.90)	4 (1.00)	2.7

Section V. Policy Recommendations

Based on my analysis, I recommend that the Legislature enact an EPR law for used solar panels that includes a labeling requirement for new solar panels sold in or into the state to address the imminent influx of used solar panels. The policy alternative that scored the highest is the EPR law for solar panels, followed by the modification to California's e-waste program, and finally, the labeling requirement for new solar panels sold in or into the state. An EPR law for used solar panels would ensure that the cost of managing used solar panels is included in the price of solar panels, which would reduce negative externalities, such as future management and environmental costs incurred by the public, and address the existing market failure. When well-designed and implemented, EPR laws provide manufacturers, who have the most control over and knowledge on the product they make, with the flexibility to create a program to manage their products within the parameters prescribed in statute. EPR laws allow the Legislature to include requirements that matter to them and their constituents, while providing state agencies with the authority to oversee and enforce the law to ensure program participants meet the Legislature's requirements.

EPR laws have had a slow start in California and the United States, compared to the European Union and other countries, but are gaining momentum and political favorability. Advocates of EPR laws have spent many years educating California's Legislators and their staff about EPR because these laws can be complex and differ significantly from traditional government command-and-control policy models. As a result, California Legislators are more familiar with EPR and willing to discuss EPR as a possible solution. Another reason why EPR laws are becoming more popular is

because the direct costs to government for EPR are low compared to other policy mechanisms for their high level of effectiveness and are covered by the PROs. Therefore, an EPR law for used solar panels is politically feasible in addition to being the highest-scoring policy alternative.

While the third policy alternative, establishing labeling requirements for new solar panels sold in or into the state, did not score high as an independent policy, it would be a good complement to include in an EPR law. Labeling would improve future solar panel management and recycling by allowing key players to know whether a used solar panel contains hazardous materials. Labeling requirements may receive some pushback from manufacturers and their representative industry associations because they require an additional step in the manufacturing process and subject manufacturers to more regulation. However, labeling requirements have recently been more prevalent and successful in the Legislature, as evidenced by recent laws like SB 54 and AB 2440 that include labeling requirements for products. Together, these policies would create a convenient, cost-effective system for collecting and safely managing used solar panels and would address many of the barriers currently present in the solar panel reuse and recycling market. These policies would also provide flexibility as solar panels continue to gain popularity and evolve as technology improves.

Although the first two policy alternatives had similar scores, I strongly recommend that the Legislature does not combine the two, as has been proposed in AB 2. Splitting used solar panels into an EPR program and the e-waste program based on who owns them would increase confusion about which program manages specific solar panels and decrease program effectiveness. Information barriers like this may reduce

use of both programs, create free riders for one program over another, or introduce unintended consequences.

A. Limitations

Any recommended policy for used solar panels faces the following limitations: a lack of currently available information about the scope of regulated entities, the cost of recycling solar panels, and the impact that a policy may have on future solar panel sales, as well as timing limitations. First, it is difficult to find comprehensive information about the number of entities that would be regulated under an EPR program for used solar panels or impacted by the law. This includes the number of domestic and international manufacturers, distributors, and retailers that sell solar panels in or into California, the number of solar companies that currently sell or lease solar panels, and the number of businesses that can collect and reuse, recycle, or otherwise manage solar panels. Without this information, it is difficult to concretely estimate costs and determine the effectiveness of a proposed policy. Through collaborative partnership between policymakers, state agencies, academics, and other interested parties, we can compile this information to develop better policies.

Second, more research is needed to determine the potential financial, environmental, and social costs of recycling used solar panels compared to landfilling solar panels. Currently, solar panel recyclers are mostly small businesses that do not operate on a commercial scale. As a result, solar panel recyclers could become more cost effective as they scale up and as recycling technologies improve, but we will not have long-term data like this until used solar panels become more prevalent. The environmental costs of solar panel recycling will depend on the type of technology used

to dismantle solar panels and process the components. Ideally, this process would be less resource intensive than virgin material production, but that will be unknown pending additional research and may change as recycling technologies evolve. Finally, solar panel recycling may impose a social cost if the negative externalities, which have been incorporated into the cost of the product through the proposed EPR program, prohibit lower-income individuals from purchasing or leasing solar panels, or if the placement of solar panel recycling facilities disproportionately impacts low-income communities or communities of color. The Legislature can prevent negative impacts like this, though, through careful development of the EPR law.

Third, additional regulations to solar panels could negatively impact solar panel use, which is directly opposed to the state's policy goals over the last twenty years. Solar panels have become increasingly popular over time, as well as increasingly more affordable. Future studies could analyze whether the costs of managing solar panels will decrease new solar panel use or if it is insignificant enough to allow solar to continue to grow in the energy market. However, a study would need to consider the cost of collecting and managing used solar panels, which would not be known until used solar panel EPR programs, such as Washington State's or Niagara County's, have been operational for several years.

The final limitation to addressing the problem through policy implementation is timing. The recommended policy in this report is the first step to addressing the problem, but timing will be the key to ensuring successful program implementation. Like many policies, EPR laws require significant negotiation between parties, which can take several years. Further, EPR laws require policy entrepreneurs to connect interested

parties and identify a window of opportunity to bring the policy forward in the Legislature (Jones, et al., 2015). This window of opportunity will likely present itself soon, as more people become aware of the looming problem and it begins to impact local governments and ratepayers. However, policy entrepreneurs and the Legislature cannot wait until solar panels are a prevalent problem to identify a solution without negative impacts to people and the environment.

Section VI. Conclusion

This policy report explored the literature related to the impending surge of used solar panels in the waste stream, analyzed policy options to address the problem using rational policy analysis, and recommended that the Legislature enact an EPR law for solar panels that includes a labeling requirement. Solar panels started gaining popularity in California in the early 2000s and most solar panels start to lose efficiency after 20 to 30 years, so solar panels will be removed from buildings and other installations in increasingly large quantities over the next few years. This is a problem because California does not have a plan to manage these solar panels, some of which contain hazardous materials and are difficult to properly manage. The literature identified key barriers to the growth of solar panel reuse and recycling, including barriers in the current solar panel reuse and recycling technologies, infrastructure, recycling markets, and the regulatory environment.

I used Meltzer and Schwartz's (2019) Five-Step Rational Policy Analysis to identify the problem and establish criteria to analyze the policy alternatives. The criteria included cost effectiveness, equity, and administrability, and I assigned weights to the criteria depending on relative importance related to this report. I selected policy alternatives based on their potential to address the main problem, as well as one or more of the barriers to solar panel reuse and recycling. The policy alternative included creating an EPR program for used solar panels, adding used solar panels to the state's existing e-waste program, and establishing labeling requirements for new solar panels sold in or into the state.

Based on my analysis of the policy alternatives using the criteria, the EPR program for used solar panels came in first, followed by adding used solar panels to the e-waste program, and finally, establishing labeling requirements. While labeling requirements did not sufficiently address multiple aspects of the problem or short-term needs, it is a critical component to reduce barriers to used solar panel collection and recycling in the future. Therefore, my final policy recommendation for the Legislature to consider is an EPR program for used solar panels that includes a labeling requirement. Both components of this policy are gaining popularity in the Legislature, which improves the political feasibility of the policy as a result. There are some limitations to this policy, including a lack of information around the universe of regulated entities, costs, and the potential impact on future solar panel sales, as well as a need to time policy introduction correctly. Nevertheless, an EPR program for used solar panels would allow the state to continue to move toward a fully circular economy.

Used solar panels will start coming off buildings and other installations in increasingly large quantities over the next few years, and the state needs a plan to address these used solar panels. Without a plan, used solar panels will inundate the waste stream, costs will be passed on to local governments and ratepayers, and the state will lose out on an opportunity to maximize the number of solar panels that are reused or recycled into new products, contributing to circular economy. The Legislature can ensure that the state is ready for the influx of solar panels and moving toward a fully circular economy by creating an EPR program for solar panels that includes labeling requirements.

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Appendix. Acronyms and Short Names Reference Guide

AB – Assembly Bill

CalRecycle – California Department of Resources Recycling and Recovery

CEC – California Energy Commission

CPUC – California Public Utilities Commission

DOE – US Department of Energy

DTSC – California Department of Toxic Substances Control

EPR – extended producer responsibility

HHW – household hazardous waste

Legislature – California State Legislature

RCRA – Resource Conservation and Recovery Act

SB – Senate Bill

SEIA – Solar Energy Industries Association

US EPA – US Environmental Protection Agency