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Solving Solar: How Past Policy Collides With Future Technology

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SOLVING SOLAR: HOW PAST POLICY COLLIDES WITH FUTURE TECHNOLOGY

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ABSTRACT

This Comment discusses the importance of developing a solar waste management plan. Specifically, this Comment presents the argument that the United States should not create a large federal regulatory framework that includes expansive subsidies for solar panel recycling, but instead should invest in solar recycling technologies that offer solar recyclers the opportunity to profitably recycle junk panels. Ultimately, the federal government's role should be limited to one of investment and support as states craft solar waste management systems that work for them.

In support of this argument, this Comment explores the history and future of solar panel development, the current state of solar production and recycling, and the magnitude of the threat solar waste presents. Additionally, this Comment discusses how nations outside the United States are addressing the solar waste problem, the advent of new solar recycling technologies, how Congress may adapt the existing Resource Conservation and Recovery Act to include solar panels and encourage recycling of junk panels, the success story of lead-acid battery recycling, and what the solar recycling network of the future may look like.

Ultimately, this Comment concludes that given recent advancements in recycling technology, with proper planning, encouragement, and investment from both state and federal governments, the private sector will be incentivized to recycle used solar panels without burdensome government intervention while sustaining a profitable business. Such a result will create a truly clean and renewable source of energy and relieve American taxpayers from bearing the cost of expensive solar recycling subsidy programs.

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* J.D. Candidate, Texas A&M University School of Law, May 2024. I would like to thank the *Texas A&M Law Review* for its help in publishing *Solving Solar*—may this Comment add a unique perspective to the conversation of renewable energy. I would also like to thank all those who have invested in and supported me along the way, including my wife, family, professors, and fellow classmates.

I. Introduction

As the world grapples with an energy crisis that leaves many countries and individuals with skyrocketing costs and energy grid instability, it has never been more important to discuss the future of energy and the role of renewables in that future.[1] Renewable energy sources are not only necessary to combat climate change and reduce emissions, but they also allow for reduced dependence on oil-producing nations.[2] Such a reduced dependence frees domestic and international energy markets from the whims of bad actors that control major oil supplies and thus creates a more stable and sustainable energy market.[3]

The development of renewable and reliable energy sources is not only a national security concern, but also a critical requirement to combat climate change.[4] Greenhouse gas emissions from non-renewable energy sources have already contributed to an increase in droughts, destructive weather events, extreme temperatures, and sea level rise.[5] Unless humanity reduces emissions and shifts to renewable energy sources, climate change's effects are likely to worsen.[6] In its 2021 report, the Intergovernmental Panel on Climate Change found that by 2040 it is probable that global temperatures will increase between 2.16°–3.42°F, and by 2100, temperatures could increase by 10.26°F.[7] Such a rapid rise in global temperatures will result in extreme weather and climate events that could threaten the habitability of entire countries.[8] To prevent such a future, governments and organizations across the world must act now to establish a plan for a renewable and net zero carbon emissions future.[9]

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1. Philip Barrett, *How Food and Energy Are Driving the Global Inflation Surge*, IMF Blog (Sept. 12, 2022), https://www.imf.org/en/Blogs/Articles/2022/09/09/cotw-how-food-and-energy-are-driving-the-global-inflation-surge [https://perma.cc/Q9CK-A3SW].

2. *Local Renewable Energy Benefits and Resources*, U.S. Env't Prot. Agency, https://www.epa.gov/statelocalenergy/local-renewable-energy-benefits-and-resources [https://perma.cc/3GV5-EYR2] (explaining how local renewable energy production reduces carbon emission and reduces dependence on imported fuels).

3. *See id.* (discussing how locally produced renewable energy reduced dependence on imported fuels).

4. Lindsay Milliken et al., *Countering Climate Change with Renewable Energy Technologies*, Fed'n of Am. Scientists (July 8, 2021), https://fas.org/blogs/science policy/countering-climate-change-with-renewable-energy-technologies/ [https://perma.cc/A4MF-M398].

5. *Id.*

6. *Id.*

7. Intergovernmental Panel on Climate Change, Summary for Policymakers 14 (2021), https://www.ipcc.ch/report/ar6/wg2/ [https://perma.cc/2K2D-B5H3] (noting that by 2040 temperatures may rise 1.2°–1.9°C and by 2100 as much as 5.7°C).

8. *Id.* at 15.

9. *See id.* at 14.

Undoubtedly, solar energy will play a major role in securing a renewable and sustainable energy future.[10] However, increased dependence on solar energy will come at a cost in the form of millions of tons of solar panel waste per year.[11] As of today, there is no organized system or approach toward solar panel disposal in the United States.[12] As a result, solar panels in the United States are rarely recycled and thus often end up in landfills.[13] However, solar panels contain several hazardous materials that can leach out of the panels and into the surrounding environment.[14] This toxic leaching can even occur when solar panels are disposed of in landfills compliant with U.S. regulations.[15]

Although many solar panels have an estimated life span of over 25 years (depending on the type of solar panel and the environment in which it was used),[16] improved technology and economic incentives are causing an even higher replacement rate.[17] Consequently, solar panel disposal is becoming an issue not only for panels manufactured 25 years ago but also for newer panels.[18] This issue is only going to worsen as the solar industry continues to expand and the number of panels in use increases.[19] Without a proper framework for recycling in place, the United States runs the risk of creating a waste problem that rivals the plastic waste crisis.[20]

However, an avenue that encourages solar panel manufacturers and third parties to recycle solar panels is beginning to take shape. Solar panels contain valuable materials that, if properly isolated, are poten-

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10. *30% by 2030: A New Target for the Solar+ Decade*, SOLAR ENERGY INDUS. ASS'N, https://www.seia.org/research-resources/30-2030-new-target-solar-decade [https://perma.cc/8GFA-ANNN] [hereinafter *30% by 2030*].

11. *See* Atalay Atasu et al., *The Dark Side of Solar Power*, HARV. BUS. REV. (June 18, 2021), https://hbr.org/2021/06/the-dark-side-of-solar-power [https://perma.cc/6EJL-78CF].

12. *Id.*

13. *See id.*

14. *Id.*

15. Michael Shellenberger, *If Solar Panels Are So Clean, Why Do They Produce So Much Toxic Waste?*, FORBES (May 23, 2018, 12:28 PM), https://www.forbes.com/sites/michaelshellenberger/2018/05/23/if-solar-panels-are-so-clean-why-do-they-produce-so-much-toxic-waste/?sh=6feb50c4121c [https://perma.cc/BBC9-Z6YK].

16. *End-of-Life Solar Panels: Regulations and Management*, U.S. ENV'T PROT. AGENCY, https://www.epa.gov/hw/end-life-solar-panels-regulations-and-management [https://perma.cc/9PP9-E8YF] (Oct. 23, 2023).

17. Atasu et al., *supra* note 11.

18. *Id.*

19. *Id.*

20. *See* Dieter Holger, *The Solar Boom Will Create Millions of Tons of Junk Panels*, WALL ST. J. (May 5, 2022, 12:30 PM), https://www.wsj.com/articles/the-solar-boom-will-create-millions-of-tons-of-junk-panels-11651658402#:~:text=the%20solar%2Denergy%20boom%20will,between%2025%20and%2030%20years [https://perma.cc/X8R2-CADB].

tially worth more than the cost of recycling the solar panel.[21] Most solar panels are primarily comprised of glass and aluminum.[22] However, the remaining materials in these panels consist of valuable materials that can be difficult to extract—like silicon, silver, and copper—and toxic materials that are dangerous to handle—like lead and cadmium.[23] The successful isolation and recovery of these materials offer recyclers the opportunity to offset the increased cost of recycling solar panels and encourages manufacturers and third parties to recycle used solar panels without the need for expansive government incentive programs.[24]

While new and promising solar panel recycling techniques have the potential to vastly improve the economic viability of solar panel recycling, greater investment in recycling technology is required to make this potential a reality.[25] Rather than create a bloated regulatory scheme and provide expansive subsidies and tax credits for solar panel recycling, the United States should shift investment to solar panel recycling technology and work closely with states to encourage solar panel recycling. A shift of investment from solar recycling subsidies to solar recycling technology presents the opportunity to improve the economic viability of solar panel recycling and thereby encourage manufacturers and third parties to create a solar panel recycling network.[26] With cooperation on the federal and state levels and implementation of the lessons learned from the success of recycling lead-acid batteries, the United States could make solar panel recycling not only economically viable but also environmentally conscious and fiscally attractive.[27]

This Comment begins in Part II by discussing the background of solar panels, how they work, their development, the materials involved in their production, and current trends found in the solar industry. Part III describes the current solar panel disposal process, emphasizes the importance of a disposal plan, and discusses how other countries are addressing the solar waste problem. Part IV examines the newest advancements in solar panel recycling technology, the challenges related to solar recycling, and the possibility of using existing state and federal law to encourage adoption of and investment in emerging technologies. Part V discusses the Resource Conservation

21. *See* Lineesh Punathil et al., *Recovery of Pure Silicon and Other Materials from Disposed Solar Cells*, INT'L J. PHOTOENERGY, Apr. 2021, at 1, 3, https://doi.org/10.1155/2021/5530213.

22. *See* Idiano D'Adamo et al., *Economic Feasibility for Recycling of Waste Crystalline Silicon Photovoltaic Modules*, INT'L J. PHOTOENERGY, June 2017, at 1, 3, https://doi.org/10.1155/2017/4184676.

23. *See id.*

24. *See generally* Punathil et al., *supra* note 21, at 1, 3.

25. *See id.* at 1.

26. *See infra* text accompanying notes 109–18.

27. *See infra* text accompanying notes 133–45.

and Recovery Act ("RCRA") and draws parallels between the current state of solar panel recycling and the state of lead-acid battery recycling before the implementation of the RCRA. Part VI explores what the future solar panel recycling network may look like under the model set forth in this Comment. Finally, Part VII argues that rather than creating a new regulatory framework that provides expansive subsidies at U.S. taxpayers' expense or adopting a framework like that of the European Union, the United States should apply the RCRA to solar panels and invest in recycling technologies that make solar panel recycling economically viable for manufacturers and third parties.

II. The Roadmap of Solar Energy

Currently, fossil fuels—which emit greenhouse gases—supply approximately 80% of the world's energy[28] and, according to the Environmental Protection Agency, are responsible for 65% of global greenhouse gas emissions.[29] However, renewable energy sources have quickly grown on the global stage. In 2020, renewables became the United States' second largest source of energy—behind only natural gas.[30] While wind energy is currently the most prevalent source of renewable energy in the United States,[31] the use of solar photovoltaics, or solar panels, is the fastest-growing form of renewable energy both in the United States and globally.[32]

A. *The Promise of Solar Energy*

For the past decade, the amount of solar energy produced in the United States has grown by 33% per year and is now capable of producing enough energy to power 23 million homes annually.[33] To understand why the solar industry has grown so quickly in recent years, one must understand the energy potential of solar power and the incentives in place to encourage solar investment. From an energy-potential perspective, enough solar energy reaches Earth's surface each hour to satisfy all of humanity's energy needs for an entire year.[34]

28. *Fossil Fuels*, Env't & Energy Study Inst., https://www.eesi.org/topics/fossil-fuels/description [https://perma.cc/QH45-46NK] (July 22, 2021).

29. *Global Greenhouse Gas Emissions Data*, U.S. Env't Prot. Agency, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data [https://perma.cc/KP72-FVJA] (Feb. 15, 2023).

30. *Today in Energy*, U.S. Energy Info. Admin. (July 28, 2021), https://www.eia.gov/todayinenergy/ [https://perma.cc/L63C-MFDM].

31. *Id.*

32. *Renewable Energy*, Ctr. for Climate & Energy Sols., https://www.c2es.org/content/renewable-energy/ [https://perma.cc/DW3Y-FV7V].

33. *Solar Industry Research Data*, Solar Energy Indus. Ass'n, https://www.seia.org/solar-industry-research-data [https://perma.cc/T8QL-9NGP].

34. *Renewable Energy*, *supra* note 32.

Thus, only a fraction of this energy potential is necessary to satisfy current energy demand.[35]

Additionally, solar panels can be affixed to nearly any rooftop or placed in any open space to collect sunlight.[36] Although the efficacy of solar cells depends on a number of factors, including geographic location, weather conditions, and time of day, solar panels have the potential to produce energy in almost every inhabited region of Earth.[37] Besides their potential for wide adoption and promising energy production capabilities, solar panels have become more popular because of widespread subsidies and incentives.[38] Overall, the solar industry has received billions of dollars in tax incentives, rebates, and grants and, as a result, has grown steadily.[39]

Because of the promising technology, and the steady investment from both the United States and international governments, the solar industry shows no signs of slowing its rapid growth.[40] The United States' solar industry alone is projected to employ over one million Americans and produce more than 30% of the United States' electricity per year by 2030.[41] Due to this rapid rise, it is important for governments and authorities to consider the consequences of such exponential growth and establish policies and procedures to address the looming threat of solar waste.

B. *The Rise of Solar Energy*

In 1883, Charles Fritts, building on the work of his predecessors who discovered the photovoltaic effect,[42] created the first solar cell by

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35. *Id.*

36. *Reliable Energy Sources*, INSPIRE CLEAN ENERGY, https://www.inspirecleanenergy.com/blog/clean-energy-101/reliable-energy-sources [https://perma.cc/LT8D-Z99S].

37. *See Solar Explained: Where Solar Is Found and Used*, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/energyexplained/solar/where-solar-is-found.php [https://perma.cc/4FWB-KHRT] (Apr. 6, 2022).

38. *See What Rebates and Incentives Are Available for Solar Energy?*, SOLAR ENERGY INDUS. ASS'N, https://www.seia.org/initiatives/what-rebates-and-incentives-are-available-solar-energy [https://perma.cc/JKF6-7AXG]; *see also* Ayodele O. Ogunlana & Nataliya N. Goryunova, *Tax Incentives for Renewable Energy: The European Experience*, 19 EUR. PROC. SOC. & BEHAV. SCIS. 507, 507–13 (2017), https://doi.org/10.15405/epsbs.2017.01.69 (explaining tax incentives for renewable energy).

39. SCULLY CAP., EXAMINATION OF FEDERAL FINANCIAL ASSISTANCE IN THE RENEWABLE ENERGY MARKET 1 (2018), https://www.energy.gov/ne/articles/report-examination-federal-financial-assistance-renewable-energy-market [https://perma.cc/7Q46-ECAH].

40. *Solar Industry Research Data*, *supra* note 33.

41. *30% by 2030*, *supra* note 10.

42. *See Photovoltaic Effect*, SCIENCEDIRECT, https://www.sciencedirect.com/topics/engineering/photovoltaic-effect [https://perma.cc/PM4J-YGC5] (defining the photovoltaic effect as the process that produces an electric current when a semiconductive material is exposed to light).

coating selenium with a thin layer of gold.[43] This inaugural solar cell, only capable of converting 1%–2% of collected light into usable electricity, was the first proof of concept for today's booming solar industry.[44] Since Fritts's discovery, the solar industry has received billions of dollars of investment and made monumental strides toward an efficient, affordable, and sustainable future.[45] Today, solar panels have reached efficiencies in excess of 20%[46] and are responsible for 3.3% of total electricity generated in the United States.[47] With an annual growth rate of 50% in the United States, solar's share of energy production is only expected to increase.[48] However, the solar industry's growth is not only present in the United States. In fact, solar energy is the fastest-growing form of renewable energy in the world, with China producing and installing more solar panels than any other nation.[49]

The entire solar industry and its unprecedented growth are predicated on a simple and fundamental physical process—the photovoltaic ("PV") effect.[50] The PV effect occurs when photons, the particles that make up light, are absorbed by conductive materials.[51] When absorbed, the energy in photons is transferred to conductive materials and produces an electric current without generating greenhouse gases.[52] Solar panels rely on the PV effect for their energy production, and thus are an effective source of energy wherever they can collect sunlight.[53] However, solar panel adoption did not begin to take hold until the energy crisis in the 1970s, when fossil fuel prices began to soar,[54] and then again in the 2000s, with environmental concerns rising to the forefront of political discourse.[55]

43. Elizabeth Chu & D. Lawrence Tarazano, *A Brief History of Solar Panels*, SMITHSONIAN MAG., https://www.smithsonianmag.com/sponsored/brief-history-solar-panels-180972006/ [https://perma.cc/GDR2-4MEJ].

44. *Id.*

45. *See* SCULLY CAP., *supra* note 39, at 1.

46. Chu & Tarazano, *supra* note 43.

47. *Renewable Energy*, *supra* note 32.

48. Chu & Tarazano, *supra* note 43.

49. Adam Vaughan, *Time to Shine: Solar Power Is Fastest-Growing Source of New Energy*, GUARDIAN (Oct. 4, 2017, 3:00 PM), https://www.theguardian.com/environment/2017/oct/04/solar-power-renewables-international-energy-agency [https://perma.cc/2DT7-88KQ].

50. *Photovoltaic Effect*, ENERGY EDUC., https://energyeducation.ca/encyclopedia/Photovoltaic_effect [https://perma.cc/M28C-8VGT].

51. *Id.*

52. *Id.*

53. *Id.*

54. Fred Frommer, *How the 1970s U.S. Energy Crisis Drove Innovation*, HISTORY (Oct. 17, 2022), https://www.history.com/news/energy-crisis-1970s-innovation#:~:text=tech%20Advances%20for%20Energy%2DSaving,response%20to%20the%20energy%20crisis. [https://perma.cc/X6LE-BF7B].

55. Rebecca Leppert & Brian Kennedy, *Home Solar Panel Adoption Continues to Rise in the U.S.*, PEW RSCH. CTR. (Oct. 14, 2022), https://www.pewresearch.org/fact-tank/2022/10/14/home-solar-panel-adoption-continues-to-rise-in-the-u-s/ [https://perma.cc/8JCZ-52X7].

The passage of the 2005 Energy Policy Act (2005 "EPA") in the United States set the stage for the solar industry to begin its boom.[56] The 2005 EPA established generous tax credits and incentives for solar installation for both residential and commercial purposes,[57] and by 2016 solar became the fastest-growing energy source in the world.[58] The most prevalent type of solar panel in the world today is known as first-generation solar.[59] These solar panels comprise 90% of the market and are preferred for their high efficiency relative to their cost.[60] While first-generation solar cells are primarily comprised of glass and aluminum, they also contain valuable materials like silver and copper.[61] Second-generation solar, or thin-film solar, makes up far less of the solar market but was developed as a less material-intensive alternative to first-generation solar.[62] However, second-generation solar has struggled to achieve efficiencies comparable to first-generation solar and therefore has not enjoyed the same level of market penetration.[63] Lastly, third-generation solar is comprised of a variety of materials and technologies.[64] Current trends in third-generation solar development involve the use of organic materials and efforts to increase efficiencies beyond that of first-generation solar.[65] While third-generation solar panels may grow in popularity, they are still considered an emerging technology.[66] As a result, first-generation solar panels are likely to remain the most common form of solar panel for the foreseeable future.[67]

First-generation solar panels consist of three primary components: a metal frame, a glass panel, and a PV module.[68] The metal frame of the panel is used to support the internal components and create a moisture barrier.[69] The glass panel is a transparent, durable glass sheet that

56. David Hart & Kurt Birson, Deployment of Solar Photovoltaic Generation Capacity in the United States 20 (2016), https://www.energy.gov/sites/prod/files/2017/01/f34/Deployment%20of%20Solar%20Photovoltaic%20Generation%20Capacity%20in%20the%20United%20States.pdf [https://perma.cc/H59U-4QHH].

57. *Id.*

58. *See* Vaughan, *supra* note 49.

59. *See* Justyna Pastuszak & Pawel Wegierek, *Photovoltaic Cell Generations and Current Research Directions for Their Development*, Materials, Aug. 12, 2022, at 1, 5, https://doi.org/10.3390/ma15165542.

60. *Id.*

61. *See* D'Adamo et al., *supra* note 22.

62. *See* Pastuszak & Wegierek, *supra* note 59, at 10.

63. *Id.* at 1, 12.

64. *Id.* at 14–15.

65. *Id.*

66. *Id.* at 14.

67. *Id.* at 5.

68. Shauna, *#SunseapShares: The Anatomy of a Solar Panel*, EDP Renewables: Sunseap (May 3, 2022), https://mtvsolar.com/the-anatomy-of-a-solar-panel/ [https://perma.cc/CC33-PBB4].

69. *Id.*

protects the internal components from the elements.[70] Finally, the PV module consists of many solar cells soldered or glued together and sandwiched between a thin encapsulant to repel moisture and debris.[71] It is inside the solar cells that most of the valuable materials within a solar panel lie.[72] Most commonly, a solar cell is comprised of pure silicon, silver, aluminum, lead, and trace amounts of other elements that are placed on the cell in thin layers.[73]

However, this complex manufacturing process has not prevented countries around the world from investing heavily in solar panel production. For example, since 2010, China has added over 300,000 solar manufacturing jobs and invested over $50 billion into its solar panel manufacturing and supply chain industry.[74] Meanwhile, India has begun to invest heavily in the solar industry and spent $14.5 billion in 2021 to expand its renewable energy capacity and further its goal to create a completely domestic solar panel manufacturing and supply chain system.[75] Additionally, in 2022, the Biden administration announced a $56 million investment in solar manufacturing, and various private companies and organizations have committed billions to both the manufacturing and purchasing of solar panels in the United States.[76]

Investment in the solar industry and the production of solar panels clearly show no signs of slowing down. Consequently, it is estimated that solar panel waste could amount to 1 million tons annually by 2035 and increase to 10 million tons annually by 2050.[77] Thus, it is critical for not only the United States but governments abroad to create a

70. *Id.*

71. *Id.*

72. *See generally* Punathil et al., *supra* note 21 (showing that different materials can be derived from used solar cells).

73. *See id.* at 1.

74. INT'L ENERGY AGENCY, SPECIAL REPORT ON SOLAR PV GLOBAL SUPPLY CHAINS 7 (2022), https://iea.blob.core.windows.net/assets/d2ee601d-6b1a-4cd2-a0e8-db02dc64332c/SpecialReportonSolarPVGlobalSupplyChains.pdf [https://perma.cc/RS2T-C3K5].

75. Lauren Frayer, *'Sunny Makes Money': India Installs a Record Volume of Solar Power in 2022*, NPR (Nov. 21, 2022, 4:26 PM), https://www.npr.org/sections/goatsandsoda/2022/11/21/1138409818/sunny-makes-money-india-installs-a-record-volume-of-solar-power-in-2022 [https://perma.cc/AD92-C28D].

76. *Biden-Harris Administration Announces $56 Million to Advance U.S. Solar Manufacturing and Lower Energy Costs*, ENERGY.GOV (July 14, 2022), https://www.energy.gov/articles/biden-harris-administration-announces-56-million-advance-us-solar-manufacturing-and-lower [https://perma.cc/Q6XE-BJCW]; Andy Uhler, *U.S. Industry Group Commits to $6 Billion Solar Panel Buy—on One Condition*, MARKETPLACE (June 22, 2022), https://www.marketplace.org/2022/06/22/us-industry-group-commits-to-6-billion-solar-panel-buy-on-one-condition/ [https://perma.cc/2CN9-XB3Y]; Mack Wilowski, *First Solar to Invest $1 Billion in New U.S. Factory*, INVESTOPEDIA (Aug. 31, 2022), https://www.investopedia.com/first-solar-to-invest-1-billion-in-new-u-s-factory-6541142 [https://perma.cc/T42M-SGQJ].

77. Holger, *supra* note 20.

solar panel disposal and recycling plan to address the looming threat of solar waste.

III. Solar Panel Disposal Today

As of today, there is no organized approach toward solar panel disposal in the United States. However, several states, including California and Washington, have begun to address solar panel waste issues.[78] California has been a pioneer in the solar industry and leads the nation in solar installations and solar energy production.[79] However, its aggressive adoption of solar technology brings a new problem—what to do with the solar panels at the end of their life.[80] Similarly, Washington was an early adopter of solar energy and has passed legislation to address solar waste problems.[81]

However, these two states have chosen to address their solar waste problems differently. California reclassified solar waste from toxic waste to universal waste.[82] While this change makes transportation, storage, and disposal more accessible for Californians, it does not actually address the disposal process, nor does it encourage recycling.[83] On the other hand, Washington created a "photovoltaic module stewardship and takeback program" that requires manufacturers to establish a solar panel takeback and recycling program for panels sold within the state.[84] Washington's plan does address the root issue of solar panel disposal, but it will also result in increased costs as manufacturers must fund and operate a solar panel recycling network.[85] Regardless, these plans underscore the need to begin considering how solar waste is handled and may serve as test cases for how the United States as a whole should proceed.

Today, only about 10% of solar panels disposed of each year in the United States are recycled due to profitability issues and misaligned incentives.[86] This unfortunate reality is caused by many problems, but chief among them are: (1) the lack of a concerted effort on the state or

78. Laurie Berger, *California's Complicated Transition on Solar Panel Disposal*, Silicon Valley L. Grp. (Sept. 2, 2021), https://www.svlg.com/calif-s-complicated-transition-on-solar-panel-disposal.html [https://perma.cc/2EEB-W3LE]; Wash. Rev. Code § 70A.510.010.

79. Berger, *supra* note 78.

80. *Id.*

81. *See* § 70A.510.010.

82. Berger, *supra* note 78.

83. Rachel Kisela, *California Went Big on Rooftop Solar. Now That's a Big Problem for Landfills*, L.A. Times: Bus., https://www.latimes.com/business/story/2022-07-14/california-rooftop-solar-pv-panels-recycling-danger [https://perma.cc/55SG-VBKK] (July 15, 2022, 7:13 PM).

84. § 70A.510.010.

85. *Id.*

86. Taylor L. Curtis et al., Solar Photovoltaic Module Recycling: A Survey of U.S. Policies and Initiatives 5 (2021), https://www.nrel.gov/docs/fy21osti/74124.pdf [https://perma.cc/G2LH-73VM].

federal level to provide guidance for, or collect data on, a solar waste management framework and (2) the increased cost of recycling solar panels relative to the cost of disposing of them in a landfill.[87] Because the U.S. federal government has not provided meaningful guidance regarding solar panel recycling, states have largely been left to their own devices to determine how to manage their solar waste.[88] As of today, only a few states have addressed this problem by passing legislation to encourage or mandate solar panel recycling.[89] Many states have not addressed the problem at all, and a major reason for failing to do so is cost.[90]

Currently, it costs approximately $15–$45 to recycle a single solar panel, whereas the cost to dispose of the panel in a landfill is between $1 and $5 dollars.[91] The cost differential between recycling and landfill disposal would not necessarily be a problem if the recycling processes created products worth more than the cost of recycling. However, in the best-case scenario today, recycling procedures for solar panels involve separating the panels into their major components and crushing the glass panes into cullet—a glass powder worth about three dollars per panel.[92] Thus, subsidies and incentives are necessary to make this *current* recycling process economically viable. Unfortunately, the economic reality is that most states cannot afford solar recycling subsidies.[93] Therefore, without federal backing for solar recycling incentives, 90% of the United States' solar waste ends up in landfills.[94]

Unlike the United States, the European Union has already taken steps to address the problem of solar panel disposal with the 2012 Waste Electrical and Electronic Equipment ("WEEE") Directive.[95] The WEEE Directive establishes what it calls an "Extended Producers Responsibility" framework for solar panel disposal and gives the European Commission power to discipline non-compliant member states.[96] The Extended Producer Responsibility framework requires manufacturers of solar panels to bear responsibility for the disposal of

87. *See id.* at vi.
88. *See id.* at 4.
89. *Id.*
90. *Id.* at 9 (noting that solar panel recycling is "cost prohibitive and more expensive than disposal").
91. *Id.*
92. Casey Crownhart, *Solar Panels Are a Pain to Recycle. These Companies Are Trying to Fix That.*, MIT TECH. REV. (Aug. 19, 2021), https://www.technologyreview.com/2021/08/19/1032215/solar-panels-recycling/ [https://perma.cc/QS3T-DMLG].
93. *See* Statista Research Department, *State and Local Government Debt Outstanding in the United States in 2020, by State*, STATISTA (Oct. 21, 2022), https://www.statista.com/statistics/312660/us-state-and-local-government-debt-outstanding-by-state/ [https://perma.cc/6RAL-7ZBD].
94. *See* CURTIS ET AL., *supra* note 86, at 1.
95. *FAQ*, SOLAR WASTE/EUR. WEEE DIRECTIVE, http://www.solarwaste.eu/faq/ [https://perma.cc/5HAT-3SCV] (giving basic information on the European WEEE Directive).
96. *Id.*

the solar panels once they reach their end of life at no additional cost to the consumer.[97] This model can create profitability issues as it requires solar panel manufacturers to establish retrieval and disposal systems for every solar panel they produce.[98] Thus, the European Union provides various subsidies and incentives to make solar panel production more attractive and keep consumer prices as low as possible, thereby encouraging the adoption of solar energy.[99]

Additionally, if a member state does not comply with the Directive, the European Commission sends a formal letter requesting compliance with the WEEE Directive.[100] If that member state still fails to comply after receiving the letter, the Commission may refer the matter to the Court of Justice, which has the power to reprimand and impose penalties on the non-compliant country.[101] While the WEEE Directive has reduced the improper disposal of solar panels in the European Union, it has created additional costs and red tape for an already highly regulated industry.[102]

Participants involved in the solar panel recycling discussion often propose that the United States should adopt a similar model to the WEEE Directive.[103] However, promising solutions and advancements in the solar recycling industry offer the United States a better alternative to not only prevent a solar waste crisis but establish an economical and sustainable solar recycling industry that does not require expansive governmental incentive programs.[104]

Major solar markets outside the United States and the European Union, such as India and China, are also under threat from the looming glut of solar waste.[105] Like the United States, India boasts of ambi-

97. *Id.*

98. *Id.*

99. *See* Ogunlana & Goryunova, *supra* note 38.

100. *Infringement Procedure*, EUR. COMM'N, https://ec.europa.eu/info/law/law-making-process/applying-eu-law/infringement-procedure_en [https://perma.cc/TXB4-G8H8].

101. *Id.*

102. *See* COMM'N OF EUR. CMTYS., COMMISSION STAFF WORKING PAPER ACCOMPANYING THE PROPOSAL FOR A DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ON WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE): IMPACT ASSESSMENT 5 (2008).

103. *See* Meghan McElligott, Article, *A Framework for Responsible Solar Panel Waste Management in the United States*, 5 OIL & GAS, NAT. RES., & ENERGY J. 475, 506–07 (2020).

104. Punathil et al., *supra* note 21, at 2 (discussing a safe and cost-effective industrial process to recover 99.99% pure silicon and silver from 1 kilogram of solar cells resulting in a profit of $185.43); *Solar Cell Extraction System*, TG COS., https://www.tg-companies.com/solar-cell-extraction-system [https://perma.cc/S6DF-YAM4] (explaining the basic process of proprietary technology that allows the extraction of an uncontaminated solar cell for the recycling process).

105. Jasleen Bhatti & Swati Sharma, *Time's Running Out: Is India Ready to Handle 34,600 Tonnes of Solar Waste by 2030?*, DOWN TO EARTH (Jan. 13, 2022), https://www.downtoearth.org.in/blog/waste/time-s-running-out-is-india-ready-to-handle-34-600-tonnes-of-solar-waste-by-2030--81104#:~:text=SolarPower%20Europe%20and

tious solar installation targets but lacks any formal policy for its solar waste management.[106] Meanwhile, China, the world's largest producer of solar panels, has pledged to increase its solar recycling capacity.[107] However, China's current recycling capacity, relative to its production, is severely lacking, and no formal plan for solar panel recycling exists.[108]

The unfortunate reality is that the United States is not alone in its failure to address solar panel recycling. As a result, solar waste management is not only an issue the United States must address, but instead, a global problem that threatens the renewable industry's promise of a clean and sustainable future. However, new developments in solar panel recycling technology may provide solar-producing nations the opportunity to recycle the incoming wave of solar waste economically and efficiently.

IV. The Future of Solar Panel Recycling

The economics of the solar recycling industry will not improve unless the recycling technology used to process solar waste makes strides in both its cost to implement and its ability to effectively extract valuable materials from used solar panels. As discussed, today's recycling process is fairly unsophisticated, fails to economically extract the valuable materials from used solar panels, and can cost between $15–$45 to recycle a single panel.[109] A major reason for the industry's failure to improve the recycling process and the quality of the materials that can be recovered from used panels is the complexity of the solar panel's construction.[110] Because a solar cell consists of thin layers of various materials sandwiched between one another, recyclers either grind the entire panel into cullet[111] or process the panel with the intent to recover one specific material at the cost of losing the others.[112] Additionally, traditional material isolation processes require harsh

%20PVCycle%2C%20supported,Solar%20Energy%20Federation%20of%20India [https://perma.cc/7U56-S6KJ]; Lu Ruyi, *China to Crank up Solar Panel Recycling as Scrappage Set to Mount from 2025*, Yi Cai Glob. (Sept. 21, 2022), https://www.yicaiglobal.com/news/china-shall-promote-pv-modules-recycling-miit-says#:~:text=china%20will%20begin%20to%20produce,by%202050%2C%20the%20agency%20forecast. [https://perma.cc/UP7P-SDMR].

106. Bhatti & Sharma, *supra* note 105.

107. Ruyi, *supra* note 105.

108. *New Policy Grapples with Incoming Tide of Renewable Energy Waste*, China Dialogue (Feb. 24, 2022), https://chinadialogue.org.cn/en/digest/new-policy-grapples-with-incoming-tide-of-renewable-energy-waste/ [https://perma.cc/5Q5K-QNA5].

109. *See supra* notes 90–92 and accompanying text; *see also* Angela Youngman, *Recycling Solar Panels: A New Challenge for Going Green*, Tech Informed (Oct. 6, 2021), https://techinformed.com/recycling-solar-panels-a-new-challenge-for-going-green/ [https://perma.cc/779S-CNLF].

110. *See* Punathil et al., *supra* note 21, at 3.

111. *See* Crownhart, *supra* note 92.

112. *See* Punathil et al., *supra* note 21, at 2.

and dangerous chemicals, such as hydrofluoric acid, that not only increase the cost of recycling but also pose an environmental and health hazard.[113] However, recent developments in solar panel recycling technology offer recyclers the opportunity to eliminate dangerous processing chemicals, improve the quality of the materials recovered, and enhance the economic feasibility of solar panel recycling.[114]

To be effective, the future process of solar panel recycling must: (1) recover all value producing materials in solar panel waste, such as pure silicon, silver, lead, and aluminum; (2) eliminate the use of hydrofluoric acid as it presents both environmental and health concerns; and (3) provide recyclers with favorable economics.[115] Until recently, it seemed improbable that this triple mandate could be satisfied given the current state of recycling and the level of complexity involved in solar panel construction.[116]

However, in April 2021, solar recycling researchers began to crack the code of solar recycling layer by layer.[117] Through a series of treatments with inexpensive and manageable reagents such as sodium hydroxide, nitric acid, and phosphoric acid, combined with heat treatments, researchers successfully extracted pure silicon, silver, lead, and aluminum from a waste solar cell.[118] Additionally, the entire recycling process was conducted at low, energy-efficient temperatures within one hour.[119] Finally, the researchers found that while this method of recycling is more expensive than current recycling procedures, with a cost of $68.90 per kilogram of solar waste, the materials produced were valued at $254.32 per kilogram of solar waste.[120] This means that recyclers could enjoy a potential profit of $185.43 per kilogram of solar waste recycled when implementing this method.[121]

Not only were researchers able to satisfy the profitability concerns of solar recycling with this method, but they also effectively recovered much of the valuable material from a waste solar cell and did so without the use of hydrofluoric acid.[122] Clearly, with millions of tons of solar waste on the horizon, solar recyclers capable of implementing this recycling process on a large-scale stand to benefit handsomely.[123]

However, the future of solar recycling is not beholden to this single method of recycling. TG Companies (“TG”), a solar technology star-

113. *Id.* at 1.
114. *Id.* at 3.
115. *See id.* 1–3.
116. *See generally* D’Adamo et al., *supra* note 22.
117. *See* Punathil et al., *supra* note 21, at 1.
118. *Id.* at 3.
119. *Id.*
120. *Id.* (converting from $/kg to $/lb., this procedure would cost approximately $31.25/lb. of solar waste and produce materials worth approximately $115.36/lb).
121. *Id.* (converting to profit per lb. of solar waste, this procedure would produce a profit of approximately $84.11/lb. of solar waste recycled).
122. *See supra* note 118 and accompanying text.
123. *See supra* notes 118–21 and accompanying text.

tup focused on solar recycling solutions and backed by the National Science Foundation, claims to have developed recycling technologies that can extract all valuable components of waste solar panels to "enable a profitable business without any government support."[124] While less transparent than the previously discussed researchers, TG explains that its technology is designed to remove intact and uncontaminated solar cells using thermal decomposition.[125] TG has not publicly explained how its technology isolates the valuable materials within the solar cell but claims its patent-pending process effectively extracts silver, copper, tin, and lead.[126]

While TG's reported technological advancements could provide significant contributions to humanity's solar recycling efforts, the technology still needs several years to mature.[127] The company is still seeking investment to finance a pilot processing facility that can recycle 100,000 solar panels a year using TG's patent-pending process.[128] Additionally, experts in solar recycling do not know if TG's promises are fully achievable and suggest that the company may struggle to adapt if the material composition of solar panels changes over time.[129]

Regardless, development of solar recycling technology is taking place on the cutting edge of science. While the discussed recycling methods are not perfect, as their scalability and impact in the field have yet to be proven, they show significant promise for the future and profitability of solar recycling.[130] But to deliver on their promises, these innovations need financial support and resources. However, policymakers in the United States federal government need not create an extensive regulatory framework to provide support and resources to the solar panel recycling effort. Instead, the United States need look no further than the history of lead-acid battery recycling and the Resource Conservation and Recovery Act.

V. The Resource Conservation and Recovery Act: How Policy of the Past Influences Policy of the Future

One of the primary concerns surrounding the discussion of U.S. solar recycling policy is the regulatory and legislative avenue by which the United States will choose to address the challenges of solar panel

124. *Building a Sustainable Future*, TG Cos., https://www.tg-companies.com/ [https://perma.cc/MX4X-89NF].
125. *Solar Cell Extraction System*, *supra* note 104.
126. Maddie Stone, *Solar Recycling Is Broken, but There's a Plan to Fix It*, Verge (Dec. 29, 2021, 8:40 AM), https://www.theverge.com/2021/12/29/22857157/solar-recycling-new-better-method [https://perma.cc/6EJL-78CF].
127. *See id.*
128. *Id.*
129. *Id.*
130. *See supra* notes 117–21, 124–29 and accompanying text.

waste and recycling. While there are multiple avenues on the state and federal levels by which the solar waste crises may be addressed, the primary question is whether Congress will create an entirely new regulatory framework for solar recycling or adapt existing legislation to address this new challenge. If Congress were to use existing legislation to address solar waste concerns, that legislation would likely be the Resource Conservation and Recovery Act ("RCRA").[131]

The RCRA, passed in 1976, sought to regulate the "treatment, storage, transportation, and disposal of hazardous wastes."[132] Under the RCRA, "hazardous waste" is defined as waste that poses a risk to human health or contributes to a risk of mortality or illness when improperly treated.[133] Because solar panels can leach materials such as lead and cadmium into the environment,[134] they would clearly fall under the RCRA if it was not for the RCRA's household hazardous waste exemption.[135] This exemption allows household hazardous waste to be regulated on the state and local levels.[136] Fortunately, this issue can be easily rectified by federally reclassifying solar panel waste just as California reclassified solar waste generated within its borders.[137] Alternatively, since solar panels contain toxic materials, the 2005 EPA may specifically list solar waste as hazardous waste subject to RCRA regulations.[138]

Once properly classified and subject to RCRA regulations, solar panel waste would be tracked from its creation to its disposal using waste manifests. The Uniform Hazardous Waste Manifest is a form the 2005 EPA and the U.S. Department of Transportation require for the transport and handling of "hazardous waste for offsite treatment, recycling, storage, or disposal."[139] The manifest system creates a chain of custody that requires handlers and transporters of the hazardous waste to identify the quantity and type of waste present and acknowledge receipt of the waste.[140] Ultimately, the final recipient of the waste must provide a final copy of the manifest to the waste genera-

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131. *See generally* Resource Conservation and Recovery Act of 1976, Pub. L. No. 94-580, 90 Stat. 2795 (providing for the recovery of energy and other resources from discarded materials).

132. *Id.* at § 1003(4).

133. *Id.* at § 1004(5)(A)–(B).

134. *See* Atasu et al., *supra* note 11.

135. *Household Hazardous Waste: Regulating HHW*, U.S. ENV'T PROT. AGENCY, https://www.epa.gov/hw/household-hazardous-waste-hhw#:~:text=although%20household%20hazardous%20waste%20is,the%20state%20and%20local%20level [https://perma.cc/84TS-UKC4].

136. *Id.*

137. Berger, *supra* note 78.

138. 40 C.F.R. § 261.30–.31 (showing the extensive lists and categories of hazardous waste recognized by the 2005 EPA).

139. *Hazardous Waste Manifest System*, U.S. ENV'T PROT. AGENCY, https://www.epa.gov/hwgenerators/hazardous-waste-manifest-system [https://perma.cc/494E-KT5X] (Feb. 11, 2023).

140. *Id.*

tor, in this case, solar panel manufacturers, as confirmation that the waste has reached the proper facility.[141]

However, participants in the solar waste conversation often argue that adaptation of the RCRA would not sufficiently address the looming threat of solar waste due to the complexity of the challenge and the reality that much of the electronic waste subject to RCRA regulations today ends up in landfills.[142] Additionally, while the manifest system would allow both the federal government and solar waste generators to understand where their waste ultimately goes, this system alone does not necessarily facilitate or require solar waste recycling.[143] However, these arguments fail to take into account the historical use of the RCRA to successfully encourage and improve the recycling of hazardous waste in the past and the newfound economic opportunities present in solar recycling that would encourage solar manufacturers and third parties to engage in solar recycling.[144] Rather than look to the RCRA as a complete solution for solar recycling, the federal government should use the RCRA as a tool to assist states in taking the necessary steps to encourage solar recycling within their borders. Such a solution allows the federal government to provide resources and support while giving states the freedom to craft their own unique solutions.

Interestingly, the recycling success story of the lead-acid battery (encouraged by the RCRA and cooperation between federal, state, and local governments) could serve as a model for the solar recycling industry of tomorrow. Between 1960 and 1984, the percentage of spent lead-acid batteries recycled in the United States fluctuated wildly as the incentive to recycle was heavily dependent on the price of lead at any given time.[145] During this time, lead-acid battery recycling rates reached as low as 61%, and most spent lead-acid batteries that were not recycled were disposed of in landfills.[146] This presented an environmental concern given the large quantity of lead and other hazardous materials lead-acid batteries contain.[147] While the environmental damage associated with lead-acid batteries concerned various governmental entities and environmental organizations, profitability concerns and policy challenges made achieving a

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141. *Id.*

142. *See generally* McElligott, *supra* note 103.

143. *Id.*

144. *See generally Hazardous Waste Manifest System*, *supra* note 139.

145. U.S. ENV'T PROT. AGENCY, STATES' EFFORTS TO PROMOTE LEAD-ACID BATTERY RECYCLING 11 (1991).

146. *Id.*

147. Lea Unterreiner et al., *Recycling of Battery Technologies—Ecological Impact Analysis Using Life Cycle Assessment (LCA)*, 99 ENERGY PROCEDIA 229, 233 (2016), https://doi.org/10.1016/j.egypro.2016.10.113 (listing a table of the materials found in a typical lead-acid battery broken down by percentage of total weight).

consistent level of lead-acid battery recycling difficult.[148] However, through a series of policy changes implemented in many states by 1991, the percentage of spent lead-acid batteries recycled in the United States increased by 35%.[149]

Ultimately, by leveraging the RCRA and increasing cooperation between state and federal governments, the United States began recycling 95% of the spent lead-acid batteries generated each year by the early 1990s.[150] More specifically, by 1991, 34 states, with the help of federal resources, passed legislation to encourage lead-acid battery recycling.[151] The majority of state legislation included provisions that banned lead-acid batteries from municipal landfills, compelled retailers and battery manufacturers to accept spent consumer batteries, and required retailers to post state requirements to educate consumers.[152] Some states went as far as to charge consumers an additional fee for failure to return a spent lead-acid battery to a retailer when purchasing a new one.[153] Likewise, the federal government did its part by increasing environmental protections,[154] identifying model legislation for states to implement,[155] and allocating resources to assist states in implementing recycling legislation and monitoring the lead-acid battery recycling chain.[156] Ultimately, the 2005 EPA found that state takeback provisions established for lead-acid batteries played a major role in improving lead-acid battery recycling rates.[157] These provisions allowed consumers to easily return spent batteries to retailers when purchasing a new one, and in turn, retailers entered the spent batteries into the recycling stream.[158]

Fortunately, lead-acid batteries and solar panels share many characteristics that allow commonalities between the policies of the past that improved lead-acid battery recycling and policies of the future that are required to address the coming solar waste crisis. Specifically, solar panel classification under the RCRA would allow the federal government to assist states in solar waste regulation and would require implementation of the RCRA manifest system. Additionally, the high

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148. *See generally* U.S. ENV'T PROT. AGENCY, *supra* note 145 at 11 (discussing the lead-acid battery recycling industry and the challenges to maintaining a consistent level of lead acid battery recycling).

149. *Id.* at 3.

150. *Id.*

151. *Id.* at 4.

152. *Id.*

153. *Id.*

154. James Morton Turner, *Recycling Lead-Acid Batteries Is Easy. Why Is Recycling Lithium-Ion Batteries Hard?*, CLEANTECHNICA (July 24, 2022), https://cleantechnica.com/2022/07/24/recycling-lead-acid-batteries-is-easy-why-is-recycling-lithium-ion-batteries-hard/ [https://perma.cc/86E2-46BX].

155. U.S. ENV'T PROT. AGENCY, *supra* note 145, at 22.

156. *Id.* (summarizing industry data and providing information related to the lead-acid battery recycling industry).

157. *Id.* at 5.

158. *Id*.

level of consumer dependence on solar manufacturers and installers is ripe for the establishment of takeback programs like those established for lead-acid batteries.[159] For instance, most consumers seeking to install or replace solar panels on the roofs of their homes or businesses are reliant on solar manufacturers and installers.[160] This point of contact between consumers and solar retailers is critical for the establishment of solar takeback programs like those found with lead-acid batteries.[161] However, it is up to states to take advantage of this point of contact and encourage consumers to give their spent solar panels to solar installers who, in turn, place the junk panels into the solar recycling stream.

This system, which has already found success with lead-acid batteries, coupled with the promising innovations in solar recycling technology discussed earlier in this Comment will likely create economic incentives for manufacturers and third parties to establish recycling facilities and supply chains. Failure to do so will likely result in the loss of a competitive edge and amount to manufacturers or recyclers leaving money on the table. These incentives combined with state legislation like that passed for lead-acid batteries[162] would likely increase solar recycling rates drastically and protect taxpayers from a substantial financial burden in the form of solar recycling subsidies. However, to make this future a reality, both state and federal governments must cooperate to increase investment in the solar recycling space and implement effective policies that encourage recycling without overburdening producers and consumers. Fortunately, this challenge, while unique, is not unprecedented, and the success story of lead-acid battery recycling can become the success story of the solar recycling future.

VI. The Solar Recycling Network of Tomorrow

Ideally, the future solar recycling network will require virtually no governmental support and little to no action on behalf of the consumer. Such a scenario would prevent governmental bloat, avoid significant expenses to taxpayers, and would not place burdensome responsibilities on consumers. Convenience for the consumer is critical to the success of solar panel recycling efforts, as increased respon-

159. *Id.*

160. *See generally Sunrun Retains Its Title as the Largest Residential Solar Installer in the U.S.*, Wood Mackenzie (Mar. 31, 2021), https://www.woodmac.com/news/opinion/sunrun-retains-its-title-as-largest-residential-solar-installer-in-the-us [https://perma.cc/W7B4-43VR] [hereinafter *Sunrun*].

161. *See generally* U.S. Env't Prot. Agency, *supra* note 145, at 3, 5 (establishing that consumer participation is important for a recycling program).

162. *See supra* note 145 and accompanying text.

sibility or requirements on consumers would likely lead to confusion and reduced recycling rates.[163]

However, as presented in this Comment, avenues exist by which spent solar panels can be removed, transported, catalogued, and recycled, all with virtually no effort on behalf of the consumer.[164] Instead of relying on consumers, new and promising solar panel recycling technologies present the possibility of a future where manufacturers and third parties will be economically incentivized to recycle solar panels simply due to the value of the recoverable materials inside of spent solar panels.[165] So the question becomes—what might the solar panel recycling network of the future look like, and what will be the roles of the federal government, state governments, and private industry?

To answer this question, it is helpful to look at the history of the RCRA and the interactions between the federal government, state governments, and private industry during joint recycling efforts. Fortunately, we need not look much further than the success of the lead-acid battery recycling effort.

Ideally, the federal government's role would be limited to two primary functions: (1) creating and awarding research grants to encourage and support the further development of solar panel recycling technologies and (2) advising states by tracking and compiling recycling data to determine the most effective recycling policies and legislation.[166] These functions are not new to the federal government and were not only used to encourage lead-acid battery recycling but are used routinely today.[167] In the 1990s, the federal government leveraged the RCRA to encourage lead-acid battery recycling by providing funding support, research reports, and regulatory recommendations to the states.[168] Additionally, the Uniform Hazardous Waste Manifest required by the RCRA allowed both the federal government and states

163. *See* Blake Morgan, *Why Is It So Hard to Recycle?*, FORBES (Apr. 21, 2021, 11:00 AM), https://www.forbes.com/sites/blakemorgan/2021/04/21/why-is-it-so-hard-to-recycle/?sh=62fe2a783b77 [https://perma.cc/5PTS-MTB7] (finding that the top reason Americans do not recycle regularly is a lack of convenient access).

164. *See supra* note 159 and accompanying text.

165. *See supra* notes 120–21 and accompanying text (discussing new solar panel recycling technologies that could allow solar recyclers to run a profitable business model).

166. *See supra* notes 154–56 and accompanying text (discussing the federal government investment and support in lead-acid battery recycling).

167. *See Biden-Harris Administration Announces Nearly $74 Million to Advance Domestic Battery Recycling and Reuse*, *Strengthen Nation's Battery Supply Chain*, DEP'T OF ENERGY, (Nov. 16, 2022), https://www.energy.gov/articles/biden-harris-administration-announces-nearly-74-million-advance-domestic-battery-recycling [https://perma.cc/PJ55-DXWE] [hereinafter *Biden-Harris Administration*]; *see also* U.S. ENV'T PROT. AGENCY, *supra* note 145 at 7 (a research report produced by the United States Environmental Protection Agency that compiles lead acid battery recycling data and discusses successful state policies and procedures).

168. *See* U.S. ENV'T PROT. AGENCY, *supra* note 145, at 7.

to understand where lead-acid battery waste was being generated, who was handling the waste, and where it ultimately was disposed of.[169]

By applying the lead-acid battery success story to solar panel recycling, we can deduce that in a similar solar panel recycling network, the federal government would employ the RCRA's waste manifest system and create solar panel recycling research grants.[170] By utilizing the RCRA's waste manifest system, the federal government could provide states with reliable data on solar panel waste generation, transport, and disposal, just as it did with lead-acid battery waste data.[171] This data would be used to inform state policy to address solar panel waste management. Additionally, just as the federal government has provided funding to support the research and infrastructure behind the battery supply chain and recycling effort,[172] it should provide research grants for further development of solar panel recycling technology.

However, one may argue that to adequately address the solar waste problem, the United States should follow the European Union and establish a uniform solar recycling framework to which all states must adhere.[173] While this solution may lead to the increased recycling of junk solar panels, it ignores the success of past recycling efforts without an expansive federal recycling framework while incurring significant costs.[174] Furthermore, a purely federal solution for solar panel recycling is unlikely to adequately recognize the unique nature of each state. For instance, the effectiveness and usable life duration of solar panels depends heavily on geographical location.[175] Temperature, humidity, and light intensity are just a few factors that affect the performance of solar panels.[176] As a result, the different geographical locations and climates of different states will directly affect state recycling policy as the unique environmental circumstances of each state will affect solar panel effectiveness and usable life.[177] Thus, due to the

169. *Hazardous Waste Manifest System*, *supra* note 139.

170. *See supra* notes 150, 154–56 and accompanying text (discussing the federal government's use of the RCRA and support of the lead-acid battery recycling effort).

171. *See* U.S. ENV'T PROT. AGENCY, *supra* note 145, at 7.

172. *Biden-Harris Administration, supra* note 167.

173. *See* McElligott, *supra* note 103, at 506–07 (arguing that the United States should adopt the WEEE).

174. *See supra* notes 102, 150 and accompanying text.

175. *See* Osman Abdeen et al., *The Impacts of the Geographical Location on the Performance of PV System—Skikda in Algeria and Atbara in Sudan: Case Study*, 10 INT'L J. OF RENEWABLE ENERGY TECH. 328, 345 (2019), http://dx.doi.org/10.1504/IJRET.2019.10023910.

176. *Id.* at 335.

177. *See* Benjamin Mow, *STAT FAQs Part 2: Lifetime of PV Panels*, NAT'L RENEWABLE ENERGY LAB'Y (Apr. 23, 2018), https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html [https://perma.cc/WR9V-EZB7]; *see also* NAT'L RENEWABLE ENERGY LAB'Y, OVERVIEW OF FIELD EXPERIENCE – DEGRADATION RATES & LIFETIMES 4 (2015).

myriad of degradation rates and efficiencies experienced in different climates, states will have varying recycling timelines and employ various quantities of solar panels to achieve energy generation goals.[178] These differences are significant, and thus will likely affect which recycling policies and procedures are effective within each unique state. Consequently, it is important to give states deference on how they choose to address the solar panel recycling issue within their borders and limit the federal government's role to one of advisement and support.

With this understanding of the federal government's role within the solar panel recycling framework proposed in this Comment, it is important to discuss how states may encourage solar panel recycling within their borders. The 2005 EPA found that state-established takeback programs were one of the most effective policy tools for moving spent lead-acid batteries into the recycling stream.[179] The pieces to establish similar takeback programs for junk solar panels are already in place within the solar industry. For instance, most retail consumers rely upon solar panel installers for the installation and removal of solar panels.[180] Additionally, solar panel installers rely on manufacturers to supply them with panels and thus already have an existing relationship. These points of contact between consumers, installers, and manufacturers are analogous to the points of contact in the lead-acid battery industry.[181] However, in the case of solar panels, recycling can be even more convenient for the consumer because, unlike lead-acid batteries, consumers do not have to take spent solar panels to a retailer or manufacturer. Instead, solar panel installers come to consumers' homes and businesses to remove old panels and replace them with new ones.[182] These types of programs create convenience for consumers and thereby lead to greater recycling rates.[183]

Takeback programs are just one avenue by which states may choose to encourage solar panel recycling within their borders. Just as states banned lead-acid batteries from their landfills and instituted penalties for failure to return a spent-lead acid battery when purchasing a new one,[184] states may choose any number of methods by which to encourage solar panel recycling. However, states may be able to avoid drastic regulatory measures thanks to the recycling technologies dis-

178. *See generally id.*

179. *See* U.S. ENV'T PROT. AGENCY, *supra* note 145, at 5.

180. *See generally Sunrun*, *supra* note 160.

181. *See* U.S. ENV'T PROT. AGENCY, *supra* note 145, at 5–6.

182. *See generally SEIA National PV Recycling Program*, SOLAR ENERGY INDUS. ASS'N, https://www.seia.org/initiatives/seia-national-pv-recycling-program [https://perma.cc/YR9T-C4LV] (establishing that some installation companies have takeback programs for their solar panels).

183. *See* Morgan, *supra* note 163 (explaining that the main reason Americans do not recycle more is lack of convenience).

184. *See* U.S. ENV'T PROT. AGENCY, *supra* note 145, at 7.

cussed in this Comment.[185] While states may need to push the solar recycling industry to move forward, the value of the recoverable materials inside junk solar panels may do most of the encouraging for them.[186]

With further investment in solar panel recycling technology and improvements in economic viability, it is possible that private industry may begin building a solar panel recycling network on its own.[187] As of today, even with solar recycling profitability issues, private organizations are choosing to recycle solar panels as a matter of principle.[188] With this in mind, it is quite likely that environmental organizations, current solar recyclers, and even industry players simply seeking to create a sustainable business would initiate or expand solar panel recycling operations as new technologies emerge that improve solar recycling profitability.

Ultimately, just like the lead-acid battery recycling network, the solar panel recycling network of tomorrow will likely require cooperation between the federal government, state governments, and industry participants.[189] However, by learning from the success of the past and implementing the recycling technology of the future, the United States can create a solar panel recycling network that is both economically viable and environmentally conscious.

VII. Conclusion

To usher in a renewable energy era in the United States, the federal government, state governments, and industry players must cooperate to create a solar panel recycling framework that adequately addresses the looming solar waste problem.[190] However, neither the federal nor state governments should set out to create a new regulatory framework from scratch. Instead, leaders and policymakers need only look to the success story of lead-acid battery recycling[191] and the legislation and policies that made the lead-acid battery recycling effort so successful. By modeling solar panel recycling initiatives after the legislation and policies proven to successfully address lead-acid battery recycling,[192] the United States would not only be likely to substan-

185. *See supra* notes 120–21 and accompanying text (discussing new solar recycling technologies that could offer recyclers the opportunity to run profitable solar recycling businesses).

186. *See* Punathil et al., *supra* note 21.

187. *See End-of-Life Management for Solar Photovoltaics: Recycling*, Solar Energy Indus. Ass'n (Jan. 2020), https://www.seia.org/sites/default/files/2020-11/SEIA-Recycling-Program-Factsheet-January%202020%20final.pdf [https://perma.cc/UJ8C-JTY8].

188. *See id.*

189. *See supra* note 150 and accompanying text.

190. *See* Atasu et al., *supra* note 11 (explaining that millions of tons of solar waste per year are on the horizon).

191. *See supra* notes 145–50 and accompanying text.

192. *See supra* notes 150–51 and accompanying text.

tially increase solar panel recycling rates but also avoid burdening taxpayers with expensive subsidy programs.

By leveraging the RCRA, the federal government can assist states in implementing and enforcing solar recycling policies that encourage solar panel manufacturers and third parties to invest in a solar recycling network. However, just as taxpayers should not be forced to support a sweeping solar recycling subsidy plan, manufacturers and third parties should not be required to build out recycling networks without any support. Thus, rather than focus solar recycling funds on subsidies, both the federal and state governments should shift investment to the promising solar recycling technology discussed in this Comment.[193] Improvement in the functionality and scalability of this technology presents the opportunity to not only make solar recycling economically feasible but also fiscally and environmentally attractive.

Today, solar panel recycling is inefficient, wasteful, expensive, and inadequate.[194] If the federal government were to enact sweeping legislation and subsidies for the solar recycling industry, as some have suggested,[195] the United States would be reinforcing the ineffective solar recycling system it uses today.[196] Instead of relying on taxpayers to shoulder the burden of subsidizing the solar recycling industry, policymakers and government officials, both on the state and federal levels, should look to invest in innovative recycling technologies and utilize lessons learned from the success of lead-acid battery recycling. Such an approach not only advances the solar panel recycling network of today, but also informs the legislation and policies that will build the solar panel recycling network of the future.

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193. *See supra* notes 120–21 and accompanying text (discussing new solar recycling technologies that could offer recyclers the opportunity to run profitable solar recycling businesses).

194. *See supra* notes 90–91 and accompanying text.

195. *See* McElligott, *supra* note 103, at 511–12.

196. *See supra* notes 86, 91 and accompanying text (noting that only 10% of waste solar panels in the United States are recycling for 15–45 dollars per panel).