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Solar Ready:  
Harmonizing the Solar Ready Scope for  
Safer & more productive Solar Deployments

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**Abstract**

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A Solar Ready building is one that is engineered for future adaptation of solar PV. This thesis reviews the literature of existing Solar Ready standards and analyzes the solar installation process with the goal of proposing an ideal standard for future implementation. An analysis of the work processes performed during solar system installation identifies those work packages that are suitable for pre-installation within the scope of new construction. The installation process is a composite of several specialty building trades including: electrical, roofing, carpentry and IT; thus exposing workers to a unique array of hazards. Non-solar workers operating on rooftops can be subjected to hazards that may be magnified by the presence of a rooftop solar system. Since the Solar Ready scope can dictate the economic and safety characteristics of a solar system, it should be implemented using an evidence-based approach for maximum impact. The research includes a review of renewable energy policies including incentives, mandatory building codes and voluntary green building certifications; analysis of solar installation work processes and costs as well as a review of policy cases. The resulting model Solar Ready scope is validated through a survey questionnaire and informal interviews.

- Review of existing policies
- Characterizing the qualitative benefits of Solar Ready (Economic, Productivity, Safety)
- Analyzing the installation work process to recommend a model for future policies
- Verifying the results through surveys and interviews
- Discover previously unidentified benefits
- Identify potential issues or unintended outcomes

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## GLOSSARY

AC: Alternating current, a form of electricity with cycling direction of charge and distributed by electrical utilities to buildings.

AHJ: Authority having jurisdiction, can refer to any of the local authorities that review permit applications and inspect construction projects.

ANTI-ISLANDING: A standard for the operation of DERs whereby operation must cease within a maximum time period (<2 seconds) upon detection of an anomaly in the electrical grid.

BOS: Balance of system, referring to the components in a PV system that are needed to complete the installation of other components (PV modules, mounting system, inverter, conductors). These are not specified in the design. E.g.: nuts, bolts, washers, etc.

CBECS: Commercial Buildings Energy Consumption Survey, a comprehensive dataset by the US Department of Energy

C&I: Commercial and Industrial, referring to non-residential building types within the solar market.

CONDUIT: A raceway or conduit is an enclosure for electrical wiring.

DC: Direct current, a form of electricity with constant flow in one direction and generated by PV panels.

DER: Distributed energy resource, herein used interchangeably with DG.

DG: Distributed generation, herein used interchangeably with DER.

EV: Electric vehicles, herein used in the context of EV-charging.

FERC: Federal energy regulatory commission, the federal body that regulates inter-state electrical commerce.

GRID-PARITY: A point in time in which the LCOE from renewable DERs is equal to or less than the cost of electricity purchased from the utility. This varies by market and geographic region.

GRID-TIED: A mode where a renewable DG operates in synchrony with the utility grid and can export excess generation to the utility grid.

ICC: International code council, a body that publishes building codes on a 3 year cycle. These are modified and adopted by local jurisdictions.

INVERTER: Solar system component that converts DC electricity from PV panels to AC electricity for use in a building.

INTERCONNECTION: Can refer to the process or the specific location within the electrical system, where a DG system makes physical contact with the utility grid.

INSOLATION: The average cumulative solar radiation measured on a  $m^2$  area over the course of a year. Units are  $\text{kWh}/m^2/\text{day}$ .

ITC: Investment tax credit, a tax credit (in the US) available to renewable energy systems owners.

KW: Kilowatt, a unit of measure for power equivalent. Often used to denote the generating capacity of an PV generator.

KWH: Kilowatt hour, a unit of measure for energy equivalent. Used to measure consumption (and production) of energy.

LCOE: Levelized cost of energy, the total cost per unit (kW-hr) of energy amortized over the lifetime of the energy generator.

NEC: National electric code, published by the NFPA on a 3 yera cycle, is the electrical code that is modified and adopted by local jurisdictions.

NEM: Net energy metering

NFPA: National fire protection association, a body that publishes fire codes that are applied to various industrial sectors.

NREL: National Renewable Energy Laboratories

OCPD: Over-current protection device, or “breaker”, is a device that “opens” or disconnects an electrical current, safeguarding from excessive current draws that can lead to fire.

PURPA: Public utility regulatory policies act (1978), federal law that regulates utilities and promotes domestic energy production and energy-efficiency.

PV: Photovoltaic

SERVICE PANEL: The electrical service panel contains OCPDs or “breakers” that safeguard electrical circuits within a building. The terms *service panel*, *main*

*service panel* and *electrical service panel* are used interchangeably throughout this text, although technically they can specify different components within the electrical system.

SI: Silicon, a semiconductor element that is the main component of photovoltaic cells.

SOLAR ARRAY: An array of multiple strings of solar modules. The terms *solar array*, *solar electric system* and *solar system* are used interchangeably throughout this text.

SOLAR MODULE: Another name for a solar panel, consisting of multiple solar cells connected in series, encapsulated between glass, polymer film and set in an aluminum frame.

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## DEDICATION

To my grandmothers Barbara & Carmelina,  
who have been an endless source of inspiration, love and support.

## Chapter 1

# INTRODUCTION

### **1.1 Background**

The first solar cell was patented in 1941 by Russell Ohl at Bell Labs in New Jersey. By sandwiching two thin layers of refined silicon crystal, each “doped” with a concentration of either phosphorous or boron, the resulting semiconductor composite demonstrated a photoelectric effect. This prototype solar photovoltaic *PV* cell exhibited an electric potential across the boundary between the varying layers of silicon, the P-N junction.[1]. It was not until the 1970’s that standardized “flash-testing” of solar PV cells to determine electrical characteristics such as internal resistance, open circuit voltage and short-circuit current would become a standardized process. [2] It is estimated that Ohl’s cell had a light-to-electricity conversion efficiency of only 0.5%. High production cost and low efficiency meant that PV cells would have no practical applications for the foreseeable future.

As conversion efficiency slowly improved, costs remained prohibitive for all but the most specialized applications. Remote railroad switching operations, satellites and even as cathodic protection on oil and gas pipelines were among the few applications where a critical need for electrical power coupled to the remoteness of the site made PV a feasible source of power. [3]. With time, manufacturing advances led to gains in power conversion efficiency and reduced costs. At present, cells with efficiencies approaching 21% efficiency are in production. [4]

For much of the 20th century the notion that an array of aluminum-framed panels containing glass and composite semiconductor cells joined in series could one day

generate enough energy to power entire buildings was limited to the realm of science fiction. Presently millions of homes, commercial and industrial businesses, schools, places of worship and government halls are hosts to such solar systems. As the costs of installing PV have reached a point where they are financially attractive for building occupants with adequate exposure to the sun, most new construction projects will consider adding a functioning solar electric system to the scope of construction. Solar PV is marketed as an income-producing asset with a payback period; income is received by the building occupant indirectly as electricity bill savings. A project developer will not realize a return on investment and may choose not to include solar in the original project scope. The solar PV system is a building system that is among the last to be installed during the final stages of the construction phase. Budgetary constraints or cost-overruns during earlier project phases may lead a project owner to elect not to invest in PV. As a non-essential component, it can be added at a future point in time. Hence the emergence of the concept "Solar Ready."

## **1.2 Solar Ready**

Lisell, Tetreault and Watson define the concept as "A solar ready building is engineered and designed for solar installation, even if the solar installation does not happen at the time of construction." [5] Installing a solar PV system during the construction phase offers numerous material benefits. The building rooftop is designed to accommodate a solar PV array optimized for the building's estimated energy demands. Conductors and control cables can be integrated into a dedicated chase, eliminating the need for metallic conduits attached to the building exterior. Points of interconnection where the electricity from the solar system is fed into the building are appropriately specified and the entire electrical system is designed with the optimal safeguards in mind. Aside from advantages in the engineering and aesthetic design of integrating a PV system during the construction phase, Solar Ready provides an opportunity to eliminate hazards that solar installation workers would otherwise face.

Installing rooftop PV systems is unique in that it combines a range of tasks that traditionally fall under the domains of other specialty contractors. Roofing and waterproofing, electrical work, carpentry and even information technology are skilled trades that the solar contractor must master to successfully install a PV array. Each of these presents many hazards in its own right and requires training, hazard analysis, safety protocols, personal protective equipment and appropriate tools to be carried out safely. Falls, being struck-by a falling object and electrocution are the leading causes of construction workplace injuries. Rooftop solar installers face all three on a daily basis.

In some instances, all or part of the solar installation tasks are performed by specialized contractors respective to the task. These solar tasks included in the new construction scope present a marginal fraction of the specialty contractor's total scope within a project. More importantly, solar tasks performed during a new construction phase are performed under working conditions that mitigate solar installation hazards. Solar installation hazards that are created or amplified due to the conditions specific to a retrofit installation are eliminated. With some precaution, a Solar Ready scope would include safety elements that further mitigate the hazards present to solar contractors through all phases of the solar PV system lifetime; installation, commissioning, operations & maintenance, then finally decommissioning and recycling.

### ***1.3 Research Objectives and Overall Methodology***

Solar Ready promises to reduce the initial capital investment required for adopting a PV system and streamline the installation process on the building rooftop. Several jurisdictions across the US have adopted Solar Ready standards for new construction projects, both for residential and commercial building types. Solar Ready policies vary in their form and scope; these regulations are not harmonized. Some are limited to providing a clear rooftop space capable of housing solar panels. Others include structural, electrical and specific items to be included in the building construction

documents. Unfortunately, no Solar Ready standards to date take into account any of the hazards inherent to installing rooftop PV systems at height.

The thesis research includes a review of existing Solar Ready literature and analysis of existing policies. Indirect studies pertinent to green building, the macroeconomic effects of solar or renewable incentives and prevention through design are included in the review to provide a foundation for contextualizing the research. The review is organized into three sections, focusing on the administrative (Chapter 2), economic (Chapter 3), and safety (Chapter 4) dimensions of said policies.

Specifically, Chapter 4 relies heavily on prior research that provides a prevention through design framework for residential solar installers. The work process is analyzed for design dependencies among PV system components. Those components that exhibit independence with respect to the final PV system design are proposed as features to be included in future iterations of Solar Ready building standards. In Chapter 5, this proposed scope is validated through a survey questionnaire answered by practicing professionals that work as specialty solar and electrical construction contractors, designers, energy professionals and nonprofit organizations. Among the survey takers, some have provided additional insights through an informal interview or discussion with the author; the abstract of some of these interviews is provided throughout chapter 5. Chapter 6 contains the conclusions of this thesis research and provides recommendations for future investigations.

#### ***1.4 Market Classification and Scope of Research***

This section will describe how the solar industry within the US is segmented and why the scope of this work falls within the retail (specifically residential) segment. In the U.S., the solar electric market can be divided into various segments (see Figure 1.1), characterized by the contractual parties privy to the solar electric asset and the “off-taker” or buyer of the electrical energy that is produced. Wholesale suppliers feed electricity directly into a transmission network; the electricity is delivered wholesale.

While the majority of these resources are developed by solar developers specializing in multi-acre solar farms and referred to as utility scale there are also smaller community-solar PV arrays. These are comparatively smaller in capacity and financed by multiple parties. The typical model of capitalization in a community-solar project is where an electric utility customer is able to purchase shares of the system's capacity, in exchange for "clean energy" credits. This model allows electric utility customers to buy renewable energy when they otherwise might not have been able to install solar on their own dwelling. A community-solar PV system could be composed of a single or multiple rooftop PV arrays.

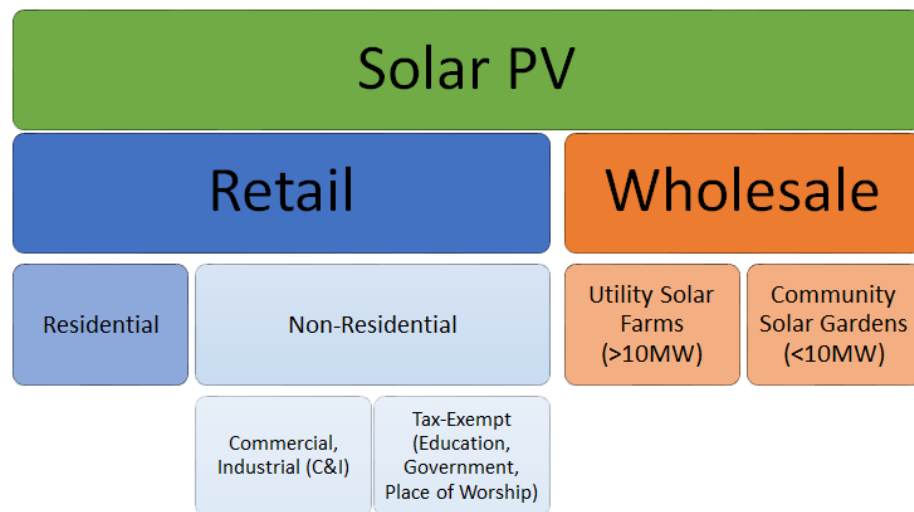


Figure 1.1: Hierarchy of Solar PV market segments

The retail segment is as diverse as the classifications that span the built environment. Solar contractors that install PV systems do not discriminate amongst residential, commercial, industrial, municipal and other building types. The scale of each solar generator will vary depending on the footprint of the underlying building. Within this study,

Commercial buildings include all buildings in which at least half of the

floorspace is used for a purpose that is not residential, industrial, or agricultural. By this definition, CBECS includes building types that might not traditionally be considered commercial, such as schools, hospitals, correctional institutions, and buildings used for religious worship, in addition to traditional commercial buildings such as stores, restaurants, warehouses, and office buildings. [6]

The convention within the solar industry serving the retail market segment has been to refer to the Residential, Commercial and Industrial *C&I*, or Tax-Exempt for those buildings under ownership of an entity with tax-exempt status. Tax incentives have a significant role in financing solar projects. The Investment Tax Credit (for business) is a credit up to 30% of the system cost, and there are others such as depreciation. Tax-exempt status may reduce the value of such incentives.

Solar Ready proves to be an effective tool for the new construction of all building types with good solar insolation. But there is scant mention of the non-residential sector in the Solar Ready literature, making the residential sector a more accessible target for meaningful discussions. So while the policy review (Chapter 2) covers both residential and non-residential sectors and Chapter 4 explains how safety measures may differ between residential and non-residential rooftops, the scope of this thesis is limited to the residential sector.

## REFERENCES

- [1] W. (Wolfgang) Palz. *Power for the world : the emergence of electricity from the Sun*. Pan Stanford Pub, 2011. ISBN: 9789814303385.
- [2] William M Keogh, Andrew W Blakers, and Andres Cuevas. “Constant voltage I–V curve flash tester for solar cells”. In: *Solar Energy Materials and Solar Cells* 81.2 (2004), pp. 183–196. ISSN: 0927-0248. DOI: <https://doi.org/10.1016/j.solmat.2003.11.001>. URL: <http://www.sciencedirect.com/science/article/pii/S0927024803002411>.
- [3] Galberth; Robert L, Arnold; Roy L, and Bollinger; John C. “Power output control circuit for solar-powered cathodic protection system”. Jan. 1979. URL: <http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PT01&Sect2=HITOFF&p=1&u=/netahtml/PT0/search-bool.html&r=1&f=G&l=50&d=PALL&RefSrch=yes&Query=PN/4136309>.
- [4] *2018 Most Efficient Solar Panels on the Market — EnergySage*. 2018. URL: <https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/> (visited on 06/26/2018).
- [5] Andrea Watson et al. *Solar ready : an overview of implementation practices*. eng. NREL/TP ; 7 A 40-51296. Golden, Colo.: National Renewable Energy Laboratory, 2012.
- [6] *About the Commercial Buildings Energy Consumption Survey (CBECS)*. 2012. URL: <https://www.eia.gov/consumption/commercial/about.php> (visited on 07/05/2018).

## Chapter 2

### LITERATURE AND POLICY REVIEW

The intent of a Solar Ready scope is to facilitate later adoption of solar electric systems. An effective Solar Ready scope has the potential to reduce the costs of a solar PV system, eliminate or reduce time spent in confined and otherwise hazardous spaces, and reduce time spent at heights and provide well-designed fall protection. A review of the literature reveals scant peer-reviewed sources on Solar Ready. Instead, there are many studies on the economic impacts of incentives for developing solar PV and renewable energy resources. These have been a guiding force in the proliferation of rooftop solar PV systems in the US and in advanced economies across the globe. On a smaller scale, local building codes dictate many aspects of the design and installation of those systems.

A successful Solar Ready guideline for new construction will deliver safer, more efficient deployment of solar electric generation. In order for Solar Ready to reach a broad scope of new construction projects and successfully deliver on the five dimensions that comprise Solar Ready: rooftop, siting, electrical, safety and interconnection; two questions must be answered. The first, to what extent of design should the five dimensions be implemented into the Solar Ready scope? The second, what form of policy will motivate building developers to implement Solar Ready practices?

This chapter is a review of the policy instruments that are directly related to Solar Ready design and implementation. Policies are identified in three formats including financial incentives, technical resources and regulatory standards. The review presents prior policy in green building standards, renewable energy incentives and building codes for rooftop solar construction as precedents in the development of Solar Ready

policies.

Government investment in R&D plays a significant role in developing new technologies and achieving cost reductions. R&D and technical assistance instruments are not covered within this review. The review includes Solar Ready and related policies found across the United States. Policies found outside the US are included when details of the policy itself or the context of its implementation contribute to the research.

Solar Ready as expressed through the diverse policy instruments under review can include different components. A later part of this research will present a comprehensive reference list of Solar Ready features applicable to any building type. When properly defined, implemented and validated, the benefits of Solar Ready can easily be transformed into a turnkey solar asset capable of generating clean renewable energy.

### **2.1 Green Building Codes: A model for 3rd party validation**

An efficient method of validating the Solar Ready scope may be helpful if problems in the quality of a Solar Ready scope inhibit the goals of safer, more efficient solar installations. Such a validation with issuance of a Solar Ready certificate might also serve the purpose of documenting the scope of improvements made with the expectation of realizing future savings when “upgrading” to a complete PV system. Hence one aim of the policy review is to bring to discussion the question of whether there is a need for a third-party to certify the Solar Ready scope on a new construction.

In considering the question, *what is the motivation to implement the Solar Ready features in new construction* and ultimately the solar electric installation, the following is an overview of the development of Green Building standards. Standards for Green Buildings are categorically independent from government policy. Instead, they are largely self-regulated by non government organizations like the US Green Building Council *USGBC* in the US or the German Green Building Council in Germany.

Kibert (2016) traces the advent of green building standards as a response to the need for clear definitions of what constitutes a green building and “how to determine if a building meets the requirements of this definition.”[1] The Building Research Establishment Environmental Assessment Method (BREEAM), the first formal standard and assessment model, emerged in 1989 in the UK. It was subsequently adopted in Canada and in Hong Kong and to date, has registered over 1 million buildings for certification.

Regardless of national origin, green building rating systems achieve the same purpose. Aside from promoting the sustainability goals of greater “efficiency, health, and performance of the built environment”, Kibert notes that these rating systems are considered among the most successful market-driven environmental movements. Of the most notable achievements is the creation of “a model for other sectors ... to create a consensus-based, market-driven approach that has rapid uptake, not to mention broad impact.”[1]

With over 6.2 billion sq ft of commercial floor space having LEED certification as of 2017, the USGBC has seen enormous success.[2] Serving as an example for a voluntary authentication of scope validated through a third-party, it is necessary to summarize the process of attaining LEED certification. A member of the building design team must register the project with the rating body, submit documentation to the USGBC, self-verify that the project meets or exceeds the standards for each of the point categories the project is applying towards and finally accept the corresponding level of certification. [1] In addition to the time and resources dedicated towards the certification process, a standard registration fee and floor area based certification fee are paid by the building owner.

The process that the USGBC has devised for validating the building features that comprise a sustainable building is voluntary and incurs a significant cost. This is a partnership between a third-party authority, in this case, the USGBC, and the property owner. The success of the program is evidenced by the growing number

of LEED certified buildings. Additionally there is a growing body of peer-reviewed research documenting the real energy-efficiency gains realized under LEED-certified and higher green building standards.

The Living Building Challenge *LBC* is another green building certification framework that is gaining acceptance. Like the credit rating system in LEED, the LBC employs “Petals” arranged into seven categories. Each petal is then subdivided into “imperatives” that address building systems like water, energy and materials. The LBC provides a model that is different from the LEED system in seeking to deliver “regenerative” buildings. By this metric, the building returns net-positive benefits to the three pillars of sustainability, ecology, economy and society.[3].

A form of certification for the Solar Ready scope could further serve the purpose of integrating any permit approvals or pre-approvals into the certification. Furthermore, as new methods for financing DER systems are developed, a Solar Ready certificate granted by a third-party can serve as a means to commodify otherwise unused rooftop space. Faced with the choice of a building that is certified as Solar Ready and one that is not, a potential PV integrator would opt for the Solar Ready building as the optimal site to develop a DG resource. Such a third-party validator might even serve as a clearing platform for potential DER sites, further optimizing the growth of renewable energy resources, monetizing rooftop space that would otherwise be underutilized.

## **2.2 Policy Instrument: Incentives**

Financial incentives come in several different types and provide monetary subsidies that offset the cost of installing and operating a renewable energy system. The two most influential in the US are tax credits and net energy metering laws. Some states and utilities offer cash incentives that correspond to energy production or system capacity. Incentives have been integral in greater adoption of Solar PV and yet are constantly changing. Whether or not a Solar Ready scope can be included in the basis of calculating some of the incentives designed to offset capital costs is considered

below. A thorough understanding of revenue mechanisms will prove that any attempt to reduce the installation cost of rooftop solar PV, such as Solar Ready, is worthwhile.

### *Feed-In-Tariffs*

Government policy has been a driving force in both the development of renewable energy technologies and in their implementation. Germany provides an early example of how government policy is a driving force in shifting electricity generation on a national scale through a set of policy tools. Runci (2005) notes how at the time, it was not yet clear to what extent these policies would affect the energy mix. Germany was the global leader in installed wind capacity and second to Japan in installed solar PV capacity. Yet investing in (R&D) of new technologies as well as “A variety of policy instruments (taxes, credits, standards, etc.), favorable electricity feed laws, export promotion programs and government secured loans for renewable energy projects,” had earned Germany status as the global leader in installed renewable DER capacity at the time of the writing. [4]

The most consequential of these instruments was implementation of the Electricity Feed Law introduced in 1990 and the Renewable Energy Law in the year 2000. These mandated a Feed In Tariff *FIT* or guaranteed price for electricity from renewable sources.[5] The ultimate result of these policies is that by 2012, Germany was a global leader in the adoption of PV systems supplying a significant share of the generating mix. In total renewables supplied 23% of total electricity consumption, 21% of that share (28.56 TerraWatt-hours) from PV. Germany led the world in total cumulative PV capacity, at 32 GW in 2012. In per-capita installed PV capacity, the results of the policy matrix are even more significant, with Germany leading the world at 0.4 kW of PV capacity per capita. For comparison, the US and China had negligible per capita PV capacity, while Spain and Australia, also leaders in renewable energy adoption at the time, had 0.1 kW per capita.[5]

Japan offers another approach to providing incentives to promote distributed gen-

eration. According to Sukki et al., policies in Japan have included direct subsidies to offset installation costs, net billing agreements between DER producers and utility companies, as well as a FIT. The literature frames Japanese renewable incentive policies in the context of two historical milestones. The first being the oil crisis of the 1970s, and the second is the 9.0 magnitude earthquake off the coast of Tohoku in March 2011, causing a massive tsunami and critical failure at the Fukushima-Daichi nuclear power plant. [6] It points out two approaches, incentivizing investment (in renewables) and incentivizing production (of renewable energy). The former approach is captured in a FIT. The latter by a renewable energy portfolio standard.

The strength of a FIT is exemplified in the German EEG, which according to Sahu, “maximizes the investors’ transparency, longevity and certainty ... within the costs of overall costs or benefits.[5] [pp. 626] Sahu notes that these policies do come at a cost. The German FIT is financed by surcharges on customer’s utility bills. The rapid penetration of DG PV systems in Germany has led to increased energy costs for consumers.

#### *Net Energy Metering: Rolling the Meter Backwards*

In the US, Net Energy Metering is the predominant policy instrument that provides indirect revenue for solar PV. In contrast to a FIT, which provides a guarantee of cash payments for excess energy exports (from DG), NEM provides a credit structure to offset future energy consumption. “Often referred to as ‘running the meter backward,’ because the customer essentially offsets utility purchases of electricity for all generation produced on-site.” [7] [pp. 90]

NEM regulations are made at the state level, through a state energy or utility commission. They are not uniform and subject to change. The value of NEM credits, often measured in kilowatt hours *kWh*, will vary depending on the local tariff structure, utility and NEM regulations. For maximum benefit to the owner of a rooftop solar PV system, a NEM credit is valued at the retail rate, or the price that the utility

customer would have purchased that kWh of electricity. “In some states, the export price ... is set explicitly at the utility’s avoided cost,” a much lower value than the retail rate. NEM credit values can also vary depending on the utility rate structure.

### *Tax Credits: the ITC and MACRS*

In the US, NEM provides an indirect cash flow in the savings that it generates in the place of consuming more expensive energy. The Business Energy Investment Tax Credit *ITC* (the ITC is available to businesses and homeowners) provides a direct discount on the system cost through a tax credit. In 2015, federal law extended the ITC at the 30% rate through 2020. After 2020, it will gradually be reduced, first to 26% in 2021, 24% in 2022 and 10% in the years following.[8]

In a similar vein, the Modified Accelerated Cost-Recovery System *MACRS* is a depreciation tax credit provides a further discount for businesses that include depreciation expenses on their balance sheets. Solar PV, among other renewable technologies including fuel cells, geothermal electric systems, and some wind turbines have been eligible to take a five-year depreciation schedule since 1986. In 2008, eligible technologies were able to take a 50% bonus depreciation in the first year.[9]

One of the driving forces behind the securitization of solar assets has been the substantial returns available to tax-equity investors. With the new federal tax code in 2018, guidance on the these two tax credits has changed substantially. With a reduction in the corporate tax rate, from 35% to 21%, some analysts expect there will be less tax liability, and thus less tax-equity financing available to fund solar PV project development.[10]

Although the structure of tax credit incentives continues to change, these two are powerful forces that drive investment into solar PV technologies. With a tax credit equal to 30% of installed solar PV system cost, and further tax credits available to businesses with depreciating assets, these are significant incentives to install solar PV on a rooftop. The design, material and labor costs incurred when installing a

Solar Ready scope should be included in the cost basis for both of these credits. Yet unless the complete rooftop solar PV system is installed in the same fiscal year as the Solar Ready scope, those costs are not eligible to be included in the ITC or MACRS calculations.

### ***2.3 Policy Instrument: Codes, Mandates and Standards***

Rooftop solar PV is a construction activity that lies at the intersection of roofing, electrical, structural and even IT trades. As evidenced above, there are also financial considerations and in the future the potential for energy storage for resilience, demand response, etc... and capacity for EV charging; the scope of a renewable energy contractor is likely to expand.

As such, rooftop solar falls under the purview of several jurisdictional bodies. Permit applications for rooftop solar systems can include electrical, structural or building, interconnection agreements with the utility and more. Ground-based systems may require more permits related to the geographic realities of the site; these are not included in this research.

Rooftop solar systems are coded into various building codes, including electrical, energy, fire, building and others. The following is a review of building codes, including any of the former categories, specific to Solar Ready.

Solar Ready policies are found mainly as building codes. The main areas that are covered include electrical system safety (NFPA NEC), structural standards, and firefighter safety. Interconnection standards are developed by electrical utilities, where decisions are made at the state-level. Federal level regulations are made by the FERC / PURPA, although arguably these have less impact on the smaller scale retail systems found on building rooftops.

Policies related to renewable energy and solar PV specifically are found at every level of government; from the federal tax code to housing associations. Some policies have their origin in trade associations like the National Fire Protection Association

(NFPA), publisher of the National Electric Code (NEC) or the International Code Council (ICC), publisher of the International Building Code (IBC). The electrical and building codes are published by trade associations and later adopted at a state level. In Washington state for example, the NEC is adopted at the state level by the Department of Licensing and Industries, whereas building codes are adopted at the county or municipal level.

### *Solar Ready Building Standards*

The following describes building standards for Solar Ready. The first comprehensive guide for a Solar Ready scope and the reasoning behind it appears courtesy of the The National Renewable Energy Laboratories *NREL* in Golden, CO. This hub for innovation in renewable energy technologies published a Planning Guide for Solar Ready Buildings in late December, 2009.[11]. Pointing out that “New construction that is solar ready will be in a position to take advantage of an environment more favorable to renewable energy,” depicts the expectation that PV system costs would continue to fall, as they had in the past. Also highlighting the fact that “Without the forethought to make buildings solar ready, solar installation may not be technically possible,” as many a rooftop replete with obstructions, at a bad angle to the sun or a building in need of costly electrical upgrades may prove to be. Such ”roadblocks” to solar ultimately shift the payback period of a PV system so far into the future that the investment is no longer favorable. [pp. 1] The guide identifies the following areas for “General Solar Guidelines”:

- Avoid shading
- Check zoning laws
- Determine the siting for a solar array
- Keep the south-facing portion of a sloped roof obstruction-free
- Minimize rooftop equipment to maximize available open area

- Recommendations on rooftop materials
- Structural requirements for load of array
- Engineering requirements for wind loads (specific to rooftop and site)
- Record roof specifications on drawings
- Add additional safety equipment for solar equipment access and installation

The NREL Solar Ready planning checklist includes guidelines specific to solar thermal systems, including solar water heating and solar ventilation. These thermal technologies are not be covered in this work. The guidelines specific to PV systems include the following:

- Identify electrical panel location for convenient PV system interconnection and keep space available in the electrical panel for the PV breaker
- Specify [electrical] panel capacity sufficient to accommodate the total power into the building.<sup>1</sup>
- Lay out locations for the inverter and BOS components
- Identify interconnection standards specific to the building location
- Run electrical conduit from the solar collector location to the electrical panel and other electrical components
- Consider any special load needs, i.e., storage
- Avoid shading as much as possible<sup>2</sup>
- Perform an energy production estimate for the proposed system using modeling software

These two lists comprise all the characteristics of the built structure that need to be considered to design a rooftop PV array. The list is comprehensive, consider

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<sup>1</sup>Specific guidelines per the NEC allow for the sum of these sources to be 20% greater than the panel rating.

<sup>2</sup>This guideline is specific to the document and emphasis is on the difference between PV panels and solar thermal panels.

features such as wind loading, the load bearing capacity of the roof as well as general safety equipment. Two key domains are mentioned more than once, and these are the Solar Zone on the roof and an electrical conduit between the future inverter location and the PV array location on the roof. Both of these critical concepts in solar design will be covered in further detail in a later chapter.

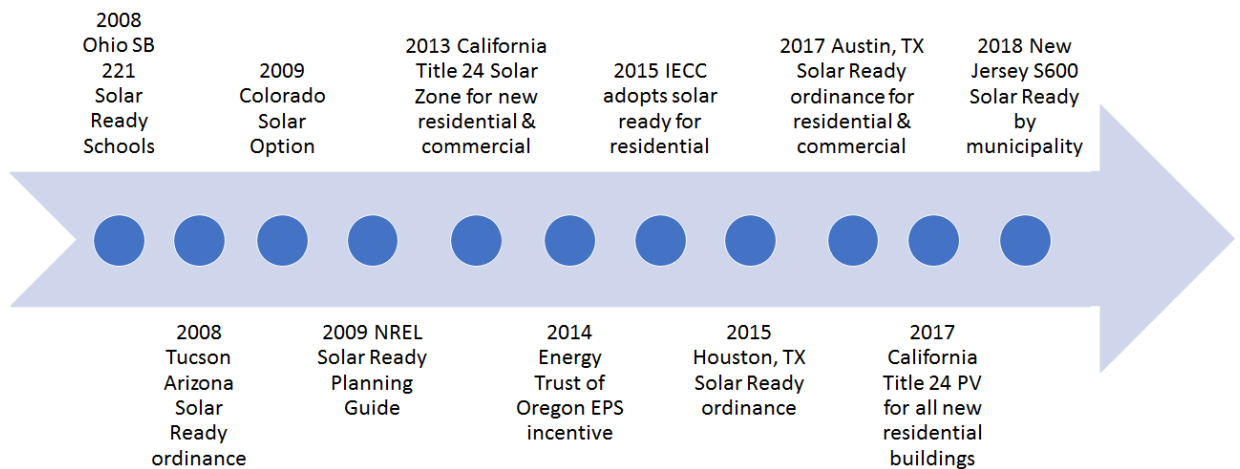


Figure 2.1: Timeline of Solar Ready Building Codes

A later report by NREL (2009) focuses on three methods of implementing Solar Ready for new construction, as well as further definition of the concept.[12] These are “Solar ready legislation, certification programs for solar ready design and construction, and stakeholder education.” The report provides a sample of Solar Ready legislation for jurisdictions to consider when implementing such statutes. It also notes that, at the time it was published, there was little or no data to support the effectiveness of such programs. It also provides examples of Solar Ready policies that were in place in 2012. These include the following:

- 2000 Guam (residential solar hot-water)
- 2007 City of Boston, Massachusetts (residential affordable housing)
- 2008 City of Tucson, Arizona (residential)
- 2008 State of California (residential)
- 2009 State of Colorado (residential)
- 2009 State of New Jersey (residential multi-unit)

Since 2012 many of the ordinances referred to above have changed. The 2009 Planning Guide for Solar Ready Buildings sets a solid foundation of features to be included when designing a Solar Ready building. The timeline in figure 2.1 shows the progression of Solar Ready policies from Ohio Solar Ready Schools to the time of this study.

#### **2.4 Policy Case I: Ohio**

- Statewide building standard mandating solar ready for school construction
- Includes: site orientation; structural load-bearing minimums; conduit run; service panel sizing; reserved space in service panel

The first verbatim Solar Ready policy appears in Ohio. In Ohio the construction, operation and maintenance of all public schools fall under the purview of the Ohio Facilities Construction Commission *OFCC*. In 2008 the Ohio state legislature enacted Ohio SB 221, which included several “key alternative energy requirements,” including an advanced energy portfolio standard, energy efficiency standards and Solar Ready schools. [13]. The advanced energy portfolio standard set a goal of sourcing 25% of the state’s energy supplied by investor-owned utilities from alternative energy sources. The latter can be either renewable generators certified by the public utilities commission or conventional facilities that have been upgraded and do not exceed benchmark greenhouse gas emissions.

The OFCC “Is responsible for guiding capital projects for state agencies, state-supported universities and community colleges, and Ohio’s comprehensive public K-12 school construction and renovation program.” [14]. This commission publishes the *Ohio School Design Manual* on an annual basis. The manual consists of design standards for new construction and renovation of school facilities. In 2008 the manual was updated to meet the USGBC’s LEED for Schools criterion. It also contains an addendum that is in response to OH SB 221, calling for the OFCC to “prescribe standards for solar ready equipment... capable of accommodating the eventual installation of roof top, solar photovoltaic energy equipment.” [15].

This Solar Ready addendum includes designation of a solar zone on the roof, clear of obstructions and shade free during peak sun-hours (9:00am to 5:00pm). It prescribes planting tree species that when fully grown, will not mask the PV array. The roof structure should be capable of supporting the additional dead load from the PV array. The standard calls for “An adequately sized chase from the main electrical room, electrical service closets and the mechanical room to the roof.” It suggests locating the electrical room on an exterior wall on the north side or shading “an adjacent exterior electrical equipment pad.”

Finally the addendum makes a recommendation for building massing, to orient on the east-west cardinal points. A waiver can be given for sites that are shaded or “when other conditions exist that make use of the roof area for solar energy production impractical.” [15]

These recommendations provide the basic physical parameters for a rooftop solar array. They do not address the interconnection or permitting needs that are necessary to connect a solar electric system to the utility grid. The standard can apply to a generic PV array of unspecified size. The call for a chase between electrical equipment and roof allows for any size and quantity of conduit and other cabling to be installed on the building.

It is unknown whether or not this program has been successful nor how many

schools since 2008 have been completed to the Solar Ready standards. One area for further research may be to quantify the number of OFCC buildings that are Solar Ready and then determine of those how many went on to install complete PV arrays. One study by Baird, Chen and Holmes (2014) shows that the implementation of USGBC LEED standards for schools had been moderately successful. At five and a half years of implementing LEED for schools under the Ohio School Design Manual, over 300 projects were registered for a LEED rating system. 98 of those projects had attained some level of LEED certification, representing 10% of the total number of LEED certified schools in the US at the time. [16]

## ***2.5 Policy Case II: Arizona***

- ARS 34-452: Statewide building standard recommending Solar Ready feasibility study for school & state construction
- Includes: site orientation, feasibility study
- Tucson ordinance no. 10549: City-wide ordinance requiring Solar Ready for all new residential construction.
- Includes: solar zone; conduit run; reserved space in service panel; permanent signage; documentation

Crucial to understanding the viability of rooftop solar PV is the solar resource. The average annual quantity of direct sunlight that falls on a square meter of the earth's surface is dependent on latitude and local climate conditions, namely cloud cover. The model depicted in figure 2.2 is based on geostationary satellite imagery as well as historical climactic data. Parts of Western Washington average around 3 kWh/m<sup>2</sup>/day, whereas most of Arizona receives greater than 6.5 kWh/m<sup>2</sup>/day. Solar insolation is the determining factor for how much energy a PV system is able to generate.

Therefore, it is little surprise that the state of Arizona enacted a Solar Ready

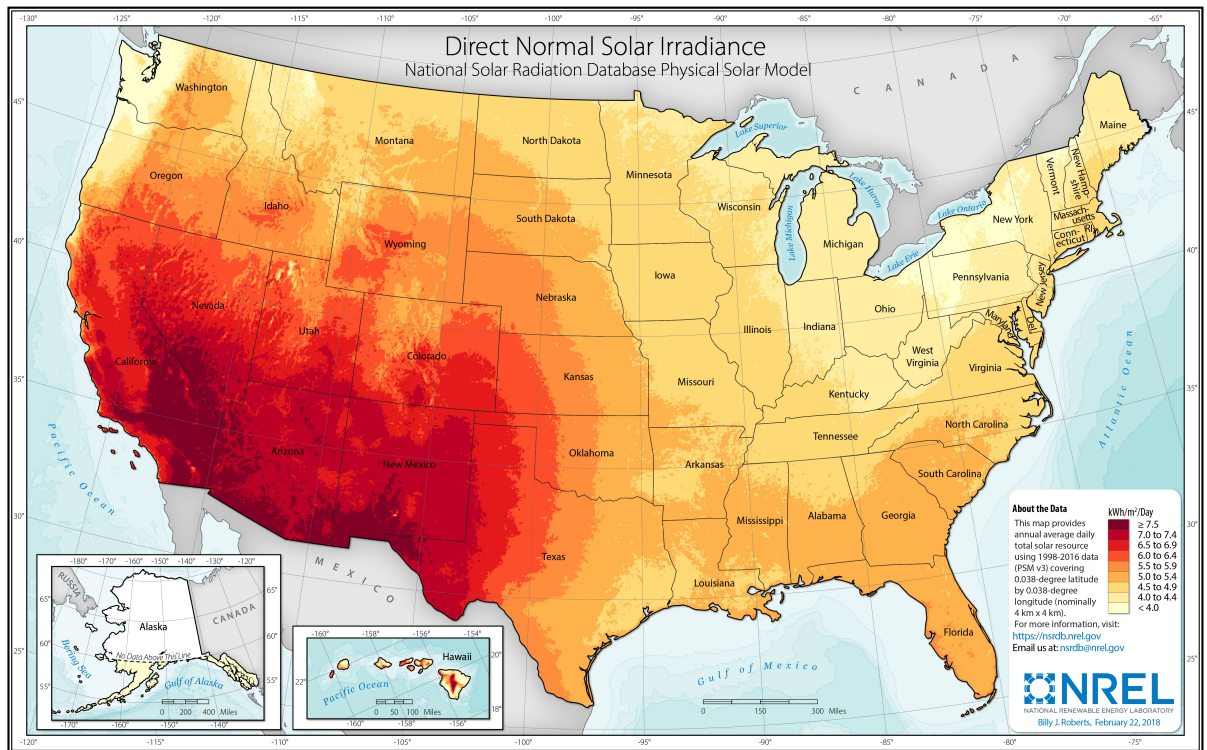


Figure 2.2: Direct Normal Solar Irradiance [17]

policy very early in 1997. This particular piece of legislation, ARS 34-452 (1997) applies to “buildings designed and constructed by the department of administration, school districts and universities.” In its original form it does not call out solar PV; it does call for a written evaluation of solar potential for both space and water heating. The evaluation includes proper site orientation and use of solar daylighting devices. [18]

This legislation is similar to the previously analyzed statute in Ohio, although it is less impactful in several key areas. Arizona ARS 34-452 ostensibly covers the same scope of educational facilities as Ohio SB 221; yet there is no comparable Arizona School Design manual published by the Arizona School Facilities Board. There is a

public record of \$5 million of funding from a Federal grant that was made available to invest in PV facilities in schools across the state beginning in 2009. [19] However this is not a Solar Ready policy. The scope of the Solar Ready statute is very broad and only covers the Siting category.

Within the state of Arizona, some jurisdictions have gone further and enacted Solar Ready ordinances and or amendments to their building codes. The City of Phoenix is considering implementing a Solar Ready provision for detached one and two family dwellings in the 2018 code cycle for residential buildings.[20] [pp. 289]. This amendment pertains to solar PV. The City of Tucson enacted a *Residential Solar Readiness Ordinance* in 2008. Tucson ordinance no. 10549 covers all new single family and duplex residential construction. It calls for “stub-ins”, or runs (ostensibly both electrical conduits and plumbing for solar hot-water) to “allow greater ease and convenience in subsequent solar energy system installations.” [21]

The Tucson ordinance is notable in that it is the first policy identified in this review with a scope that includes the new residential market segment. The scope of the Solar Ready standard is unspecific and only includes the run category. Also of interest is the coalition that gathered to propose the ordinance. These include “Technicians for Sustainability, the Tucson Association of Realtors, the Sierra Club, the Southern Arizona Homebuilders Association, architectural professionals and representatives of solar energy installation companies.” [21] Upon enactment, the ordinance was further developed and provided an option of including a Solar Ready scope for either solar hot-water or solar PV. Specific to a PV system, the new building must include documentation in the form of a site plan with a solar zone on the roof and other critical interconnection components. It has specifications for the electrical service that must be capable of receiving a “backfeed” from the PV system with a minimum size for the PV array. Finally, it requires that a space be reserved in the electrical service panel (but not a pre-installed breaker) along with signage indicating “reserved for Photo Voltaic.” [22]

## **2.6 Conclusion**

This review has provided a review of policies utilized to promote the use of solar PV on rooftops. It has defined two policy instruments, incentives and building codes, that have been enacted and executed. Over time the content of these has changed and will continue to do so. As solar itself has transformed from “alternative” energy to the mainstream, there will likely be a continued trend of less tax incentives, very few production and capacity credits and hopefully a harmonized methodology to determine net-metered credit rates. In their place will come energy and building codes that promote the safe, efficient use of rooftop solar PV panels. These will ensure the most effective use of rooftop space. They will ensure that inherent to the design, at no point in the lifecycle of a DG will the rooftop PV present a risk to building occupants, tradespeople that install, operate and maintain the PV systems and other personnel such as first responders.

This analysis concludes that to ensure sustainable growth of rooftop solar systems, policy development needs to address two critical areas. The first includes interconnection of the DG PV system and the utility grid. This includes the physical interconnection of the utility customer’s rooftop solar PV system and the grid, along with the compensation mechanisms that dictate the value of excess energy that is exported from the PV system to the utility grid. The second comprises local building codes that dictate those permits that are needed to (legally) install a rooftop PV system. Compliance with local AHJs can alter the physical characteristics of a PV system and it’s costs. Such changes require administrative resources as well as change orders for the original specifications.

The review has also identified a number of state and municipal level mandates for the inclusion of a Solar Ready scope to be included in new construction projects. Most of the policies are in the form of building standards or codes. Variation is found in a number of characteristics such as the range of solar system design parameters that

are included in the scope (e.g. rooftop area designated for solar zone or installation of a conduit from the electrical service to the roof), the jurisdiction where the policy applies and class of building.

This section also reviews the framework of voluntary Green Building certification programs. This research aims to open a discussion about whether such a model might have a place in further promoting sensible design for future DG within the built environment. The next section will analyze the economic justification for Solar Ready and evaluate two contemporary policies against the administrative and economic instruments that have been defined to that point in the research.

For Solar Ready to be effective, it must address both issues identified above effectively. If such a guideline can further standardize and even expedite the permitting processes, it has achieved the goal of making a new building “Solar Ready” in the physical sense of having integrated the solar PV system components that are costliest and most hazardous to install through a retrofit, as well as having a set of permits or preliminary permits allowing the system owner to legally install the system and export excess energy to the local utility grid.

## REFERENCES

- [1] Charles J Kibert. *Sustainable construction : green building design and delivery*. Fourth edi. pp. 5-6. Hoboken, New Jersey: Hoboken, New Jersey : John Wiley & Sons Incorporated, 2016.
- [2] *USGBC Statistics*. 2016. URL: <https://www.usgbc.org/articles/usgbc-statistics> (visited on 05/14/2018).
- [3] “Living Building Challenge 3.1 : A visionary path to a regenerative future”. In: *Living Future Institute* 31 (2016), pp. 1–82. URL: [https://living-future.org/sites/default/files/16-0504%20LBC%203%7B%5C\\_%7D1%7B%5C\\_%7Dv03-web.pdf](https://living-future.org/sites/default/files/16-0504%20LBC%203%7B%5C_%7D1%7B%5C_%7Dv03-web.pdf).
- [4] Paul J Runci. “Renewable Energy Policy in Germany: An Overview and Assessment”. In: *Pacific Northwest National Laboratory Technical Report PNWD-3526* (2005). URL: <http://globalchange.umd.edu/data/publications/PNWD-3526.pdf>.
- [5] Bikash Kumar Sahu. “A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries”. In: *Renewable and Sustainable Energy Reviews* 43 (2015), pp. 621–634. ISSN: 1364-0321. DOI: <https://doi.org/10.1016/j.rser.2014.11.058>. URL: <http://www.sciencedirect.com/science/article/pii/S1364032114009976>.
- [6] Firdaus Muhammad-Sukki et al. “Feed-in tariff for solar photovoltaic: The rise of Japan”. In: *Renewable Energy* 68 (2014), pp. 636–643. DOI: 10.1016/j.renene.2014.03.012. URL: <http://dx.doi.org/10.1016/j.renene.2014.03.012>.

- [7] Joseph Wiedman and Tom Beach. “Distributed Generation Policy: Encouraging Generation on Both Sides of the Meter”. In: *The Electricity Journal* 26.8 (2013), pp. 88–108. ISSN: 1040-6190. DOI: <https://doi.org/10.1016/j.tej.2013.08.008>. URL: <http://www.sciencedirect.com/science/article/pii/S1040619013001905>.
- [8] DSIRE. *Business Energy Investment Tax Credit (ITC)*. 2015. URL: <http://programs.dsireusa.org/system/program/detail/658> (visited on 02/20/2017).
- [9] DSIRE. *Modified Accelerated Cost-Recovery System (MACRS)*. 2016. URL: <http://programs.dsireusa.org/system/program/detail/676> (visited on 02/20/2017).
- [10] Solar Energy Industries Association SEIA. *Solar Market Insight Report 2017 Year in Review*. URL: <https://www.seia.org/research-resources/solar-market-insight-report-2017-year-review> (visited on 06/30/2018).
- [11] Lars Lisell, T. Tetreault, and A. Watson. *Solar ready buildings : planning guide*. NREL/TP ; 7A2-46078. Golden, Colo.: National Renewable Energy Laboratory, 2009.
- [12] Andrea Watson et al. *Solar ready : an overview of implementation practices*. eng. NREL/TP ; 7 A 40-51296. Golden, Colo.: National Renewable Energy Laboratory, 2012.
- [13] Eric Romich. *Renewable Energy Policy Series: Ohio SB 221*. 2010. URL: <https://ohioline.osu.edu/factsheet/CDFS-4001> (visited on 05/07/2018).
- [14] *Overview/History of OFCC*. URL: <http://ofcc.ohio.gov/Home/Overview-History> (visited on 07/24/2018).
- [15] Ohio School Facilities Commission. *2008 Ohio School Design Manual*. 2008. URL: <http://ofcc.ohio.gov/Resources/Design-Manual-OSDM/2008-OSDM> (visited on 05/07/2018).

- [16] Duwayne Baird, Qian Chen, and Grant Holmes. “Investigation of LEED School Projects in Ohio”. In: *50th ASC Annual International Conference Proceedings* (2014). URL: [www.gbig.org%20http://ascpro0.ascweb.org/archives/cd/2014/paper/CPRT247002014.pdf](http://www.gbig.org%20http://ascpro0.ascweb.org/archives/cd/2014/paper/CPRT247002014.pdf).
- [17] Billy J. Roberts. *Solar Maps — Geospatial Data Science — NREL*. 2018. URL: <https://www.nrel.gov/gis/solar.html> (visited on 07/25/2018).
- [18] *ARS 34-452 Solar design standards for state buildings*. 1997. URL: <https://www.azleg.gov/viewdocument/?docName=http://www.azleg.gov/ars/34/00452.htm>.
- [19] Janice K Brewer and John Arnold. *Solar Energy Project Information*. Tech. rep. Phoenix, AZ: State of Arizona, 2009. URL: <http://www.azsfb.gov/sfb/Announcements/Solar%20Projects%20Memo.pdf>.
- [20] *Building construction code change proposal Proposed Amendment to 2018 International Residential Code (IRC) Chapter 1*. Tech. rep. Phoenix, AZ: Planning & Development Department, City of Phoenix, 2018. URL: [https://www.phoenix.gov/pddsite/Documents/2018%20International%20Residential%20Code%7B%5C\\_%7DIRC.pdf](https://www.phoenix.gov/pddsite/Documents/2018%20International%20Residential%20Code%7B%5C_%7DIRC.pdf).
- [21] Karen Masbruch. *Residential Solar Readiness Ordinance*. Tech. rep. Tucson, AZ, 2008. URL: <https://www.tucsonaz.gov/files/pdsd/pdfs/GreenBuilding/june17-08-311.pdf>.
- [22] *Solar Ready Ordinance*. Tech. rep. Tucson, AZ: Planning and Development Services Department, 2009. URL: [https://www.tucsonaz.gov/files/pdsd/permits/Solar%7B%5C\\_%7DReady%7B%5C\\_%7DSummary.pdf](https://www.tucsonaz.gov/files/pdsd/permits/Solar%7B%5C_%7DReady%7B%5C_%7DSummary.pdf).

## Chapter 3

### **THE VALUE OF SOLAR READY: CHARACTERIZING THE ECONOMIC BENEFITS OF SOLAR READY**

The purpose of building a Solar Ready building is to accommodate a solar PV system in the future; either at a time when PV module prices have decreased or when the building owner has made the decision to invest in a solar system. One of the purported benefits of including a Solar Ready scope in the construction of a new building is to achieve savings on the cost of installing a rooftop solar array. This chapter includes a review of the literature in support of the potential cost savings for Solar Ready. This includes historical trends in crystalline silicon PV cell prices, a model for the cost components typical across all solar installations and theoretical estimates for the cost savings of Solar Ready. Chapter 5 includes aggregate survey data reporting on the validity of potential cost savings. This chapter closes with policy cases for California and Oregon. California has had a Solar Ready energy code for several years and is embarking on a full solar mandate requiring PV installation on all new homes. In Oregon, a non-profit entity has created a unique incentive structure that rewards builders for energy-efficiency upgrades.

Solar PV is an improvement that must be installed by licensed contractors. System hosts may elect to purchase the system outright or lease the system from a third-party. If electing to purchase the system, the host may elect to use debt to finance this investment. Increased electrical production can be classified as a positive cash-flow, since it offsets the cost of electricity that would otherwise be purchased from the electrical utility. One of the arguments against Solar Ready is the increased cost borne by the builder. Since the increased investment arguably benefits the building

occupant in the future, either through decreased capital investment in the system cost or increased electrical production; the builder has little incentive to bear the costs of making the building Solar Ready. This concept is known as the “split-incentive”. [1] This argument highlights the benefit of having a Solar Ready incentive available to builders.

### ***3.1 Falling cost of Si cells***

In 2008 at the first appearance of Solar Ready in the literature, one of the primary arguments driving this topic was the high but steadily declining price of solar modules. This argument assumes that prices will continue to decrease over time and that the component price of solar modules is significant enough to influence the total cost of a solar system. The merits of this argument are analyzed below.

Historically the cost of PV cells has been very high relative to the value of the electrical energy that they produce upon deployment. Swanson relates how since the advent of “the terrestrial photovoltaic industry in the mid 1970s, the conventional wisdom was that crystalline silicon solar cells, which were descended from space solar cells, were hopelessly expensive as a terrestrial energy source... leaving crystalline silicon for space applications only.” [2] [pp. 443 - 444]. Swanson provides a price point for crystalline silicon PV modules of \$32/W in 1979 and \$3.10/W in 2002, illustrating the manufacturing maxim that for every doubling in production capacity, a cost reduction of approximately 20% ensues.

For contemporary pricing, an industry report (2016) speculates spot pricing “to be in the sub US\$0.40c/W range.” [3]. Figure 3.1 shows the a linear regression model applied to historical pricing data for total system costs, including PV modules, inverters, balance of system and so called “soft costs” associated with marketing and operating a solar business. The regression line slope of -0.461 can be interpreted as a price decrease of \$0.461 per year for the 16 year period between 1997 - 2013. Analysis and figure by the author with data courtesy of [4].

Installed system price (2013 \$/Watt) over time for residential & commercial PV systems  $\leq 10$  kW

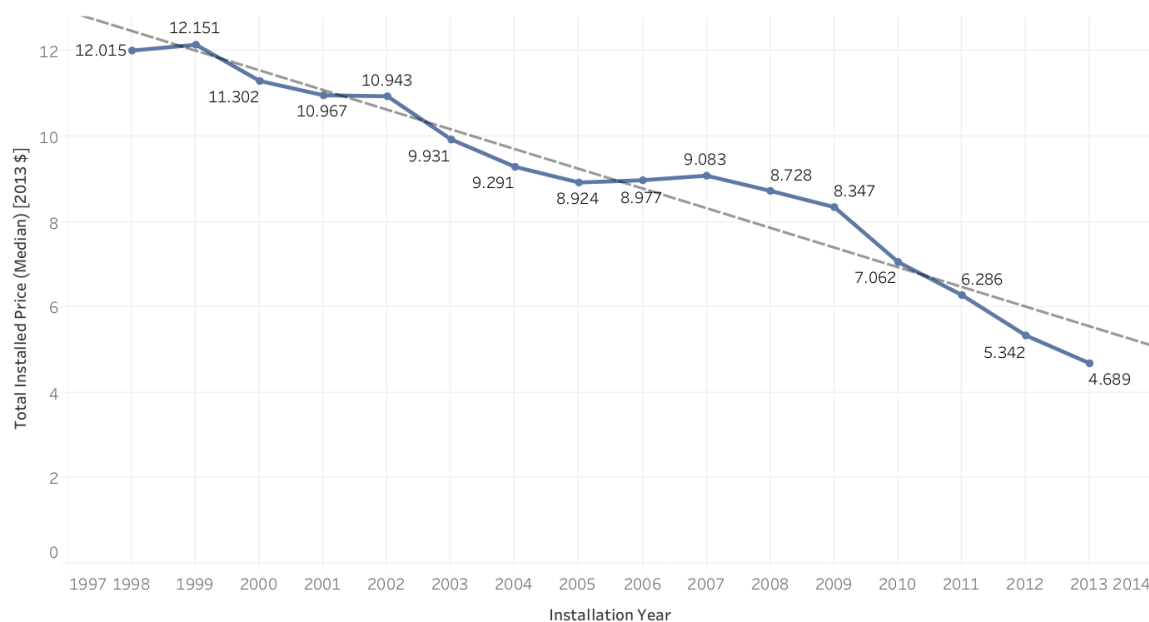


Figure 3.1: Installed Price, Module Price Index, and Implied Non-Module Costs over Time for Residential & Commercial PV Systems  $\leq 10$  kW

Another metric to measure the costs of energy from solar PV is the levelized cost of energy (LCOE). Reichelstein & Yorston define the LCOE as:

A life cycle cost per kilowatt hour (kWh)... the minimum price per kWh that an electricity generating plant would have to obtain in order to break-even on its investment over the entire life cycle of the facility. This break even calculation essentially amounts to a discounted cash flow analysis to solve for the minimum output price required to obtain a net-present value of zero. [5] [pp. 118]

NREL reports that between 2010 and 2017, the average LCOE across the US for residential rooftop solar PV fell from \$0.52 / kWh to \$0.15 / kWh. [6] The LCOE

accounts for installation, maintenance and decommissioning costs amortized over the productive lifetime of the PV array. Unlike a price per installed peak DC capacity, the LCOE is especially useful in comparison to leasing or power prices established through Power Purchase Agreement (PPA) contracts, two common forms of solar as a service.

NREL provides in its Q1 2017 Solar Photovoltaic Cost Benchmark report that for commercial systems modeled after a 200 kW PV array on a flat roof, module costs represent \$0.35 c/W out of \$1.85 c/W total installed costs, or 19%. [7]. Corresponding LCOE metrics range from \$0.09/kWh to \$0.12/kWh, not considering any tax incentives. This report states that for the commercial segment of the PV market, cost reductions of 72% were achieved in the period 2010 - 2017. The variations in LCOE have to do with latitude and climate, both of which affect capacity factor and ultimately, overall energy production.

The literature provides evidence that Si cell prices have decreased significantly in the past 30 years, justifying this aspect of Solar Ready. Regardless of whether or not Si cell prices have bottomed out, sources predict that the trend in decreasing PV installation costs are likely continue through 2020 and beyond.[8] The fact remains that PV modules remain the single greatest component cost of a PV system. Yet innovation in other categories may present the greatest opportunities for increased productivity in the near to long term. Namely those “soft costs” including marketing and overhead expenses incurred by a solar contractor during the course of operations. An effective Solar Ready scope can reduce soft costs such as permitting, pre-construction engineering and potentially even marketing through consumer advocacy.

### ***3.2 Comparing retrofit to new construction solar installation costs***

Concurrent to the preceding argument, engineering a building to easily adopt a solar system in the future may deliver several benefits during the installation of such a

Table 3.1: Costs of a Solar Ready scope, included in the new construction compared to a retrofit. Originally published in [9]

Solar Ready Cost Savings New vs. Retrofit						
		New		Retrofit		
Work package	Material	Labor	Total	Material	Labor	Total
Panel upgrade	\$459	\$480	\$939	\$459	\$1,200	\$1,659
Conduit run	\$374	\$416	\$790	\$374	\$1,040	\$1,414
Relocate vents	n/a	n/a	n/a	-	\$300	\$300
Panel installation multi-plane roof	n/a	n/a	n/a	-	\$1,000	\$1,000
Total	\$833	\$896	\$1,729	\$833	\$3,540	\$4,373

system in the future. These benefits include a faster pre-installation process and installation process for the solar system. The total material costs of the solar system depend on the Solar Ready specifications and the solar system specifications. incurred by the respective party installing either scope of work. This research contends that the labor costs for the Solar Ready scope would offer significant savings in comparison to those same work packages installed as part of a retrofit.

The 2012 NREL publication presents a theoretical case study to speculate on what these savings may be. Table 3.1 depicts a Solar Ready scope of work that includes the following work packages: i) upsizing the electrical service panel; ii) running conduit from the electrical service panel to the roof; iii) a solar zone on the roof (in this case study, rooftop vents that are present on the finished building must be relocated post-construction); and iv) installing the PV modules on a roof with multiple planes that vary. This cost analysis utilizes pricing from 2011 RS Means Construction and is for a hypothetical 10 kW PV array installed on a residential building. [9]

This case shows a theoretical savings of \$2,644 for the same scope of work. Note

that the work packages apply solely to work packages included within the Solar Ready scope. Borrowing the historical price point for installed system costs of \$6/Watt in 2011, this system has a total cost of \$60,000. [4] Notwithstanding other incentives, the net system cost after the 30% ITC tax credit is \$42,000. Including the Solar Ready scope in this case would have saved 6.3% of the total system cost, mainly from reduced labor expenses not incurred during the retrofit.

Of particular interest is the nature of the increased labor expenses during the retrofit. Running conduits to the roof from the location of the electrical service panel and between other system components is a work process inherent to all building improvements consisting of electrical equipment. The other three work packages involve design and engineering features on the roof and the building electrical system. Had the team that designed this building accounted for potential addition of solar, they may have sized the electrical panel appropriately and optimized south-oriented roof segments for solar by keeping an obstruction-free plane with a pitch suitable for solar gain.

This analysis has implications for worker health and safety. In practice as in this case, labor costs are calculated as the product of hours worked and labor wages. The retrofit therefore represents a near 400% increase in labor hours specific to the Solar Ready scope. As the bulk of this time is spent upgrading electrical systems and installing panels on the roof, this equates to a significant increase in the time spent by installers in the two most hazardous work settings: on the roof and near live electrical conductors. This subtopic is further expanded in Chapter 4.

Additional evidence in support of installation cost savings for the Solar Scope can be found in the report by Barbose, Weaver & Dargouth (2014). The analysis uses “project-level data for more than 300,000 individual residential, commercial, and utility-scale PV systems installed across 33 states,” for the time period 1998 - 2013. [4]. A summary analysis of aggregate pricing data for residential systems installed during new construction and retrofit shows a significant price difference among the

two categories. The data includes aggregate pricing for the two categories for the time period 2009 - 2013. The results of this summary analysis are found in table 3.2.

Table 3.2: Difference in installed cost of Residential PV, New Construction and Retrofit [4]

Difference in installed cost (Residential) Retrofit & New Construction						
	2009	2010	2011	2012	2013	Average
New	\$6.0	\$7.2	\$6.2	\$4.9	\$4.4	\$5.7
Residential	\$9.0	\$8.0	\$7.0	\$6.3	\$5.3	\$7.1
Difference	\$3.0	\$0.8	\$0.9	\$1.5	\$0.9	\$1.4
Percentage	33%	10%	12%	23%	16%	20%

The trend in decreasing overall costs can be seen in both categories. For new construction, installed costs decrease 26%; for retrofits they decrease by 44%. Despite this trend present in the data, the percentage of savings achieved during new construction is found to be variable over time. From this analysis it can be said that there is a significant evidence of reduced installed costs when a solar system is included in the scope of new residential construction. To accurately test the savings potential of Solar Ready buildings, historical data for the installed system costs is required. Such data would include commercial systems and information about the Solar Ready scope; including the cost of materials and labor as well as the installed equipment.

Some shortcomings to the two methods above are that they only account for the capital expenditure of installing the system. Neither method accounts for the potential increase in productive energy that might result from a more optimally oriented array resulting from Solar Ready design. Nor do they consider overhead costs that might result from worker injuries that might be avoided by the safety improvements that can be a product of Solar Ready design. Finally, the pre-construction tasks in-

volved in a solar installation that include permitting, design and procurement, might also contribute to reduced direct costs for a Solar Ready system installation.

The difference between new and retrofit installations might be attributed conceptually to the ease of access and the opportunities for integration with other construction tasks. One major component of Solar Ready, the run of conduit between the electrical service location and the roof, offers a prime example of this concept. When under construction, internal building walls are exposed when the electrical contractor is installing the electrical scope. For the electrical contractor to include additional conduits between the electrical service and the roof is a marginal addition to the electrical scope. Furthermore, this conduit is integrated into the building walls.

A retrofit in comparison requires that the conduits be attached to the building exterior. To open the walls for an integrated conduit run would be cost prohibitive. The same is true of other system components. Building elements that must be replaced or modified are similarly more expensive than if they have been engineered to host a solar array.

One important corollary is that those work processes that present the maximum savings when included in the scope of a new construction are included within the Solar Ready scope. Whether by building code, ordinance or voluntary incentive program, these areas are to be identified, proven to offer savings and included in the scope. Chapter 4 presents an analysis of the interdependence among PV system components. Through this analysis, those components that are most independent from the end PV system design and suitable for pre-installation within the Solar Ready scope are identified. Chapter 5 will present the findings from the survey and interview research regarding this finding from the literature.

### **3.3 Policy Case III: Oregon** ***The Role of a Solar Ready Certificate***

- (2014) OR Energy Trust EPS: Energy efficiency incentive program for builders
- Scope is limited to territory served by Portland General Electric and Pacific Power (northern OR & southeast WA)
- Incentive is available for both residential and C&I buildings
- Includes: site orientation; solar zone; stubbed conduit; service panel size; reserved space in service panel; permanent signage; documentation
- Incentive is provided to the builder upon verification of the scope by a 3rd party

Oregon has been a pioneer in the construction of Solar Ready buildings, both residential and commercial. Beginning in 2014, the Energy Trust of Oregon published a set of requirements for builders to include a Solar Ready scope of design for new homes in Oregon. Specifically for new homes located within the service territory of Portland General Electric or Pacific Power. Portland General Electric and Pacific Power (a division of PacificCorp) are the two largest investor owned utilities (IOU) serving the state. The Energy Trust is funded in part by a surcharge in customer utility bills, grants from the Oregon PUC (OPUC) as well as direct funds from the two IOUs.[10]. This represents a coalition of state entity, IOU electric company and third party non-governmental organization (NGO) organizing under the banner of energy conservation.

The energy trust has approached Solar Ready in a novel way. A straightforward energy audit in the form of the EPS. The EPS is an energy audit for homes and businesses. Points are given for energy-efficiency improvements that yield energy savings as compared to a baseline energy consumption model based on Oregon Residential Building Codes. Builders receive cash incentives for improvements that deliver energy-efficiency gains beyond OR energy code requirements. This program offsets the increased material costs borne on developers for building "above the code" or

to a specification that attains greater energy-efficiency gains than those prescribed in the building codes. Solar Ready is a sub-incentive within EPS. The EPS mechanism requires that the home be validated for energy-efficiency through a computer simulation of the specifications. Validation of the Solar Ready scope requires an auditor to perform a visual inspection and check off items on a standard form. With respect to Solar Ready, this approach defines what Solar Ready is, provides a verification method to validate the scope of work and pays an incentive to the interested party to implement the design elements.[11]

A copy of the entire EPS residential guideline for Solar Ready can be found in Appendix B. A summary of the requirements includes: a Solar Zone on the roof; an installed conduit from the main electrical service panel to the attic that is "stubbed" or capped off just below the roof; a space near the service panel reserved for the (future) installation of the inverter; spaces within the service panel reserved for the PV breaker. All of these features must be documented in the construction documents. In contrast to the other Solar Ready policies under review, the EPS scope offers prescriptive specifications as to conduit size, inverter location, the number of 90 °bends in the conduit and the location of the PV breakers in the service panel. All of these specifications are indicative that the standard was created with the consultation of practicing solar contractors. Additionally, Figure 1 in the Solar Ready Residential Installation Requirements gives guidance on the location of the solar zone relative to other rooftop components. Item 1.12 makes reference to setbacks for firefighters, although the wording leaves room for interpretation depending on local fire and safety codes.[11]

In November 2017, Governor Kate Brown proclaimed through executive order No. 17-20 a Solar Ready mandate for all new construction in the state of Oregon. The Solar Ready scope will apply to residential buildings beginning October 1, 2020 and two years later for commercial structures. The executive order also mandates to be ready to house electric vehicle Level II chargers in both residential and commercial

buildings, as well as a review of the 2017 US Department of Energy *Zero Energy Ready Standard*.

The true breadth of Governor Brown's executive order will not be known until the legislature approves the revised building codes that will enforce these energy efficiency improvements. Guided by Oregon's commitment to the Paris Agreement and carbon reduction targets enacted by the Oregon legislature, this executive order also mandates a goal for state buildings to adhere to the 2015 ASHRAE standard 189.1 for high-performance green buildings.[12] State buildings will essentially have to be designed to be Net-Zero or Carbon Neutral.

### **3.4 Policy Case IV: California** ***The mandate and the market***

- (2019) CA Title 24 Part 6: Statewide energy code requires solar PV for all new residential construction
- Includes: site orientation; PV array sizing based on FAR and climate zone
- Increased cost of home ownership justified by 30-yr energy savings [13]

If regulation is the definitive means of forcing market change, then California will be the model case for how such a scenario will unfurl. While again, there is scant data on Solar Ready, the Solar Mandate will play out beginning in 2020. It applies to new residential construction, including single-family and multilevel multi-family homes. Enacted as a result of the OPEC oil crisis of the 1970s through the Warren-Alquist Act, the California state legislature enacted the California Energy Commission in 1973.[14]. At the onset the commission would research and plan energy policy as well as inspect and license power plant sites and, along with the already existing California Public Utilities Commission (PUC), be a primary energy regulatory agency in the state.[14]

In 1978 this commission drafted the first set of energy-efficiency standards for non-residential buildings the First Generation standards. The commission was also

charged with updating the standards periodically. 1992 was the first year that the energy efficiency standards included residential buildings. These energy efficiency standards are codified as a part of California Title 24, the California Building Standards Code. [15]. The 2013 version of the energy code, Part 6 Section 110.10, is the first appearance of Solar Ready standards for new residential buildings.

In 2018 California made history by including a solar PV mandate in the latest energy code cycle. Taking effect in 2020, the 2019 Energy Code will require all new residential construction to include a PV system on the roof (barring exceptions for shading, etc.). A press release by the commission provides an estimate for the increase to home prices of \$40 per month. Offset by estimated savings of \$80 per month in energy costs, the result is a net savings of for end-users. [16]. It is important to note that the economics of PV will vary depending on local utility tariffs and solar insolation.

It will be interesting to see the result of this solar mandate. It may spur further decreases in the installed price of rooftop solar, especially in the “soft costs” category. Since demand for PV will essentially be all housing starts within the state, many elements of installing solar will become standardized. Solar Ready practices will become standard construction practice, as builders will include every aspect of the PV system into the new construction. This may provide an installed system cost savings of 20% compared to similar sized retrofits, documented in the NREL 2012 study above.

## REFERENCES

- [1] Us Department of Energy. “Promoting Solar PV on Leased Buildings Guide”. In: (2015). URL: <https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Promoting-Solar-PV-on-Leased-Buildings-Guide-.pdf>.
- [2] Richard M. Swanson. “A vision for crystalline silicon photovoltaics”. In: *Progress in Photovoltaics: Research and Applications* 14.5 (Aug. 2006), pp. 443–453. ISSN: 1062-7995. DOI: 10.1002/pip.709. URL: <http://doi.wiley.com/10.1002/pip.709>.
- [3] Mark Osborne. *Overcapacity: How low can module prices go?* 2016. URL: <https://www.pv-tech.org/editors-blog/overcapacity-how-low-can-module-prices-go> (visited on 05/09/2018).
- [4] Samantha; Darghouth Naim Barbose Galen; Weaver. *Tracking the Sun VII: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2013 - LBNL-6858E*. Tech. rep. 2014.
- [5] Stefan Reichelstein and Michael Yorston. “The prospects for cost competitive solar PV power”. In: *Energy Policy* 55 (Apr. 2013), pp. 117–127. ISSN: 0301-4215. DOI: 10.1016/J.ENPOL.2012.11.003. URL: <https://www.sciencedirect.com/science/article/pii/S0301421512009688>.
- [6] Kristen Ardani et al. “Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017–2030”. In: *NREL* (2017). URL: <https://www.nrel.gov/docs/fy18osti/70748.pdf>.

- [7] Ran Fu et al. “U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017”. In: (2009). URL: <https://www.nrel.gov/docs/fy17osti/68925.pdf>.
- [8] Kristen Ardani et al. *Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030*. Tech. rep. 2010. URL: [www.nrel.gov/publications..](http://www.nrel.gov/publications..)
- [9] Andrea Watson et al. *Solar ready : an overview of implementation practices*. eng. NREL/TP ; 7 A 40-51296. Golden, Colo.: National Renewable Energy Laboratory, 2012.
- [10] *Annual Report 2017*. Tech. rep. Portland, OR: Energy Trust of Oregon, Inc., 2017, pp. 14–15. URL: <https://www.energytrust.org/wp-content/uploads/2018/04/2017.Audited.Financial.Statements.pdf>.
- [11] Energy Trust of Oregon. *Solar Ready Residential Installation Requirements*. Tech. rep. 2014. URL: [https://insider.energytrust.org/wp-content/uploads/sle%7B%5C\\_%7Drq%7B%5C\\_%7Dsolarreadyreq.pdf](https://insider.energytrust.org/wp-content/uploads/sle%7B%5C_%7Drq%7B%5C_%7Dsolarreadyreq.pdf).
- [12] Governor Kate Brown. *Executive Order No. 17-20*. 2017. URL: [http://www.oregon.gov/gov/Documents/executive%7B%5C\\_%7Dorders/eo%7B%5C\\_%7D17-20.pdf](http://www.oregon.gov/gov/Documents/executive%7B%5C_%7Dorders/eo%7B%5C_%7D17-20.pdf).
- [13] Julia Pyper. *Everything You Need to Know About California’s New Solar Roof Mandate*. 2018. URL: <https://www.greentechmedia.com/articles/read/everything-you-need-to-know-about-californias-new-solar-roof-mandate%7B%5C#%7DThebasics> (visited on 08/16/2018).
- [14] *Ca - Departments California Energy Commission*. 2016. URL: [http://www.allgov.com/usa/ca/departments/natural-resources-agency/california%7B%5C\\_%7Denergy%7B%5C\\_%7Dcommission?agencyid=150](http://www.allgov.com/usa/ca/departments/natural-resources-agency/california%7B%5C_%7Denergy%7B%5C_%7Dcommission?agencyid=150) (visited on 04/29/2018).
- [15] California Energy Commission. *2016 Residential Compliance Manual*. 2016. URL: [http://www.energy.ca.gov/title24/2016standards/residential%7B%5C\\_%7Dmanual.html](http://www.energy.ca.gov/title24/2016standards/residential%7B%5C_%7Dmanual.html) (visited on 04/28/2018).

- [16] *News Release - Energy Commission Adopts Standards Requiring Solar Systems for New Homes, First in Nation*. 2018. URL: [http://www.energy.ca.gov/releases/2018%7B%5C\\_%7Dreleases/2018-05-09%7B%5C\\_%7Dbuilding%7B%5C\\_%7Dstandards%7B%5C\\_%7Dadopted%7B%5C\\_%7Dnr.html?platform=hootsuite](http://www.energy.ca.gov/releases/2018%7B%5C_%7Dreleases/2018-05-09%7B%5C_%7Dbuilding%7B%5C_%7Dstandards%7B%5C_%7Dadopted%7B%5C_%7Dnr.html?platform=hootsuite) (visited on 05/16/2018).

## Chapter 4

### **SOLAR READY SCOPE**

The built environment is a heavily regulated space. At some level of jurisdiction, everything from the spacing of rungs on a ladder to the lumens output by a light source is dictated by a body of code. Interestingly, megawatt-scale solar farms that feed electricity directly into the utility grid are not considered to be behind the meter. Selling their generation at wholesale rates, they are considered part of the utility system and as such, do not fall under the purview of local AHJ. But for all those systems that are behind the meter, erected on built structures and provide power for self-consumption, there are a multitude of rules that dictate many aspects of its design, installation and operation.

A solar installer is considered a specialty construction contractor. A typical scope of work includes functions that otherwise are the domain of distinct specialty contractors. The typical rooftop solar installation will include electrical, roofing, carpentry and other specialized competencies. This is in addition to the energy modeling and site analysis pre-construction planning that are the first step in the PV installation process. The permitting process for a solar installation will vary depending on local jurisdiction, but in some cases, this may include sending applications and passing inspections from local building, fire and electrical authorities. Additionally, the system must have the approval of the electrical utility to connect to the utility grid.

Solar Ready policies have been evolving for a decade. From Solar Ready for schools in Ohio to the solar mandate for all new residential construction in California; the scope of these policies is fragmented and dynamic. If it is deemed to be an effective means to provide safer work environments for PV installers as well as a mechanism

to reduce the installed costs, it is likely to be adopted in some form or another in more jurisdictions. This section is an analysis of the typical solar installation process with the objective of determining a model scope for Solar Ready. This model scope can be adopted by jurisdictions eager to provide guidance on how new buildings can easily adapt sustainable energy solutions. The three part analysis first identifies typical work processes. Next, it determines the dependencies for specifying individual components in the system, in order to identify what equipment to include and how to avoid incompatibility between the Solar Ready scope and the final solar system. Finally, it identifies those work processes that present the greatest hazard to solar installers.

By identifying hazards present during the installation process and characterizing the risk potential of those hazards, Solar Ready can deliver much more than a discount on installed cost and greater lifetime solar production. By eliminating and mitigating life-threatening hazards to solar workers, Solar Ready is a standard that prevents loss of life, injury and property damage.

#### ***4.1 Installation process analysis***

This section summarizes the installation of a typical rooftop solar PV system. It will analyze the components, design procedures, permitting and installation tasks to determine which of those tasks might be included in a Solar Ready scope. It closes by speculating what problems may be encountered when including a Solar Ready scope during the new construction and at the point in time when the complete solar PV system is installed on the existing Solar Ready scope.

##### *Rooftop Solar PV System installation*

All rooftop solar installations share a common progression. An analysis of the work processes typical to all installations and their independence from a final design is a critical exercise in this study. The process map and identification of tasks for the

solar installation process is based on the previous work by Professor Hyn Woo Lee of the University of Washington, Professor John Gambatese of Oregon State University, PhD candidate Chung Ho of the University of Washington.[1] For Solar Ready to be effective, it must include a scope that delivers on the benefits of pre-installed components while avoiding a scenario where the Solar Ready scope is incompatible with the solar PV system to be installed. This analysis does not distinguish differences among new construction and retrofit PV projects.

The basic stages of a rooftop solar installation begin with the owner of the building making the decision to install a solar system. This stage can be complex and timely for instances in which the building occupant or tenant is not the building owner. Especially in the non-residential commercial and industrial *C&I* sector, where ownership can be a layer or two removed from the tenant(s), decision-makers can prove difficult to identify and engage with.[2] These issues are not be explored in-depth within this thesis.

The process map in figure 4.1 displays the processes identified by Lee, Gambatese & Ho, modified with by supplementing additional installation details. The supplemental information originates from the author's experience designing and installing PV systems as well as other sources.[3]. It also includes activities for optional components, like electric vehicle *EV* charging, energy storage and system monitoring equipment. As an electrical contractor, the solar installer is poised to add any of these options to a solar installation and whether they may have elements that can be included in the Solar Ready scope is included in this analysis.

### *Component Interdependence*

The previous analysis has identified elements of the rooftop solar PV system that are typical to all installations. In this section, the independence of those elements is analyzed. If a component of a rooftop solar PV system is dependent on the final design of that system, all components must be specified with that design in mind.

SOLAR INSTALL PROCESS MAP

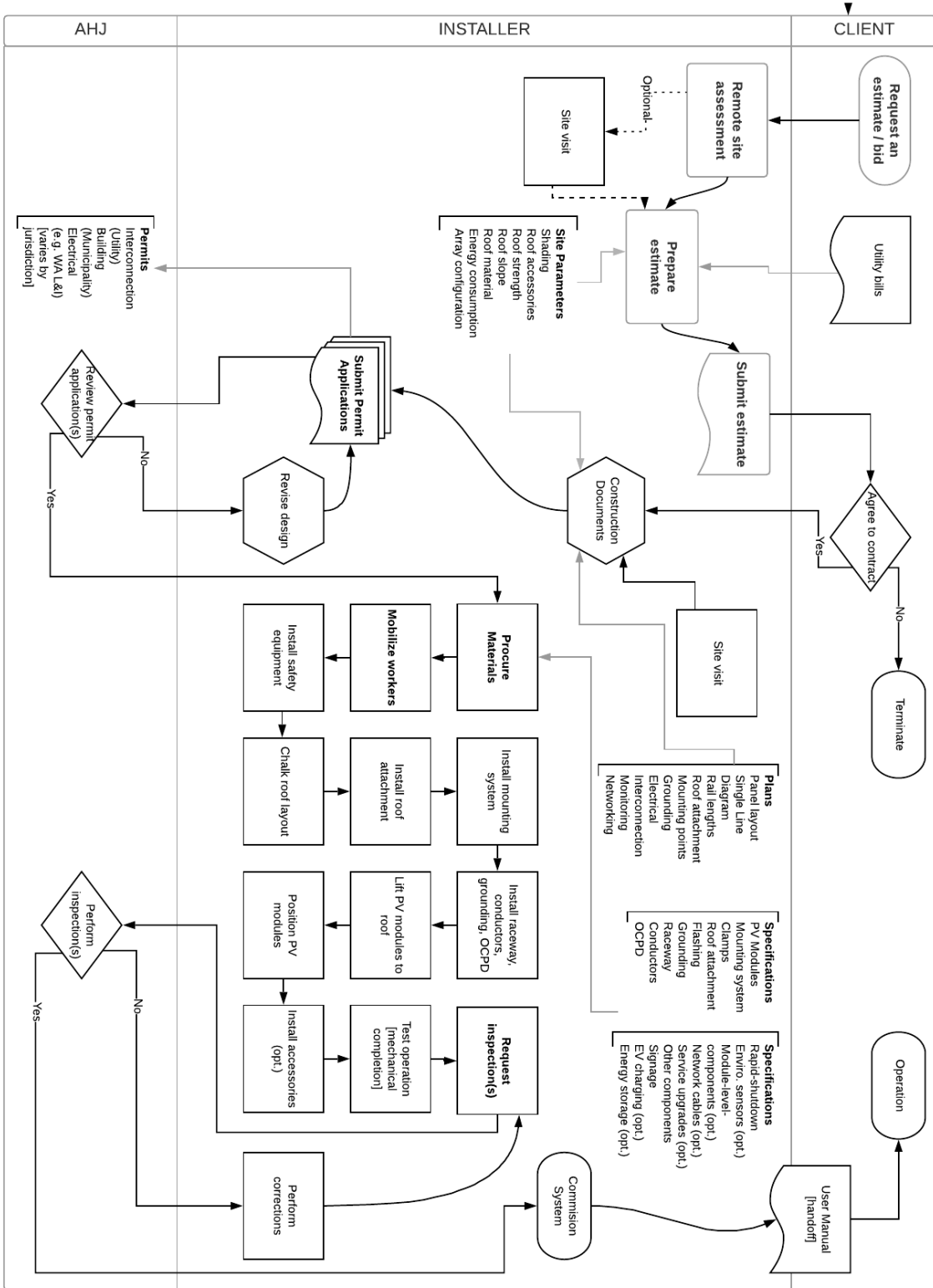


Figure 4.1: Solar Process Map

This means that for a new construction, specifications for the Solar Ready scope need to be compatible with those of the future solar system. This may result in a high degree of inflexibility at a future point in time.

There are two methods to avoid a scenario where the Solar Ready scope is incompatible with the solar system (in the future). One is to design the entirety of the solar system and extract a Solar Ready scope from this design. This method may have a time constraint, since code revisions are typically updated ever three years and solar equipment manufacturers constantly update their products. A second option would be to engineer the Solar Ready scope that is able to accommodate a minimum solar capacity based on the maximum area of the roof that is available for solar. This strategy results in greater flexibility of design for the ensuing solar system.

To gain a better understanding of the dependencies present when designing a solar array for a building rooftop, the author has created a dependency tree (Fig. 4.2) depicting a critical system elements. Black arrows depict that the element being pointed at is dependent on a characteristic of the arrow origin. Blue (dashed) arrows denote a similar relationship but the element is an abstract quantity or category of the construction process. Each major system component is shaded by a color denoting the sub-scope of work. In many cases these overlap. The “Other” group of components includes sub-components that may be required depending on the requirements of the AHJ.

The analysis concludes that roof characteristics are the predominant determining factors influencing PV system design. Roof pitch and the roofing material determine the mounting system that can be employed. Rooftop size and structural capacity limit the physical quantity of PV panels that can be attached to the roof. The rated capacity of the PV panels determines several other critical specifications, including the capacity rating of the inverter and the size of conductors for the solar circuit. These in turn determine the size of conduit needed.

Specifying other equipment such as monitoring systems with environmental sen-

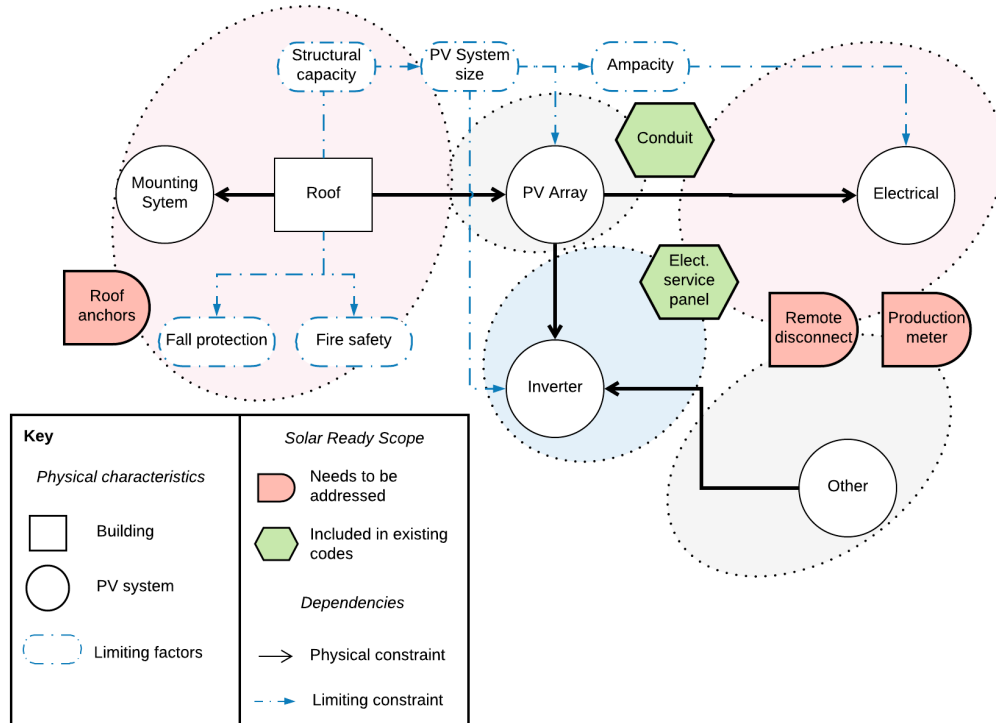


Figure 4.2: Interdependence diagram of rooftop solar PV components

sors, EV charging infrastructure, a rapid shutdown system (variable by AHJ), etc... will determine characteristics of the inverter as well as components within the electrical scope.

#### 4.2 Hazard Mitigation through Solar Ready

The primary objective of Solar Ready is invest a marginal quantity of design, time and materials during the new construction phase in order to capture savings at a future point in time when installing a PV system. Solar installers face many hazards, namely those from working at heights including falls and being struck-by falling objects; as well as electrical hazards. It should be noted that the electrocution hazards are present

in three forms, including the presence of overhead power lines near the roof, energized circuits in the vicinity of equipment being installed, and solar output circuits from the solar PV array on the roof.

Solar Ready provides two means for increasing the safety and health of solar installers. The first is by elimination and transfer of hazards. Equipment installed during the new construction phase or by other contractors is no longer included within the PV “upgrade” scope. Some scopes are completely removed from the solar PV system installation, while others reduce the complexity and time spent on certain tasks. For example, a pre-installed conduit will eliminate the time required identifying the routing of that conduit. It will reduce the time spent running solar output circuits from the roof to the site of the inverter. It may reduce or eliminate time spent in confined spaces, as conduits are often run through attics, crawlspaces and other limited entry, non-occupiable spaces. There is some transfer of hazard from the solar installer to the contractor that installs the Solar Ready scope. Yet it is proposed that such a task is not only faster to complete during the new construction phase, when other conduits are being installed and the building interior is exposed. Additionally, it is proposed that the conditions under which a Solar Ready conduit is installed are safer than they would be during a retrofit. Whether by the solar contractor or electrical contractor, it might be assumed that conditions during new construction are safer than during a retrofit solar installation.

Without data, it is difficult to draw a conclusion about differential safety measures taken during a retrofit compared to new construction. Direct observation of a Solar Ready scope and a solar system retrofit may offer a singular measurement. The time-reduction for similar scope of work presented in Chapter 2 section 2.1 as deduced from the lower labor cost is indicative of reduced labor hours. This is evidence of hazard mitigation through elimination of labor hours. A comparison of historical data comparing itemized installation costs between solar projects for retrofit and Solar Ready buildings would provide conclusive evidence in support of this claim.

Solar Ready can provide further health and safety through measures that are similar to prevention through design (*PtD*) These principles are mentioned throughout the literature. When applied to a rooftop solar PV system, they can be broad in scope. The work by Lee et. al, identifies seven areas where PtD can be applied to rooftop solar. These are focused on the design of the roof, namely the pitch, roofing material and positioning of skylights, exhaust vents and chimneys. [1]. In addition, a safe method for transporting the solar panels to the roof is among the recommendations.

None of the Solar Ready policy cases under review include roof pitch or rooftop materials within their scope. Most of them do include the concept of a solar zone. The solar zone consists of the south-facing facet of the roof in the case of a pitched roof, or a proportion of the roof dedicated to the solar array in the case of a low-slope roof. The solar zone must be free of obstructions. The question of whether a Solar Ready policy might be more effective if it prescribed an ideal roof pitch for the solar array and a roofing material is debatable. While a building that is intended to host a solar array will likely consider these design elements from an early stage, one that is not engineered to host solar will likely not consider these. Yet in the case of the fire code, energy code and building code (structural), relevant building components must meet very specific baseline standards in fire resistance, insulation-rating and load-bearing capacity. Although prescribing a specific pitch and material as part of a Solar Code will yield solar systems that are more productive and more standardized in construction, such a code may prove to be politically unrealistic and practically speaking, not possible to enact.

Figure 4.3 codes typical solar installation work packages by the hazard area that they present to solar installers. It also identifies those packages that are suitable for the Solar Ready scope. One proposal is to gather data comparing the time and material cost to install this scope during new construction to a retrofit installation. Should the data show a significant reduction in the labor cost for these packages, then there is a significant case for hazard elimination. Further data on incidence of injuries

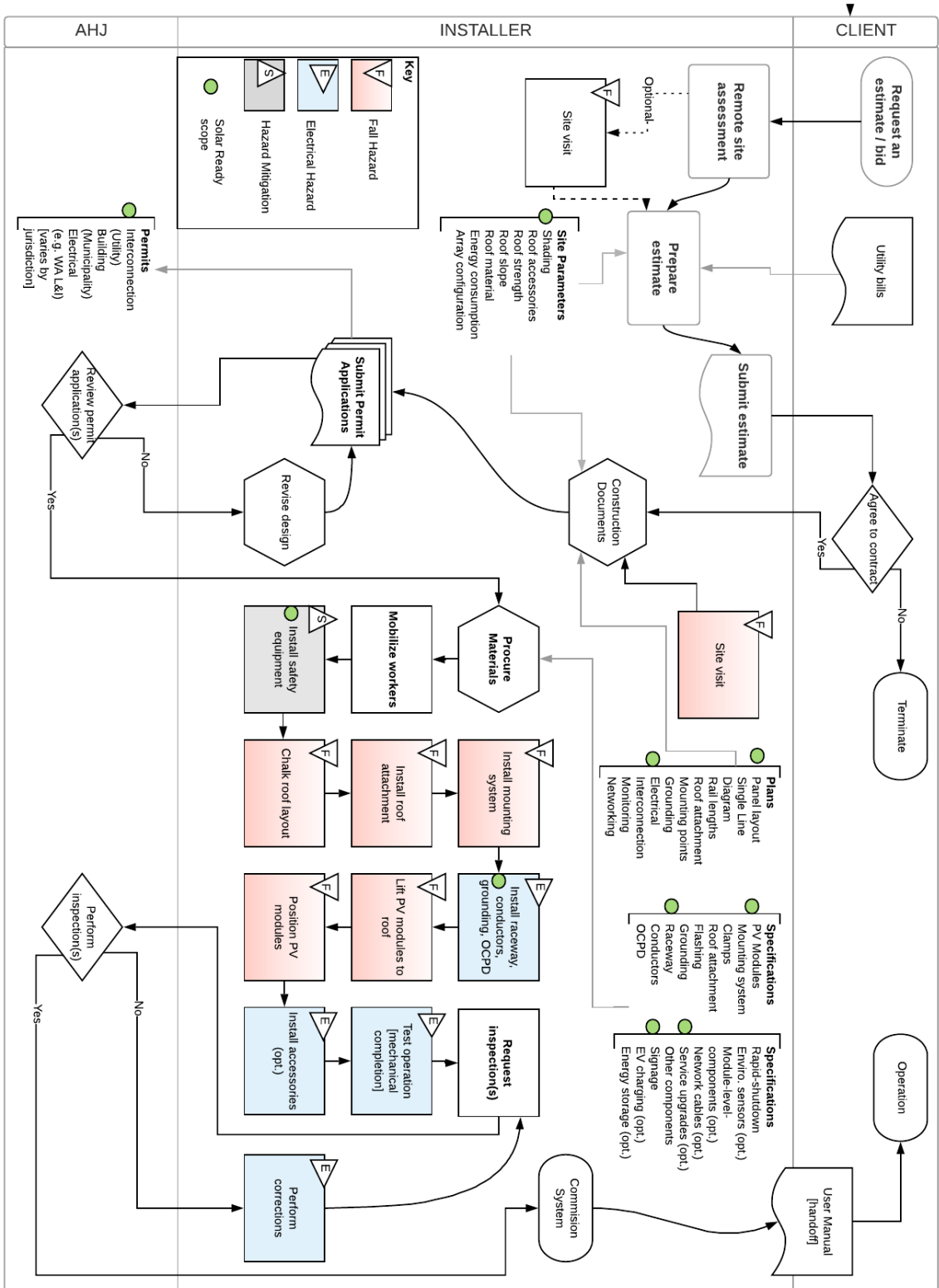


Figure 4.3: Process Map with mark-up indicating Solar Ready, hazard identification

and near misses for each type would be ideal.

An analysis of quantitative data comparing material and labor cost, incidence of injuries, fatalities and near misses between a sample of Solar Ready scopes and the same scope during a solar retrofit would yield conclusive evidence regarding the life-saving and hazard-reduction potential of such policies. With this data, the entire scope of Solar Ready would become a critical tool for jurisdictions to prevent injuries and death of solar installers across the land.

### *Solar Ready Scope*

Analysis of the solar PV system installation process has led to a reference list of Solar Ready features for inclusion in future iterations. By cross-referencing work packages identified in the analysis above to those categories identified in Chapter 2 section 4 and further prioritizing these by their potential to mitigate hazards; a model Solar Ready policy can be drafted by building code and green certification committees. This reference list can be found in Appendix B.

In comparing the model policy to existing building codes and ordinances, several differences come to light. One critical component is the interconnection approval that is granted by the existing utility. While there is no record of a pre-approval in the literature or in known practice, such a mechanism might be particularly valuable at the point in time where the building owner/system host elects to install the PV array.

### **4.3 Policy Case V: Seattle, WA**

- (2015) Seattle Energy Code Section C412: applies to C&I buildings within Seattle 20 stories or less in height
- Solar zone; minimum area (roof surface area or electrical service size); structural load-bearing minimums; modified chase or “capped roof penetration” for conduit, PV spacing in service panel
- Includes alternate provisions for solar water heating
- (2015) Seattle Residential Code Appendix U: applies to detached residential and townhouses within Seattle
- Solar zone; structural load-bearing minimums; reserved space in service panel; permanent signage; documentation
- Includes alternate provisions for solar water heating

Seattle has two separate building codes that mandate a scope of Solar Ready design and construction elements that must be included in new buildings or additions greater than a specific size. The 2015 Residential Code covers residential units, including single and multi-family units and townhouses. It does not cover multi-unit multi-story buildings; these fall under the commercial building codes. The second source for Solar Ready provisions for the city of Seattle is the 2015 Commercial Energy Code, covering a range of occupancy types.

The energy code includes two provisions related to PV systems. Section C411 mandates an on-site renewable energy system sized by the FAR of conditioned space. The requirement is 70 Watts of PV for every 1,000 sq ft of conditioned space. A building developer might opt for an alternative measure consisting of one of three energy-efficiency measures that exceed the minimum standards presented in the energy codes. Section C412 “Solar Readiness” is mandatory, although a building developer may prove that the total shading on the roof results in less than 75% of the total solar resource. Minimum solar areas are derived from either the total rooftop

area (40%) or from the electrical service (20%). The electrical service requirement is consistent with the NEC requirement allowing a PV system to “backfeed” a service panel up to 20% of rating of the service panel. [4] [pp. 127 - 128] The residential code does not specify a size for the solar zone. It does include load-bearing minimums, permanent signage and documentation. [5] Both of these codes are modifications to the (2015) International Energy Conservation Code, published by the International Code Council (ICC).[6]

Seattle’s Solar Ready provisions allow flexibility for the PV designer. They designate a solar zone on the roof and include a modified-chase or “sleeve” that penetrates the roof. This “sleeve” does not constrict the size or quantity of a future conduit but does increase the ease of future installation. One downside of the provisions is a failure to address electrical raceway and other components to facilitate the eventual addition of two auxiliary PV system components that in WA state are de facto requirements. These are the production meter and remote disconnect. The remote disconnect is required by the state electrical codes and a PV system will not pass inspection without it. The production meter is required to receive state production credits; this program is structured through the electrical utilities.

## REFERENCES

- [1] Hyun Woo Lee, John Gambatese, and Chung Ho. *Applying Prevention through Design (PtD) to Solar Systems in Small Buildings*. Tech. rep. Silver Spring, MD: Center for Construction Research and Training, 2017. URL: <https://www.cpwr.com/publications/applying-prevention-through-design-ptd-solar-systems-small-buildings>.
- [2] Us Department of Energy. “Promoting Solar PV on Leased Buildings Guide”. In: (2015). URL: <https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Promoting-Solar-PV-on-Leased-Buildings-Guide-.pdf>.
- [3] Solar Energy International. *Solar Electric Handbook*. Boston, MA: Pearson Learning Solutions, 2013. ISBN: 978-1-256-91816-5.
- [4] Seattle Department of Construction and Inspections. *Chapter 4 Commercial Energy Efficiency*. 2015. URL: [http://www.seattle.gov/DPD/cs/groups/pan/@pan/documents/web%7B%5C\\_%7Dinformational/p2623021.pdf](http://www.seattle.gov/DPD/cs/groups/pan/@pan/documents/web%7B%5C_%7Dinformational/p2623021.pdf).
- [5] Seattle Department of Construction and Inspections. *Residential Code - Seattle Department of Construction and Inspections*. 2015. URL: <http://www.seattle.gov/dpd/codesrules/codes/residential/default.htm>.
- [6] *Appendix RB Solar-Ready Provisions*. 2015. URL: <http://www.ghba.org/wp-content/uploads/pdf/advocacy/2015-IECC-Residential-NSec-002.pdf>.

## Chapter 5

### ANALYSIS OF SURVEY AND INTERVIEWS

Concrete is the most widely used material in construction and by volume, it is in fact the largest manufactured product in the world. [1] Concrete was used extensively throughout the Roman Empire, and there is evidence of lime mortar being used as a binder for stones as early as the third millennium B.C. in Egypt and the sixth millennium B.C. in Asia Minor. [2] Although constructed almost two millennia in the past, the Coliseum, the Pantheon and the entire center of Rome still stand amongst humanity's most treasured monuments of antiquity. [3] At this time-scale, the development of Portland cement in the 19th century is but a recent technological advance. Concrete is a ubiquitous design element in the construction of new buildings, despite its origins in antiquity. Should solar PV one day become as ubiquitous as concrete in the built environment, design optimizations making integration safe and seamless are in order.

To this point the thesis work has been a review of the literature, including academic research and policies. Solar Ready is a relatively new topic, first appearing in the literature in 2008. Keep in mind that the first PV cells emerged less than a century ago. At the beginning of the decade in which this research takes place, the economics of installing a rooftop solar system were entirely dependent on government subsidies to counter the high initial investment. At the close of the decade, rooftop solar will be required for all new construction in some markets (California) and it will have achieved the holy grail of "grid parity" in many additional markets around the globe. [4] In a span of decades, PV has emerged as a technology that allows a built structure to generate its own electricity. And in many instances dependent on geography and

local electricity tariffs, self-consumption realizes significant savings with respect to purchasing electricity from the electric company.

This section presents the findings of the survey questionnaire and informal interviews included within the thesis research. A copy of the survey questionnaire can be found in Appendix A. The survey was shared with practicing solar installers, building designers and experts in sustainability and policy. This survey was conducted during the summer of 2018. It collected some qualifying questions, basic demographic information and then Solar Ready specific inquiries. Survey takers shared their opinions of Solar Ready concepts.

A number of informal interviews were conducted with select survey takers. The purpose of this was to supplement the survey responses and add to the depth of some of the areas of analysis. Individuals were either solar installers, solar advocates working within a non-profit organization that actively engages in the promotion of renewable energy, or officials working at the city and state level drafting building and energy codes. The knowledge gained through these discussions uncovered seminal insights that led to new connections in the overall analysis.

One motivation for researching this topic is the author's past experiences designing solar systems for residential homes under construction. In response to the interest of various home-owners engaged in new construction or building-renovation projects; specifications for conduit-runs, electrical panel sizing and other design improvements were disseminated among the building contractors. In several cases, no solar system was installed at project completion. Yet several benefits were observed by the author, co-workers and other observers.

First and foremost was the seamless integration of the solar system. Where many retrofitted systems will have metallic conduits attached to an exterior wall, others will have solar arrays that are not contiguous, with a lone panel separated by a skylight or roof vent. Other accessories, like a production-meter required to capture local production credits and a means of remote-shutdown, add to the list of equipment that

can appear randomly mounted to a building exterior. The opportunity to have these components integrated into the walls, flush with the building's lines and siding offered the homeowner, architect and contractor a means of aligning the aesthetics of the building with the sustainable value proposition of rooftop solar. Furthermore, some of the more hazardous tasks, including modifications to the service panel, installation of the conduit to the roof and some of the panel layout could be avoided altogether.

The solar industry changes at a rapid pace. This holds true with respect to the technologies used to convert sunlight into electricity as in the installation practices employed by solar contractors. The varied policy instruments that define Solar Ready to this day can be indicative of how a building standard comes to fruition. In an ideal form, a building code is a baseline specification that delivers a compromise among multiple parties with diverging interests. In this sense, it provides the end user with a structure that will not collapse or cause harm to its occupants. In practice, building codes often come to fruition after input from industry representatives, building designers and contractors. Enactment and enforcement thus represents a compromise of interests. It is the belief of this author that as solar becomes as commonplace in a home or office building as modern appliances of convenience, such a baseline for performance is prone to become a global mandated standard for all new construction.

### **5.1 Survey**

The first section of the questionnaire captures basic demographic information, used in part to qualify subject responses. Survey participants are also asked to share their familiarity with the concept of Solar Ready. Unfortunately the sample size is not sufficient to compare familiarity with Solar Ready concepts across geographic regions. The survey received 9 valid responses out of over 50 invitations to participate sent via email, phone call, LinkedIn message and in-person. Figure 5.1 depicts the range of professions that answered the survey in the rows and the mean of familiarity with "Solar Ready" using a Likert scale. Architects, engineers and solar engineers

had worked on the most Solar Ready buildings, average 30 buildings, followed by consultants or incentives and solar contractors both reporting having worked on an average of 25 buildings.

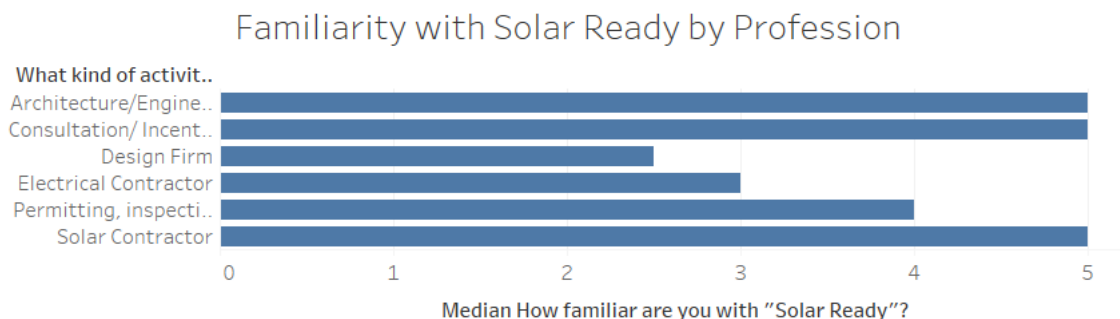


Figure 5.1: Mean familiarity with Solar Ready by profession

All of the respondents are from the Northwest region. The majority were from the Seattle area in Washington state. Demographic questions included electric utility service area, name of company, size of company, role and scope of work (residential, commercial or both). The range of years of experience in respondents' current industry ranged from a minimum of 2 years to a maximum 26 years. It is interesting that 56% of respondents work on both commercial and residential projects, 33% strictly residential and 11% strictly commercial.

## 5.2 Features to be included in a Solar Ready Scope

The primary purpose of this research is to propose a Solar Ready scope for future standards. This model Solar Ready scope contains elements of the solar installation process that when installed as a portion of a new building, will deliver improvements to safety and productivity for the installers of the full solar system scope. Previous

analysis of existing policies and the work process has revealed an array of solar system components that are eligible for the model Solar Ready scope.

The second section of the questionnaire seeks to identify what elements of a complete solar system qualify for the general Solar Ready scope. It presents respondents with a matrix of work packages that might be installed as a part of the new construction phase. The first question asks which of these features the respondent has observed in an existing Solar Ready scope; denoted "present" in figs. 5.2 - 5.5. The second question asks which features are to be included in an ideal version of the scope; denoted "future" in these figures. The questions include four categories representing the areas of work included in a solar installation. Survey results are presented in rank-order, with those Solar Ready packages receiving the most aggregate votes in first place for each work-package and "present" or "future" presence in the Solar Ready scope.

The last section of the survey employs a similar method to validate safety mechanisms that are appropriate for inclusion in the scope. Presented in rank-order relative to the total number of features, there are sections for rooftop safety elements as well as electrical safety elements.

### *Roof*

The rooftop is prominent in determining nearly all the parameters of a PV system. First and foremost, the orientation of the building itself and that of the rooftop plane(s) determines suitability for a solar system. In the northern hemisphere, south-facing rooftops are ideal for solar gain. Figure 5.2 shows that most respondents have seen inclusion of the Solar Zone on existing Solar Ready buildings. This is aligned with suggesting that such a zone be included in future iterations of Solar Ready policy.

A roof's structural characteristics are worthy of consideration. They appear as "Additional bracing for the sub-roof" in the results and come in as the next highest

### General Scope for Roof Components

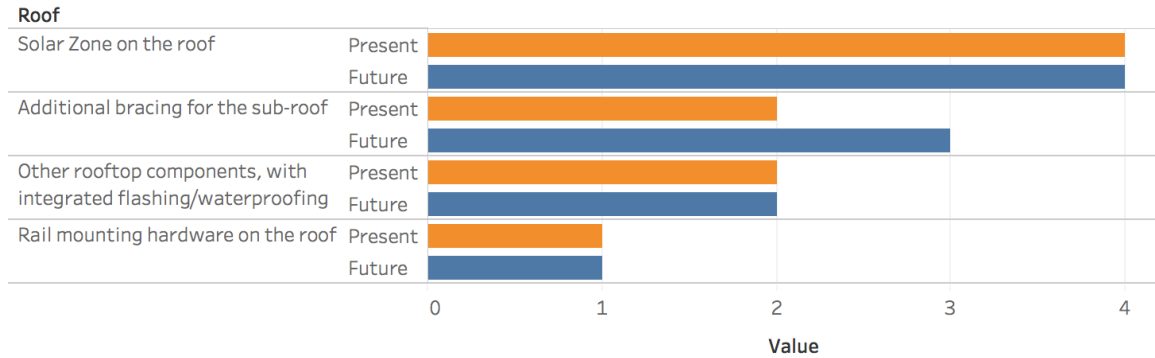


Figure 5.2: Rank-order survey results: general Solar Ready scope (rooftop)

rank tied with “Other components” among the existing solar scope ranking. In the ideal ranking, this structural improvement is the second highest ranking response. In the interviews, multiple subjects indicated that the load-bearing capacity of the roof was the initial requirement for a Solar Ready roof. This was also one of the easiest for a builder to attain, for the simple reason that most rail-mounted solar PV systems add a dead-load of only 2.5 lb/ sq ft. Such additional capacity was often included by default in the 10% envelope that is often included in the structural design of most buildings. However, for ballast-mounted systems, the additional dead-load requirement will be 40 lb/ sq ft. This much higher requirement may necessitate additional structural support. In and of itself, the need for a ballast-mounted PV system might be eliminated altogether by a rooftop design that easily accommodates a mounting-system that offers the maximum monetary value and installation productivity.

The last two Solar Ready elements do not rank as highly in the results. “Other rooftop components...” like integrated flashing or waterproofing for rooftop penetrations and other rooftop-mounted hardware has the potential to shift the risk of a leak onto the original roofing contractor. This may have positive implications for roof warranties. However, this would be relegated on a case-by-case basis. It would also

require close coordination between the solar contractor and roofing contractor. Such a collaboration in the pre-construction stage may require more of a commitment from the building occupant to install solar than a model Solar Ready scope might assume. Such is likely the case for installing “Rail mounting hardware on the roof” as a part of the Solar Ready scope. This was the lowest-ranked response.

### *Electrical*

A grid-tied solar electric system is akin to a large, permanent addition attached to the roof. Unlike a dishwasher that consumes electricity, solar generates electricity. This electricity is available to loads in the building; at times when solar generates more electricity than the loads within the building are using, this excess is sent back to the grid. Solar panels on the roof convert sunlight into direct current *DC* electrical energy. This DC is converted to alternating current *AC* before it is supplied to loads in the building or exported to the grid. Conversion from DC to AC is done by the inverter(s), the “brains” of the PV system. Inverters come in different forms, including large-capacity “central” inverters found in utility-scale PV systems, string-inverters and module-level micro-inverters.

Electrical connections must be contained in metallic conduits. The conduit “run” between solar panels on the roof and the inverter location can be one of the most time-consuming work-packages in a solar installation. Ideally it is run through a chase in the walls up to the attic space before penetrating the roof. The benefits of including the “run” have been analyzed in the previous chapter and are supported in the rank-ordered survey results for the general Solar Ready scope (electrical) presented in fig. 5.3. It is the first most reported element that is seen among existing solar installations.

The rank-ordered results for the electrical segment of the general Solar Ready scope show high consensus among survey respondents. This could indicate that existing Solar Ready buildings and codes reflect the stated intention to make installations faster and less expensive. Including a junction-box for electrical connections on the

### General Scope for Electrical Components

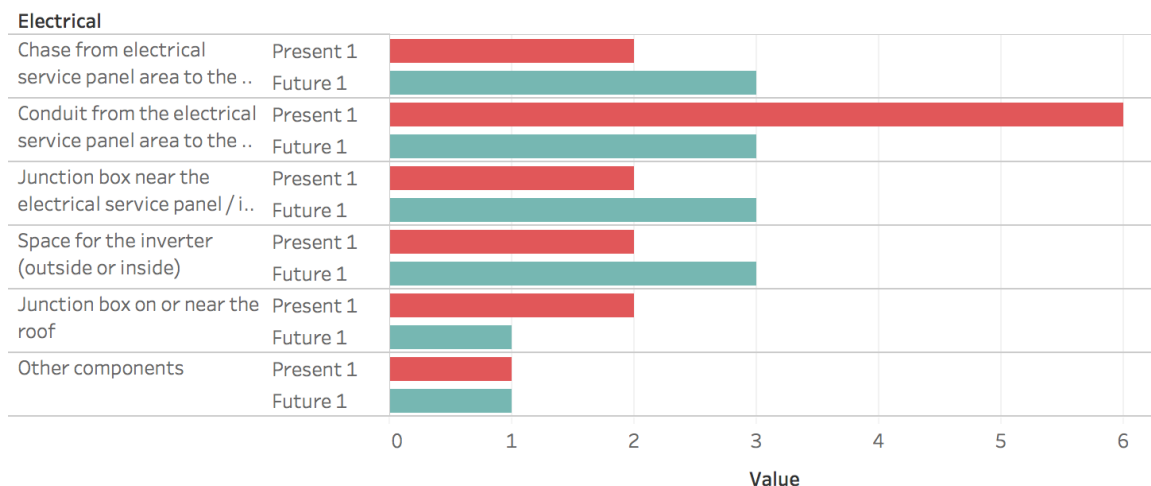


Figure 5.3: Rank-order survey results: general Solar Ready scope (electrical)

roof is slightly less recognized as an element for model Solar Ready code than as an element of existing Solar Ready code. One reason that a chase is viewed as favorably as a conduit run in the ideal scope may be that a chase offers more flexibility to the solar installation team in terms of conduit and conductor sizing.

#### *Service Panel, Other Components*

The rank ordered survey results for the service panel (fig. 5.4) and other components (fig. 5.5) to be included in the general Solar Ready scope are presented below. As indicated in the previous chapter, changes to the service panel post-construction are among the most costly work-packages that may be included in a retrofit solar installation. Therefore, these elements of the general Solar Ready scope are reported as being commonly seen in existing Solar Ready application and in the model scope.

Other elements reported in the survey include: In fig. 5.4 the two most reported elements within existing Solar Ready scopes are components for future EV charging

### General Scope for Service Panel

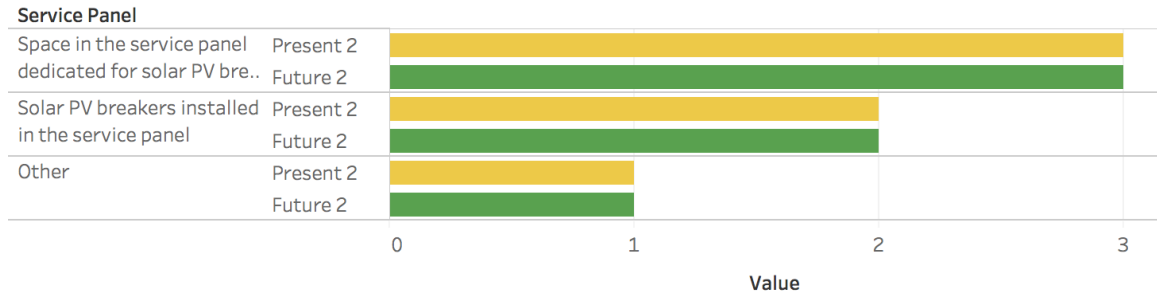


Figure 5.4: Rank-order survey results: general Solar Ready scope (service panel)

### General Scope for Other Components

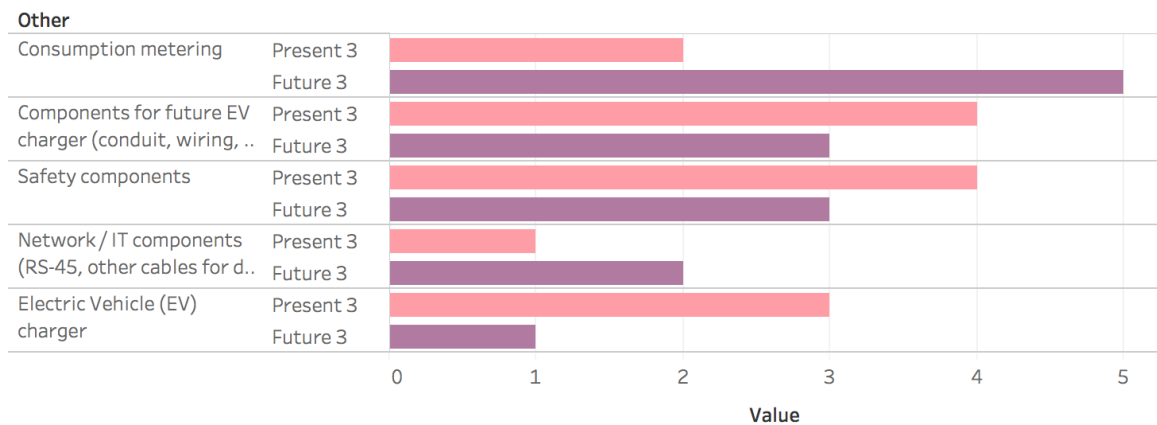


Figure 5.5: Rank-order survey results: general Solar Ready scope (other)

and Safety components. This would indicate that akin to Solar Ready, a scope for EV-charger ready improvements might be worthwhile to make available to building professionals. This also supports the notion that a solar contractor is a likely actor in introducing EV-charging infrastructure to a building as a complimentary component to the solar system.

Consumption monitoring is ranked first when other components are considered.

This feature, along with network access throughout the building, would provide integral data to many practitioners in the field of energy, insulation and mechanical systems.

### *Safety*

Rooftop pitch can vary and there are many factors that might determine the ideal pitch. Safety is an important factor here, as the steeper the pitch, the more hazardous it is to work on. The rank-ordered survey results for the safety scope within Solar Ready fig. 5.6 gives insight on what specific pitches and other rooftop characteristics might be included in the solar zone. Surprisingly, results indicate that a lower-sloped roof, 4:12 ( $18.4^\circ$ ), is more commonly found among existing Solar Ready buildings than steeper 6:12 ( $26.6^\circ$ ). One respondent suggested “Roof slope lower than 8:12 ( $33.7^\circ$ )”. The highest ranked safety element for Solar Ready in both existing and ideal categories is “Permanent anchor points.” Such anchor points are key components of any fall-restraint or fall-arrest system that would be used on a rooftop by solar installers. A study by Gambatese & Rajendran (2013) reports that of commercial buildings, “56% ... did not have any kind of PtD feature as part of the roof system.” Of those that did, 10% had an OSHA compliant parapet wall (suitable for low-slope roofs) and 34% had permanent roof anchors.[5]

Within the previously mentioned study is a comparison of the two prevention through design *PtD* measures, parapet walls and permanent anchors, that are applicable to commercial (low-slope) rooftops. It makes clear the trade-off of roof-anchors, that are less expensive to install but result in a sacrifice in productivity. In terms of a solar installation, it would be worthwhile to conduct a similar case-study to analyze fall-safety efforts, for both residential pitched roofs and commercial low-slope roofs. One hypothesis would be that the transferring the task of adding roof-anchors (or other fall-prevention strategy) to solar contractors is a greater cost than had a PtD method been installed as part of the new construction scope. This may hold espe-

## Scope for Roof Safety

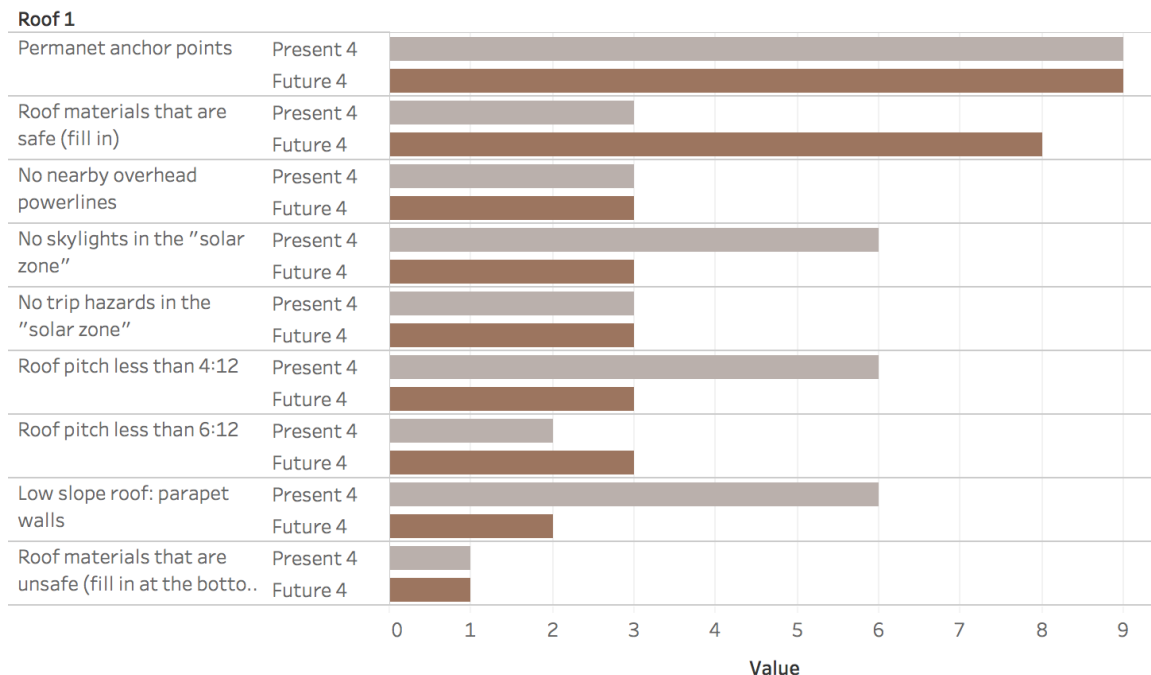


Figure 5.6: Rank-order survey results: safety scope for Solar Ready (rooftop)

cially true for pitched roofs. During the informal interviews, issues were raised with permanent anchor points being added to the Solar Ready scope. These are discussed in the section below.

Among the second-tier for existing Solar Ready clauses is “No skylights in the ‘solar zone’.” The presence of skylights on rooftops has been a documented [6] & [7] hazard for solar installers and other rooftop workers. Perhaps more than any other Solar Ready design feature, eliminating all roof openings and projections from the south-facing roof section may be the most effective way to prevent undue injury and death for rooftop workers. For large, low-slope commercial rooftops, the designation of a solar zone encompassing a proportion of the roof and preventing mechanical equipment, skylights and other roof openings and tripping hazards will achieve the

same effect.

Electrical energy created by the solar system in the form of direct current, alternating current and arc-flash potential are hazardous and can be deadly when PV electrical components are manipulated by unqualified personnel. Other electrical components within the immediate vicinity of the building likewise present grave electrical hazards. The presence of overhead power lines, operating at kilo-Watt voltages several orders of magnitude greater than any building-systems and with virtually unlimited fault current, present among the greatest electrical hazard to solar workers. [8] This fact is supported in the literature by tragic and impactful accounts of workers losing their lives after tools or equipment in their use make contact with nearby overhead power lines. The resulting shock triggers a loss of balance and results in a deadly fall off the roof. [6]. The proposed clause to limit the presence of overhead power lines near the roof was included in the roof safety question, the results of which are presented in Fig. 5.6. This clause ranks in the 3rd tier among both existing and ideal Solar Ready scopes.

### **5.3 Alignment with Safety**

This research has uncovered two modes of safety or PtD that a model Solar Ready scope can impact. The first is implicit in the solar zone on the roof and to a more limited though not less important extent in the electrical components like the conduit run, inverter space and service panel specifications. These work packages combine elements of the electrical, fire and building codes to the productivity-enhancing tasks that when executed as a part of the new construction can yield real gains in safety and efficiency during a future solar installation. These implicit measures are qualitatively defined in this work by their place within the greater solar installation scope and the hazards that are mitigated through their inclusion in the Solar Ready scope. Unfortunately, a quantitative analysis of their breadth is not realizable due to a lack of data. This absence has its roots in two key facts. There is no available data on

homes that are Solar Ready. This may change as more jurisdictions enact Solar Ready ordinances and the the passage of time allows the impact of presently burgeoning incentive programs to come out of the woodwork. Future research focusing on the program for Ohio Solar Ready Schools or the Oregon Energy Trust may offer some abstract numbers of buildings that went Solar Ready. Whether or not either program records the quantity of Solar Ready buildings that are “upgraded” is a crucial first step. Further complicating this question is the fact that multiple solar contractors may be installing these systems. For a comprehensive analysis of system cost and hazard mitigation, an extensive data collection methodology would be needed, using proprietary data with each solar company having varying dimensions of system costs, incident reports and more.

A second cause for the lack of data is in the Bureau of Labor Statistics Injuries, Illness and Fatalities (IIF) program. Solar workers are not classified independently from electricians within this trove of incident data among all employees in the US . There are over 9,000 solar installers nationwide under the classification “Solar Photovoltaic Installers 42-2231” in the BLS Occupational Employment Statistic Handbook.[9] Yet incident and fatality statistics for this group of men and women are categorized under “Electrical and wiring contractors 23832X” in the IIF. [10] Through this research and other works by the author, the few accounts of injuries and fatalities borne by solar installers is through unique FACE reports and special reports by state commissions, namely California and Oregon.

Solar Ready can include explicit methods of promoting safety for solar installers. This is by including fall protection equipment that would be installed on the roof during new construction. Through interviews it was discovered that all parties involved in this research were interested in the safety of solar installers working on the roof. The greatest concern was fall safety, and in one discussion among solar contractors and representatives of the Oregon Energy Trust, the topic of including safety components within the Solar Ready Scope was raised. An example would be the option

to install a permanent roof anchoring system on residential rooftops as a means to achieve a higher score on the Energy Trust Solar Ready checklist. All parties seemed to be aligned with this idea.

Another interview with a building code specialist raises a counterpoint. In commercial construction, fall safety is generally accounted for in new commercial construction. Buildings must either incorporate a parapet wall meeting OSHA standards or have a prescribed number of permanent anchor points corresponding to the roof area. In the residential space, the point was raised that a crew working on the roof would be more comfortable installing their own anchor points, fixed or temporary. Since residential buildings are generally timber-frame construction, the structural integrity of a permanent anchor point may become suspect, especially after the passage of time post-construction. In commercial building, permanent anchor points are typically fixed to steel structural members. This ensures a stronger anchor point for fall protection systems.

The final question in the survey, “Do you or your company have a preferred anchoring system for fall protection, and if so, what is it?” was intended to gather information about how solar contractors make use of such systems. Some notable responses include:

- So long as they’re properly installed and rated, not really.
- I think anchor points are sensible for all roofs and for lots of reasons besides solar.
- Guardian Fall Protection both temporary or permanent
- This has only come up for us on metal roofs with a higher slope, so we’ve used steel anchors under the roof cap flashing.

#### 5.4 *Perceived Cost Savings*

Cost savings is identified as the original reason for proposing Solar Ready. This research has identified two avenues for achieving cost savings: savings to the investment cost incurred during installation; and indirect savings in the form of increased revenue generated from optimized PV production. The third section of the survey questionnaire asks questions to gather information about whether existing solar systems have been able to realize the purported costs. These questions correspond to solar systems that are installed on a building with an existing Solar Ready scope.

In response to the question of whether Solar Ready achieves material savings during subsequent solar installation, responses are inconclusive. 20% of responses are “Yes” and 20% are “No”. The remaining 60% of responses offer notable insights into practical Solar Ready application. The two main perspectives are summarized below:

- No savings on material, but significant savings on labor costs.
- It can, provided it is done correctly. Often times, the wrong conduit is used or things are not optimally located, which can lead to re-work and higher costs overall.

A minority of respondents, 20%, affirmed to giving a discount on the total system cost when installed on a Solar Ready building. The open-ended question asking what are the greatest benefits to Solar Ready (5.6) revealed some perceived motivations for promoting Solar Ready. The most touched on theme is “Easier Upgrade”, followed by “Marketability” of a solar system for the building occupant in the future. These are in line with the benefits of Solar Ready that have been discovered in the literature and represent the economic benefits. The third recurring theme is the “Aesthetics” of having an integrated infrastructure in place for a solar system. “Concealing the pathways to minimize ... interruption of building occupation when Solar Ready is installed in the future,” captures the safety benefit as well as a third, better aesthetics.

The concept of better aesthetics for solar systems is worthy of further analysis. In some cases, a PV array will occupy a large segment of the building roof and change the exterior appearance. By designating a solar zone on the roof, the array layout can now be integrated into the overall building design by the architect. It will be a contiguous array, rather than separated by rooftop obstructions and openings. Finally, in much the same way that marketability allows building occupants to better consider solar as an option through enhanced education and awareness; Solar Ready induces the building designer to consider solar panels on the roof of the future building.

### **5.5 Other Issues**

Through the survey and interviews, some potential issues with Solar Ready were raised. This section will explore some of those issues and present the different perspectives learned from the research activities. These issues center around the validity of Solar Ready as a method for reducing installation costs and stretch into the concept of risk transfer and possible liability for work performed by another party.

#### *Bad Performance*

Numerous survey responses allude to the fact that Solar Ready has the potential to reduce the scope of labor during the solar system installation, if the Solar Ready scope is in fact well-designed and of quality workmanship. 37% of respondents answered “Yes” to having encountered a Solar Ready scope that was “counter-productive” to the solar installation. The recurring responses include misspecified components and bad workmanship.

Part of the reason for this disparity in workmanship is the transfer of ownership pertaining to the Solar Ready scope of work. Only 16% of solar contractors answering the survey strictly self-perform the Solar Ready scope, meaning that in most cases, work is performed by an electrical contractor. One example of how faulty workmanship in the installation of the conduit run is the presence of burs in the conduit.

Modern inverters are equipped with arc-fault detection equipment, to detect the presence of an arc flash within the solar system. This functionality can be very sensitive to defects in the insulation for the copper conductors. When joining individual sections of metallic conduit, the ends must be reamed to eliminate sharp burrs that may have been left over from cutting the conduit into smaller sections. The presence of burrs can degrade the insulation of the copper conductors. These small imperfections can lead to erroneous arc-flash warnings in the power inverter. An arc-flash fault will cause the inverter to shut down the solar system, often necessitating a service call from the installation company.

Questions of liability are of interest to any contractor. When performing work on a scope that was installed by another party, one test used to measure the extent of scope under a contractor's liability is the passing of an inspection. In the context of Solar Ready, any scope that is included in the new construction phase would be signed off by an inspector at the close of the construction phase. Thus the solar contractor installing the PV system would only be liable for everything added to that scope. This does assume that the documentation delivered upon project close-out accurately reflects the work that was performed. 40% of survey takers that answered the question reported that "Yes" they would be liable for deficiencies arising out of the Solar Ready scope when "upgrading" the work of another contractor.

## **5.6 Conclusion**

This work evolved through surveys and informal interviews. The presence of Oregon Energy Trust's incentive program, the process of drafting new energy codes, the invalidation of certain hypotheses were all results of the individuals that contributed to this research. The men and women that make up the rank and file of the solar industry, and other allied professionals in the construction and inspection departments of the authorities having jurisdiction are intellectual, generous and very passionate about their work.

The surveys validate the importance of a solar zone on the roof. This concept can be expanded to include roof pitch, surrounding hazards and a harmonization of all building codes that relate to installing solar panels on a building rooftop. By adapting fire and life safety codes into a baseline standard for a technology that has the potential to be as ubiquitous as concrete, Solar Ready can win over antagonists and deliver a very basic benefit for building occupants in the form of a roof that is safe and suitable for future solar installations.

In the electrical scope, the conduit run seems to be problematic. While it can deliver significant benefits in labor-hour reduction and in mitigating the use of ladders, working at heights or in confined spaces; this benefit is only realized when it is well-performed. Further complications arising out of new code requirements and new technologies or setting unrealistic building-occupant expectations can further complicate the benefits of the conduit run. This area of the scope could benefit from data collection and testing for the economic and safety benefits.

## REFERENCES

- [1] P. Kumar (Povindar Kumar) Mehta. *Concrete : microstructure, properties, and materials*. eng. New York, 2014.
- [2] Norbert Delatte. “Lessons from Roman cement and concrete”. In: *Journal of professional issues in engineering education and practice* 127.3 (2001), pp. 109–115.
- [3] *Historic Centre of Rome, the Properties of the Holy See in that City Enjoying Extraterritorial Rights and San Paolo Fuori le Mura*. URL: <https://whc.unesco.org/en/list/91> (visited on 08/09/2018).
- [4] *Photovoltaic Grid Parity Monitor*. 2017. URL: <http://www.leonardo-energy.org/resources/1090/photovoltaic-grid-parity-monitor-5908f331535b8> (visited on 08/09/2018).
- [5] Sathyanarayanan Rajendran and John Gambatese. “Risk and Financial Impacts of Prevention through Design Solutions”. In: *Practice Periodical on Structural Design and Construction* 18.1 (2013), pp. 71–72. ISSN: 1084-0680.
- [6] Christine Baker. *Construction case study training guide*. Tech. rep. Berkeley, CA: Commission on Health, Safety, and Workers’ Compensation, 2012, pp. 10–11, 28–29. URL: <https://www.dir.ca.gov/chswc/WOSHTEP/Publications/ConstructionCaseStudyTraining.pdf>.
- [7] *FACE 9021 Roofer Dies after Falling through Skylight Fixture in Maryland*. 2013. URL: <https://www.cdc.gov/niosh/face/In-house/full9021.html> (visited on 08/10/2018).

- [8] Solar Energy International. *Solar Electric Handbook*. Boston, MA: Pearson Learning Solutions, 2013. ISBN: 978-1-256-91816-5.
- [9] *Solar Photovoltaic Installers*. 2017. URL: <https://www.bls.gov/oes/current/oes472231.htm> (visited on 08/10/2018).
- [10] *Case and Demographic Incidence Rates*. URL: <https://data.bls.gov/gqt/RequestData> (visited on 08/10/2018).

## Chapter 6

# CONCLUSION

This section concludes the study. It contains a summary of the areas under review and highlights positive and negative impacts identified through the research. Followed by a discussion of the role of a model solar ready policy among the scope of green building certifications, building codes and full solar mandates. It closes with some proposals for future research, guided mainly by the lack of quantitative data specific to solar installer injury rates and evidence of savings in projects that include a solar ready scope. These conclusions stem mostly from the gathered through questionnaires and informal interviews.

### ***6.1 Positive impact of Solar Ready standards to date***

Surprisingly the most common reported benefits of solar ready are for the consumer. The building occupant is made more aware of the option to “upgrade to solar” and more enthusiastic to opt for PV in the future. Perhaps erroneously they perceive solar ready as a discount; evidently erroneous given the scant observance of discounts given to solar ready systems. The end-user also enjoys the aesthetic benefit of solar ready and potentially less interruption during the installation process.

One intent of this research is to highlight the need for data collection in order to further scrutinize the net benefits realized through application of the Solar Ready scope. To observe that improvements to a building’s aesthetics and increased consumer awareness for solar adoption are the immediately recognizable benefits is an exciting finding. In the absence of hard evidence supporting the safety and economic benefits of Solar Ready, the affirmation of these two “soft” benefits resonate through-

out the research. Policy-makers might heed the potential benefits stemming from these two areas when drafting future iterations of Solar Ready building standards. From a practical standpoint, market demand drives the adoption of change. Solar Ready may not be technically complex nor is it by any means an undue burden on the building developer. Yet it can capture the goodwill perceptions of green building and equitably make one of the most visible components of sustainable building an option for building end-users. Furthermore, it can entice building designers to consider sustainability as an aesthetically-enhancing building component.

### *Solar Zone*

With respect to both safety and economics, the concept of a solar zone on the roof is the most desired aspect for an idealized standard and the most beneficial as observed through this thesis research. Essentially a simple guideline that within the roof area, a portion is set aside for future solar development. The observation that this element is the most impactful is unexpected due to its simplicity. The best solutions are often elegant in their simplicity. Recalling the context of rooftop solar, mainstream adoption was not accessible until the significant price drop beginning a decade prior. This cost reduction came about as a result of the internal drop in module prices and the external harmonization of permitting and interconnection procedures.

The solar zone benefits the economic and hazard profiles of adopting rooftop PV. It establishes the best location for a solar array on the building rooftop. Lifetime generation yields optimum production as a result of maximum insolation and minimum shading. System costs and time spent on the roof are reduced by streamlined system layouts, ease of access and the elimination of openings (skylights) and tripping hazards (from within the solar zone).

The solar zone has the potential to make Solar Ready a very effective standard or building code. By aligning with other building codes that reference PV systems, it can incorporate other fire and life safety PV design constraints into the design of

the building. A solar zone that does not conflict with existing fire-codes, but instead encourages a safe working environment for first-responders on the rooftop, can guide PV design while benefiting the safety of all that work on building rooftops.

### *Electrical*

The most substantial documented evidence for savings on system cost comes in the form of the electrical subscope for Solar Ready: first in the form of the conduit run and second in the sizing and layout of the building electrical service panel. The conduit run might be the single most controversial element of the Solar Ready scope. If installed correctly, it improves building aesthetics, reduces labor-hours during the PV upgrade and mitigates exposure to working at heights, in confined spaces and others. However, the research indicates that the conduit run is the most likely component of Solar Ready to raise issues. Through misspecification, poor workmanship or obsolescence, it can be detrimental to the PV installation and result in additional scope for the solar contractor. For these reasons, the conduit run is excluded from the model standard. In its place is a chase from the main electrical service to an area near the roof. This chase may be in the form of an oversized conduit that might house future conduits.

Additional components are identified in the literature and through the research. These include infrastructure for EV charging and consumption monitoring capabilities for the building. EV charging-ready consists of a conduit from the main service panel to the parking garage as well as space in the service panel for a breaker. It provides ease-of installation and aesthetic benefits. Consumption monitoring is a requirement for some green building certification scopes. It consists of attaching current-transducers to the main service conductors as well as sub-circuits within the building. This research does not identify how a building can be made monitoring-ready, as it is more suitable to install the system as a whole. Like solar PV, monitoring is likely less expensive to install as a component of the new construction phase.

## 6.2 Areas in need of improvement

Like any other policy, Solar Ready building codes are a result of iterative deliberations amongst multiple stakeholders. A Solar Ready incentive such as the EPS voluntary rating through the Energy Trust of Oregon offers many improvements over the building code that address some of the issues. The issue of the split-incentive is resolved with the incentive paid directly to the builder. This silences the argument that the scope forces builders to incur additional costs, marginal as they may be. Although it could be argued that the incentive must be paid for by ratepayers or taxpayers, the EPS framework for verification of the scope potentially eliminates other deficiencies in the Solar Ready as building code.

### *Bad Implementation*

It has been established that the solar industry has changed dramatically in the past decade. Technological advances in equipment have been largely market-driven, with substantial demand occurring in those regions with high energy prices.<sup>1</sup> Other changes, like anti-islanding, arc-fault detection and remote-shutdown capabilities; result from policy changes intended to eliminate hazards to linemen and utility workers, first-responders and electricians. The fast pace of change in the solar industry can render a Solar Ready design obsolete within a three year code-cycle.

This may apply to a specification for a Solar Ready conduit during new construction that is not large enough or compliant with electrical codes during the time of solar installation. A requirement for a remote disconnect device on the roof may necessitate a data cable from an exterior wall to the roof, eliminating the aesthetic benefit of the concealed Solar Ready conduit run. For these reasons, the model standard encourages designers to implement an accessible chase that provides concealed

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<sup>1</sup>Energy prices are more determinant of regional market growth than solar insolation, as evidenced by New Jersey and Massachusetts being tied for the third largest retail PV markets in 2013. [1]. Average solar insolation is 4.3 kWh/m<sup>2</sup>/day and 3.3 kWh/m<sup>2</sup>/day, respectively. [2]

access to the roof and an exterior location. PV designers can enjoy the added flexibility of choosing among different inverter configurations. They may even consider adding energy storage or EV-charging capabilities in the future.

The risk that not all contractors will deliver on performance is an endemic reality for any construction project. It cannot be entirely mitigated by a robust Solar Ready standard. Yet the EPS model for verification of the Solar Ready scope may be the closest to ensuring correct specifications and documentation.<sup>2</sup> Ultimately, the minimalistic approach of providing a *tabula rasa* in the form of a solar zone is preferable to the approach of installing components that are well-suited to a system design that will most likely become obsolete in the near-to-medium term. The quality of the documentation generated for the Solar Ready scope may be the best method for transferring the intent of the Solar Ready designer to the PV designer in the future. Even if the Solar Ready scope is not suitable for the ultimate PV design, it can be analyzed in its entirety and any suitable components thus salvaged.

### *Unrealized Cost Savings*

Earlier in this work it is estimated that the savings potential of Solar Ready can be 6.3% of the system cost, while the savings of installing PV as a component of the new construction scope can render savings of 20% over a comparable retrofit system. Despite the lack of quantitative data for analysis of solar PV upgrades to Solar Ready buildings, the research found that there is no consensus as to real system cost savings from Solar Ready. Specific projects provide contending observation of the solar contractor performing the Solar Ready scope and later offering a discount on the PV upgrade to the building occupant. Yet this represents a small minority, as most contractors reported not offering a discount to upgrade a Solar Ready building. This may result from incomplete information about the Solar Ready scope or an aversion

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<sup>2</sup>Item 1.2 of the EPS installation requirements specifies: "The Installation must be of industry standard and workmanlike quality." [3]

to encountering misspecified or detrimental scopes.

The lack of any observed savings nor any transfer of such savings to end-users is a disappointing finding. In light of the 6% - 20% potential savings established in the literature, this is a strong motivating factor leading to the inception of Solar Ready building standards. This deficiency is particularly detrimental to Solar Ready advocates, in providing a counter-argument for use by Solar Ready antagonists that are motivated to reduce or eliminate the extent of these codes. Action to ameliorate the detrimental effects of this undeliverable benefit might include decoupling of potential savings in a PV “upgrade” as a benefit. The increased end-user awareness and accessibility to sustainable energy are good replacements for the surreptitious Solar Ready coupon.

Validation of the Solar Ready scope through a third party may result in superior performance and specification. However, such an audit will result in an added expense and does not directly lead to a savings in the overall cost. A topic for further research may be to quantify the value of a Solar Ready rooftop in a scenario where DERs can receive direct payments from utility system integrators.

Such a hypothetical energy landscape may be idealistic at worst and a long distance in the future at best, but it does provide a scenario where designing buildings so that they are easily adaptable for DER is an economic imperative. The value that the solar zone and the energy chase embedded within the building can realize when the building adopts PV in the future may be a hypothetical construct. Or it could evolve into a token that is traded on a future energy market, thus funding the Solar Ready scope and third-party on it’s own against the rights to a share of future energy earnings.

### **6.3 Model Policy**

A design team seeking a green building certification like LEED or the Living Building Challenge is likely to implement on-site renewable energy generation into the design.

The integration of a PV system is (now) one of the most economical tools available to designers seeking higher-tier green building certifications. The energy subcategory for the LBC requires that the building generate 105% of annual energy consumption (on a net annual basis), as well as “on-site storage for resiliency.” [4] [pp. 34]

Green building certification has the potential to transform the construction industry. Since certification is voluntary and requires greater investment, many buildings will continue to be constructed conventionally. They will have to meet local code requirements. This is the importance of building codes. They provide the baseline for livable buildings and ensure the safety of those people that interact with these.

Solar can be added to a building that is grossly energy inefficient. In such a scenario, the energy generated on the roof will offset energy consumed inside. Depending on the local energy market, adding solar in this scenario may result in a favorable investment for the building owner. But making improvements to the insulation, heating and cooling systems of the building may more often than not be a more favorable use of resources. Solar on it’s own is not a panacea towards sustainability and efficient use of energy in the built environment.

Yet a Solar Ready standard will impact the built environment in a significant way. Either as a component of a voluntary certification program or as a subsection to a building code, it sets a baseline for the adoption of a building technology that becomes ubiquitous. Providing the basic infrastructure to make buildings easily adaptable for PV in the future will safeguard workers that install the system as well as others operating on the rooftop. It will also allow future PV systems to operate better while reducing the labor-hours required for installation. It also creates a framework for the eventual adoption of other burgeoning building technologies that have yet to attain mainstream adoption or are still in the early-adopter phase.

A project seeking a green building certification is likely to incorporate a complete PV system from the earliest stages of conceptual design. The majority of new construction projects are conventional and these stand to benefit from a basic Solar

Ready scope. A solar mandate may be an option in some jurisdictions. Yet two major roadblocks would need to be overcome. Geography is a major factor in solar economics. Electrical tariffs and solar insolation vary widely around the globe. The political will for a solar mandate may be lacking, as evidenced by the fact that net-metering policies are not uniform across jurisdictions. The total effect is that the net value of the energy generated by a hypothetical solar system in one locale may be half of that generated by a similar hypothetical system in a sunnier locale with policies more favorable to DERs.

Solar Ready as a tool to benefit the safety of those working with and around solar systems is politically neutral. It provides a balance between authorities seeking to provide safe working environments for construction personnel and first responders and future building occupants exercising the option to adopt a building technology with proven environmental and economic benefits.

#### **6.4 Future Research**

This work has identified multiple avenues for future research topics. First and foremost, the identification of solar installer incident, injury and fatality rates as a unique classification separate from electrical and wiring contractors within the BLS IIF database. The solar industry holds the core value of bringing about sustainable energy solutions. The health and safety of those that install solar systems is another core value that needs to be emphasized and supported throughout. Given the hazardous working conditions that are present during solar installations, record-keeping for incidents is a priority towards preventing future occurrences.

More specific to the emergence of Solar Ready standards for new construction, a comprehensive database for Solar Ready scopes and ensuing “upgrades” to operational solar would allow for testing the hypotheses that i) Solar Ready delivers safer solar installations; and ii) Solar Ready provides real savings during solar installations. Testing for hypothesis (i) would require incident and injury rate data.

The Solar Ready installation process has been widely studied. Variations to specific designs may depend on local building codes and interconnection policies. In Washington state the remittance of production credits is structured such that a revenue-grade production meter is required as part of the solar system. Additionally, local building codes require a means of remote disconnect. These two pieces of equipment may be minor line items in the materials manifest of a PV system, yet they can grossly affect the potential labor savings otherwise realized through the Solar Ready scope. Each of these components might be investigated in greater detail, with particular focus on their engineering effectiveness and whether or not they are redundant in the context of the current state of the art in inverter and metering technologies. Anti-islanding has been embedded into inverter technology per several standards and bi-directional meters with remote data reporting are available to power utilities.

Finally, safer installation methods likely exist. Solar contractors innovate and adopt new technologies and methods on a constant basis. Analyzing the methods put into practice by diverse work crews may yield better practices that can be shared with others throughout the industry. While a permanent anchoring system for fall-protection equipment may be a worthy addition to the Solar Ready scope, there may be an installation crew that has devised a time-saving method of preparing mounting clamps prior to being on the roof. Simply identifying and disseminating novel methods may improve working conditions and reduce overall roof-time.

## REFERENCES

- [1] Samantha; Darghouth Naim Barbose Galen; Weaver. *Tracking the Sun VII: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2013 - LBNL-6858E*. Tech. rep. 2014.
- [2] Billy J. Roberts. *Solar Maps — Geospatial Data Science — NREL*. 2018. URL: <https://www.nrel.gov/gis/solar.html> (visited on 07/25/2018).
- [3] Energy Trust of Oregon. *Solar Ready Residential Installation Requirements*. Tech. rep. 2014. URL: [https://insider.energytrust.org/wp-content/uploads/sle%7B%5C\\_%7Drq%7B%5C\\_%7Dsolarreadyreq.pdf](https://insider.energytrust.org/wp-content/uploads/sle%7B%5C_%7Drq%7B%5C_%7Dsolarreadyreq.pdf).
- [4] “Living Building Challenge 3.1 : A visionary path to a regenerative future”. In: *Living Future Institute* 31 (2016), pp. 1–82. URL: [https://living-future.org/sites/default/files/16-0504%20LBC%203%7B%5C\\_%7D1%7B%5C\\_%7Dv03-web.pdf](https://living-future.org/sites/default/files/16-0504%20LBC%203%7B%5C_%7D1%7B%5C_%7Dv03-web.pdf).

## BIBLIOGRAPHY

*2018 Most Efficient Solar Panels on the Market* — *EnergySage*. 2018. URL: <https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/> (visited on 06/26/2018).

*About the Commercial Buildings Energy Consumption Survey (CBECS)*. 2012. URL: <https://www.eia.gov/consumption/commercial/about.php> (visited on 07/05/2018).

American Society of Heating, Refrigerating and Air-Conditioning Engineers. *ASHRAE 189.1-2014 Standard for the Design of High-Performance Green Buildings*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2014, pp. 22–23. URL: <https://www.scribd.com/document/357526642/ASHRAE-189-1-2014-Standard-for-the-Design-of-High-Performance-Green-Buildings>.

*Annual Report 2017*. Tech. rep. Portland, OR: Energy Trust of Oregon, Inc., 2017, pp. 14–15. URL: <https://www.energytrust.org/wp-content/uploads/2018/04/2017.Audited.Financial.Statements.pdf>.

*Appendix RB Solar-Ready Provisions*. 2015. URL: <http://www.ghba.org/wp-content/uploads/pdf/advocacy/2015-IECC-Residential-NSec-002.pdf>.

Ardani, Kristen et al. *Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030*. Tech. rep. 2010. URL: [www.nrel.gov/publications](http://www.nrel.gov/publications)..

Ardani, Kristen et al. “Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017–2030”. In: *NREL* (2017). URL: <https://www.nrel.gov/docs/fy18osti/70748.pdf>.

- Aroul, Ramya R and J Andrew Hansz. "The Value of "Green:" Evidence from the First Mandatory Residential Green Building Program". In: *Journal of Real Estate Research* 34.1 (2012), pp. 27–50. ISSN: 08965803.
- ARS 34-452 Solar design standards for state buildings*. 1997. URL: <https://www.azleg.gov/viewdocument/?docName=http://www.azleg.gov/ars/34/00452.htm>.
- Ashuri, B and H Kashani. "A Real Options Approach to Evaluating Investment in Solar Ready Buildings". In: *Computing in Civil Engineering (2011)*. Ed. by Yimin Zhu and R. Raymond Issa. Reston, VA: American Society of Civil Engineers, June 2011, pp. 768–775. ISBN: 9780784411827.
- Baird, Duwayne, Qian Chen, and Grant Holmes. "Investigation of LEED School Projects in Ohio". In: *50th ASC Annual International Conference Proceedings* (2014). URL: [www.gbig.org%20http://ascpro0.ascweb.org/archives/cd/2014/paper/CPRT247002014.pdf](http://www.gbig.org%20http://ascpro0.ascweb.org/archives/cd/2014/paper/CPRT247002014.pdf).
- Baker, Christine. *Construction case study training guide*. Tech. rep. Berkeley, CA: Commission on Health, Safety, and Workers' Compensation, 2012, pp. 10–11, 28–29. URL: <https://www.dir.ca.gov/chswc/WOSHTEP/Publications/ConstructionCaseStudyTraining.pdf>.
- Barbose Galen; Weaver, Samantha; Darghouth Naim. *Tracking the Sun VII: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2013 - LBNL-6858E*. Tech. rep. 2014.
- Brewer, Janice K and John Arnold. *Solar Energy Project Information*. Tech. rep. Phoenix, AZ: State of Arizona, 2009. URL: <http://www.azsfb.gov/sfb/Announcements/Solar%20Projects%20Memo.pdf>.
- Brown, Governor Kate. *Executive Order No. 17-20*. 2017. URL: [http://www.oregon.gov/gov/Documents/executive%7B%5C\\_%7Dorders/eo%7B%5C\\_%7D17-20.pdf](http://www.oregon.gov/gov/Documents/executive%7B%5C_%7Dorders/eo%7B%5C_%7D17-20.pdf).

- Building construction code change proposal Proposed Amendment to 2018 International Residential Code (IRC) Chapter 1*. Tech. rep. Phoenix, AZ: Planning & Development Department, City of Phoenix, 2018. URL: [https://www.phoenix.gov/pddsite/Documents/2018%20International%20Residential%20Code%7B%5C\\_%7DIRC.pdf](https://www.phoenix.gov/pddsite/Documents/2018%20International%20Residential%20Code%7B%5C_%7DIRC.pdf).
- Ca - Departments California Energy Commission*. 2016. URL: [http://www.allgov.com/usa/ca/departments/natural-resources-agency/california%7B%5C\\_%7Denergy%7B%5C\\_%7Dcommission?agencyid=150](http://www.allgov.com/usa/ca/departments/natural-resources-agency/california%7B%5C_%7Denergy%7B%5C_%7Dcommission?agencyid=150) (visited on 04/29/2018).
- California Energy Commission. *2016 Residential Compliance Manual*. 2016. URL: [http://www.energy.ca.gov/title24/2016standards/residential%7B%5C\\_%7Dmanual.html](http://www.energy.ca.gov/title24/2016standards/residential%7B%5C_%7Dmanual.html) (visited on 04/28/2018).
- Case and Demographic Incidence Rates*. URL: <https://data.bls.gov/gqt/RequestData> (visited on 08/10/2018).
- City of Boulder Energy Conservation Code 2017*. 2017. ISBN: 978-1-60983-701-3. URL: [https://www-static.bouldercolorado.gov/docs/2017%7B%5C\\_%7DCity%7B%5C\\_%7Dof%7B%5C\\_%7DBoulder%7B%5C\\_%7DEnergy%7B%5C\\_%7DConservation%7B%5C\\_%7DCode%7B%5C\\_%7D2nd-1-201711151002.pdf?%7B%5C\\_%7Dga=2.212930327.2069708652.1534295143-439395501.1532895894](https://www-static.bouldercolorado.gov/docs/2017%7B%5C_%7DCity%7B%5C_%7Dof%7B%5C_%7DBoulder%7B%5C_%7DEnergy%7B%5C_%7DConservation%7B%5C_%7DCode%7B%5C_%7D2nd-1-201711151002.pdf?%7B%5C_%7Dga=2.212930327.2069708652.1534295143-439395501.1532895894).
- Cullen, Casey. “Buildings that make Us Blossom; The Living Building Challenge in Health and Hospitality Infrastructure”. In: *Proceedings: Cornell Symposium: Hospitality, Health & Design HHDS2016 In Search of a Healthy Future*. 2016, p. 134.
- Dastrup, Samuel R et al. “Understanding the Solar Home price premium: Electricity generation and “Green” social status”. In: *European Economic Review* 56.5 (2012), pp. 961–973. ISSN: 0014-2921. DOI: <https://doi.org/10.1016/j.euroecorev.2012.02.006>. URL: <http://www.sciencedirect.com/science/article/pii/S0014292112000244>.

- Delatte, Norbert. “Lessons from Roman cement and concrete”. In: *Journal of professional issues in engineering education and practice* 127.3 (2001), pp. 109–115.
- Deng, Hengfang, David Fannon, and Matthew J. Eckelman. “Predictive modeling for US commercial building energy use: A comparison of existing statistical and machine learning algorithms using CBECS microdata”. In: *Energy and Buildings* 163 (Mar. 2018), pp. 34–43. ISSN: 0378-7788. DOI: 10.1016/J.ENBUILD.2017.12.031. URL: <https://www.sciencedirect.com/science/article/pii/S0378778817327834>.
- Department of Energy, Us. “Promoting Solar PV on Leased Buildings Guide”. In: (2015). URL: <https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Promoting-Solar-PV-on-Leased-Buildings-Guide-.pdf>.
- Dong, Jun et al. “Clean distributed generation in China: Policy options and international experience”. In: *Renewable and Sustainable Energy Reviews* 57 (2016), pp. 753–764. ISSN: 1364-0321. DOI: <https://doi.org/10.1016/j.rser.2015.12.171>. URL: <http://www.sciencedirect.com/science/article/pii/S1364032115015543>.
- DSIRE. *Business Energy Investment Tax Credit (ITC)*. 2015. URL: <http://programs.dsireusa.org/system/program/detail/658> (visited on 02/20/2017).
- DSIRE. *Modified Accelerated Cost-Recovery System (MACRS)*. 2016. URL: <http://programs.dsireusa.org/system/program/detail/676> (visited on 02/20/2017).
- Energy Efficiency and Sustainable Design in New School Construction*. 2014. URL: <http://programs.dsireusa.org/system/program/detail/3016> (visited on 05/07/2018).

Energy Trust of Oregon. *Solar Ready Residential Installation Requirements*. Tech. rep. 2014. URL: [https://insider.energytrust.org/wp-content/uploads/sle%7B%5C\\_%7Drq%7B%5C\\_%7Dsolarreadyreq.pdf](https://insider.energytrust.org/wp-content/uploads/sle%7B%5C_%7Drq%7B%5C_%7Dsolarreadyreq.pdf).

Energy Trust of Oregon. “Solar Ready Checklist”. In: (2018). URL: [https://energytrust.org/wp-content/uploads/2016/12/ENH%7B%5C\\_%7DFM0631R.pdf](https://energytrust.org/wp-content/uploads/2016/12/ENH%7B%5C_%7DFM0631R.pdf).

*FACE 9021 Roofer Dies after Falling through Skylight Fixture in Maryland*. 2013. URL: <https://www.cdc.gov/niosh/face/In-house/full9021.html> (visited on 08/10/2018).

Fu, Ran et al. “U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017”. In: (2009). URL: <https://www.nrel.gov/docs/fy17osti/68925.pdf>.

Gerarden, Todd. “Demanding Innovation: The Impact of Consumer Subsidies on Solar Panel Production Costs \*”. In: (2018). URL: [https://scholar.harvard.edu/files/gerarden/files/gerarden%7B%5C\\_%7Djmp.pdf](https://scholar.harvard.edu/files/gerarden/files/gerarden%7B%5C_%7Djmp.pdf).

*Historic Centre of Rome, the Properties of the Holy See in that City Enjoying Extraterritorial Rights and San Paolo Fuori le Mura*. URL: <https://whc.unesco.org/en/list/91> (visited on 08/09/2018).

Hoen, Ben et al. “Multi-state residential transaction estimates of solar photovoltaic system premiums”. In: *Renewable Energy Focus* 19-20 (2017), pp. 90–103. ISSN: 1755-0084. DOI: <https://doi.org/10.1016/j.ref.2017.05.006>. URL: <http://www.sciencedirect.com/science/article/pii/S1755008416304537>.

*How to Make New Buildings Truly “Solar Ready”*. 2016. URL: <https://www.sagerenew.com/press/solar-ready-buildings-in-california> (visited on 04/29/2018).

Hsieh, Chris et al. “Engineers Newsletter providing insights for today’s hvac system designer”. In: (2014). URL: [https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/standards-codes/admapn061en%7B%5C\\_%7Dv46-1.pdf](https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/standards-codes/admapn061en%7B%5C_%7Dv46-1.pdf).

- International, Solar Energy. *Solar Electric Handbook*. Boston, MA: Pearson Learning Solutions, 2013. ISBN: 978-1-256-91816-5.
- Keogh, William M, Andrew W Blakers, and Andres Cuevas. “Constant voltage I–V curve flash tester for solar cells”. In: *Solar Energy Materials and Solar Cells* 81.2 (2004), pp. 183–196. ISSN: 0927-0248. DOI: <https://doi.org/10.1016/j.solmat.2003.11.001>. URL: <http://www.sciencedirect.com/science/article/pii/S0927024803002411>.
- Kibert, Charles J. *Sustainable construction : green building design and delivery*. Fourth edi. pp. 5-6. Hoboken, New Jersey: Hoboken, New Jersey : John Wiley & Sons Incorporated, 2016.
- Korcaj, Liridon, Ulf J.J. Hahnel, and Hans Spada. “Intentions to adopt photovoltaic systems depend on homeowners’ expected personal gains and behavior of peers”. In: *Renewable Energy* 75 (Mar. 2015), pp. 407–415. ISSN: 0960-1481. DOI: 10.1016/J.RENENE.2014.10.007. URL: <https://www-sciencedirect-com.offcampus.lib.washington.edu/science/article/pii/S0960148114006326>.
- L, Galberth; Robert, Arnold; Roy L, and Bollinger; John C. “Power output control circuit for solar-powered cathodic protection system”. Jan. 1979. URL: <http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PT01&Sect2=HITOFF&p=1&u=/netahtml/PT0/search-bool.html&r=1&f=G&l=50&d=PALL&RefSrch=yes&Query=PN/4136309>.
- Lee, Hyun Woo, John Gambatese, and Chung Ho. *Applying Prevention through Design (PtD) to Solar Systems in Small Buildings*. Tech. rep. Silver Spring, MD: Center for Construction Research and Training, 2017. URL: <https://www.cpwr.com/publications/applying-prevention-through-design-ptd-solar-systems-small-buildings>.

- Li, Zhengwei, Yanmin Han, and Peng Xu. “Methods for benchmarking building energy consumption against its past or intended performance: An overview”. In: *Applied Energy* 124 (July 2014), pp. 325–334. ISSN: 0306-2619. DOI: 10.1016/J.APENERGY.2014.03.020. URL: <https://www.sciencedirect.com/science/article/pii/S0306261914002505>.
- Lisell, Lars, T. Tetreault, and A. Watson. *Solar ready buildings : planning guide*. NREL/TP ; 7A2-46078. Golden, Colo.: National Renewable Energy Laboratory, 2009.
- “Living Building Challenge 3.1 : A visionary path to a regenerative future”. In: *Living Future Institute* 31 (2016), pp. 1–82. URL: [https://living-future.org/sites/default/files/16-0504%20LBC%203%7B%5C\\_%7D1%7B%5C\\_%7Dv03-web.pdf](https://living-future.org/sites/default/files/16-0504%20LBC%203%7B%5C_%7D1%7B%5C_%7Dv03-web.pdf).
- Margolis, Robert et al. “Using GIS-based methods and lidar data to estimate rooftop solar technical potential in US cities”. In: *Environmental Research Letters* 12.7 (July 2017), p. 074013. ISSN: 1748-9326. DOI: 10.1088/1748-9326/aa7225. URL: <http://stacks.iop.org/1748-9326/12/i=7/a=074013?key=crossref.6730c0cb5513b18c3645fdd05eae8790>.
- Masbruch, Karen. *Residential Solar Readiness Ordinance*. Tech. rep. Tucson, AZ, 2008. URL: <https://www.tucsonaz.gov/files/pdsd/pdfs/GreenBuilding/june17-08-311.pdf>.
- Mehta, P. Kumar (Povindar Kumar). *Concrete : microstructure, properties, and materials*. eng. New York, 2014.
- Mormann, Felix, Dan Reicher, and Victor Hanna. “A Tale of Three Markets: Comparing the Renewable Energy Experiences of California, Texas, and Germany”. In: *Stanford Environmental Law Journal* 35 (2016). URL: <https://heinonline.org/HOL/Page?handle=hein.journals/staev35%7B%5C%7Ddid=67%7B%5C%7Ddiv=5%7B%5C%7Dcollection=journals>.

Muhammad-Sukki, Firdaus et al. "Feed-in tariff for solar photovoltaic: The rise of Japan". In: *Renewable Energy* 68 (2014), pp. 636–643. DOI: 10.1016/j.renene.2014.03.012. URL: <http://dx.doi.org/10.1016/j.renene.2014.03.012>.

*News Release - Energy Commission Adopts Standards Requiring Solar Systems for New Homes, First in Nation*. 2018. URL: [http://www.energy.ca.gov/releases/2018%7B%5C\\_%7Dreleases/2018-05-09%7B%5C\\_%7Dbuilding%7B%5C\\_%7Dstandards%7B%5C\\_%7Dadopted%7B%5C\\_%7Dnr.html?platform=hootsuite](http://www.energy.ca.gov/releases/2018%7B%5C_%7Dreleases/2018-05-09%7B%5C_%7Dbuilding%7B%5C_%7Dstandards%7B%5C_%7Dadopted%7B%5C_%7Dnr.html?platform=hootsuite) (visited on 05/16/2018).

Ohio Facilities Construction Commission. *2012 Ohio School Design Manual*. 2012. URL: <http://ofcc.ohio.gov/Resources/Design-Manual-OSDM/2012-OSDM> (visited on 05/07/2018).

Ohio School Facilities Commission. *2008 Ohio School Design Manual*. 2008. URL: <http://ofcc.ohio.gov/Resources/Design-Manual-OSDM/2008-OSDM> (visited on 05/07/2018).

Osborne, Mark. *Overcapacity: How low can module prices go?* 2016. URL: <https://www.pv-tech.org/editors-blog/overcapacity-how-low-can-module-prices-go> (visited on 05/09/2018).

*Overview/History of OFCC*. URL: <http://ofcc.ohio.gov/Home/Overview-History> (visited on 07/24/2018).

Palz, W. (Wolfgang). *Power for the world : the emergence of electricity from the Sun*. Pan Stanford Pub, 2011. ISBN: 9789814303385.

*Photovoltaic Grid Parity Monitor*. 2017. URL: <http://www.leonardo-energy.org/resources/1090/photovoltaic-grid-parity-monitor-5908f331535b8> (visited on 08/09/2018).

Pingkuo, Liu and Tan Zhongfu. “How to develop distributed generation in China: In the context of the reformation of electric power system”. In: *Renewable and Sustainable Energy Reviews* 66 (2016), pp. 10–26. ISSN: 1364-0321. DOI: <https://doi.org/10.1016/j.rser.2016.07.055>. URL: <http://www.sciencedirect.com/science/article/pii/S1364032116303859>.

*Public Utility Commission of Oregon Renewable Energy*. URL: <http://www.puc.state.or.us/Pages/Energy%20Initiatives/Renewable-Energy.aspx> (visited on 05/03/2018).

Pyper, Julia. *Everything You Need to Know About California’s New Solar Roof Mandate*. 2018. URL: <https://www.greentechmedia.com/articles/read/everything-you-need-to-know-about-californias-new-solar-roof-mandate%7B%5C%7DThebasics> (visited on 08/16/2018).

Rajendran, Sathyanarayanan and John Gambatese. “Risk and Financial Impacts of Prevention through Design Solutions”. In: *Practice Periodical on Structural Design and Construction* 18.1 (2013), pp. 71–72. ISSN: 1084-0680.

RCW. 19.28.161.

*RCW 19.28.161*. URL: <http://app.leg.wa.gov/RCW/default.aspx?cite=19.28.161>.

Reichelstein, Stefan and Michael Yorston. “The prospects for cost competitive solar PV power”. In: *Energy Policy* 55 (Apr. 2013), pp. 117–127. ISSN: 0301-4215. DOI: 10.1016/J.ENPOL.2012.11.003. URL: <https://www.sciencedirect.com/science/article/pii/S0301421512009688>.

Roberts, Billy J. *Solar Maps — Geospatial Data Science — NREL*. 2018. URL: <https://www.nrel.gov/gis/solar.html> (visited on 07/25/2018).

Romich, Eric. *Renewable Energy Policy Series: Ohio SB 221*. 2010. URL: <https://ohioline.osu.edu/factsheet/CDFS-4001> (visited on 05/07/2018).

- Runci, Paul J. “Renewable Energy Policy in Germany: An Overview and Assessment”. In: *Pacific Northwest National Laboratory Technical Report* PNWD-3526 (2005). URL: <http://globalchange.umd.edu/data/publications/PNWD-3526.pdf>.
- Russo, Mike. “Renting rooftop space is risky”. In: *RSI: Roofing, Siding, Insulation* 75.11 (Nov. 1998), p. 4. ISSN: 00337129. URL: <http://offcampus.lib.washington.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true%7B%5C%7Ddb=f5h%7B%5C%7DAN=1317880%7B%5C%7Dsite=ehost-live>.
- Sahu, Bikash Kumar. “A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries”. In: *Renewable and Sustainable Energy Reviews* 43 (2015), pp. 621–634. ISSN: 1364-0321. DOI: <https://doi.org/10.1016/j.rser.2014.11.058>. URL: <http://www.sciencedirect.com/science/article/pii/S1364032114009976>.
- Seattle Department of Construction and Inspections. *Chapter 4 Commercial Energy Efficiency*. 2015. URL: <http://www.seattle.gov/DPD/cs/groups/pan/@pan/documents/web%7B%5C%7Dinformatinal/p2623021.pdf>.
- Seattle Department of Construction and Inspections. *Residential Code - Seattle Department of Construction and Inspections*. 2015. URL: <http://www.seattle.gov/dpd/codesrules/codes/residential/default.htm>.
- SEIA, Solar Energy Industries Association. *Solar Market Insight Report 2017 Year in Review*. URL: <https://www.seia.org/research-resources/solar-market-insight-report-2017-year-review> (visited on 06/30/2018).
- Shoemaker, Michael C. and Ted Strickland. *Addendum to the 2008 Ohio School Design Manual to Provide for Solar Ready Schools*. 2008. URL: <http://ofcc.ohio.gov/Portals/0/Documents/Resources/OSDM/2008/OSDM-2008-all.pdf>.

- Solar Photovoltaic Installers*. 2017. URL: <https://www.bls.gov/oes/current/oes472231.htm> (visited on 08/10/2018).
- Solar Ready Ordinance*. Tech. rep. Tucson, AZ: Planning and Development Services Department, 2009. URL: [https://www.tucsonaz.gov/files/pdsd/permits/Solar%7B%5C\\_%7DReady%7B%5C\\_%7DSummary.pdf](https://www.tucsonaz.gov/files/pdsd/permits/Solar%7B%5C_%7DReady%7B%5C_%7DSummary.pdf).
- Specifications for Solar Readiness - City of Berkeley, CA*. URL: <https://www.cityofberkeley.info/SolarReadinessSpecs/> (visited on 04/29/2018).
- Suh, Sangwon et al. “Environmental Performance of Green Building Code and Certification Systems”. In: *Environmental Science & Technology* 48.5 (Mar. 2014), pp. 2551–2560. ISSN: 0013-936X. DOI: 10.1021/es4040792. URL: <http://pubs.acs.org/doi/10.1021/es4040792>.
- Swanson, Richard M. “A vision for crystalline silicon photovoltaics”. In: *Progress in Photovoltaics: Research and Applications* 14.5 (Aug. 2006), pp. 443–453. ISSN: 1062-7995. DOI: 10.1002/pip.709. URL: <http://doi.wiley.com/10.1002/pip.709>.
- USGBC Statistics*. 2016. URL: <https://www.usgbc.org/articles/usgbc-statistics> (visited on 05/14/2018).
- Watson, Andrea et al. *Solar ready : an overview of implementation practices*. eng. NREL/TP ; 7 A 40-51296. Golden, Colo.: National Renewable Energy Laboratory, 2012.
- Wiedman, Joseph and Tom Beach. “Distributed Generation Policy: Encouraging Generation on Both Sides of the Meter”. In: *The Electricity Journal* 26.8 (2013), pp. 88–108. ISSN: 1040-6190. DOI: <https://doi.org/10.1016/j.tej.2013.08.008>. URL: <http://www.sciencedirect.com/science/article/pii/S1040619013001905>.

Appendix A

**SURVEY QUESTIONNAIRE**

### Research Questions

no.	Question	Response	Demographic	Is Solar Ready Defined?	Is Solar Ready beneficial?	Is Solar Ready detrimental?	Is Solar Ready aligned with worker Safety?
1	What state are you located in?	fill in					
2	What electric utility serves the majority of your clients?	fill in					
3	What company do you work for?	fill in					
0	What kind of work does the company do?	Solar contractor, Electrical contractor,					
4	What is the size of the company?	5 / 10 / 15 / 20 / +20					
5	What is your title?	fill in					
6	What do you do at this company?	fill in					
7	Do you work with mainly residential, commercial or both?	Resi / Comrc / both					
8	How many years of experience do you have in your current industry?	fill in					
9	How familiar are you with "Solar Ready"?	1 / 2 / 3 / 4 / 5					
10	"To the best of your ability please try to respond the following questions	N/A					
11	How many Solar Ready buildings have you worked on?	fill in					
12	In what capacity?	Design / install solar ready only / install pv					
13	What elements have you seen incorporated into a Solar Ready design?	select all that apply [table 1]					
14	What elements would you like to see in an ideal Solar Ready scope?	select all that apply [table 1]					
15	In your own words, what would you most like to see incorporated into Solar Ready?	(fill in)					
16	Have you encountered a Solar Ready design that was counter-productive to the solar installation?	yes/no					
17	Was this a result of?	select all that apply [table 2]					
18	Has your company given a discount to install a PV array on a Solar Ready home?	yes/no/na					
19	In your experience with Solar Ready, does the scope offer material savings during the PV installation?	yes/no/other (fill in)					
20	In your own words, what do you consider the greatest benefits of Solar Ready?	(fill in)					
21	Does your company install the Solar Ready scope, is it done by another contractor, or does it vary?	Self-perform / Other contractor / Varies					

22	After installing PV on a Solar Ready building, is your company liable for any deficiencies that may arise in the Solar Ready scope of work?	Yes / No / Other (fill in)						
23	Is there any difference in Solar Ready buildings that have been verified by a third-party and those that are not?	Yes / No / Other (fill in)						
24	Are Solar Ready elements included in building plans?	Yes / No						
25	If there are any negatives to Solar Ready, what are they?	(fill in)						
26	What safety elements have you encountered in Solar Ready buildings (or non-Solar Ready buildings)?	select all that apply [table 2]						
27	What safety elements would provide your team with safer working conditions during a PV installation?	select all that apply [table 2]						
28	What building elements present the most hazards during a PV installation?	fill in						
29	What solar ready elements would provide your team with safer working conditions during a PV installation?	select all that apply [table 1]						
30	Do you or your company have a preferred anchoring system for fall protection, and if so, what is it?	Yes / No / (fill in)						

## Appendix B

### **IDEAL SOLAR READY: REFERENCE LIST OF FEATURES AND MODEL POLICIES**

This appendix includes the Solar Ready features and code examples that form the basis for the model Solar Ready scope. Below are a table listing the features suitable for a Solar Ready scope, followed by two Solar Ready building standards that define the best design practices identified through the research and finally some supplemental Solar Ready provisions to be considered in future iterations. The first building standard is the (2017) City of Boulder, Colorado energy conservation code, Section C406.<sup>1</sup> Followed by the Energy Trust of Oregon EPS Solar Ready. Lastly, some ideas for an interconnection pre-application for Solar Ready as well as a provision to install permanent anchor points under appropriate conditions.

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<sup>1</sup>City of Boulder Energy Conservation Code 2017. (2017). Retrieved from [https://www-static.bouldercolorado.gov/docs/2017\\_City\\_of\\_Boulder\\_Energy\\_Conservation\\_Code\\_2nd-1-201711151002.pdf?\\_ga=2.212930327.2069708652.1534295143-439395501.1532895894](https://www-static.bouldercolorado.gov/docs/2017_City_of_Boulder_Energy_Conservation_Code_2nd-1-201711151002.pdf?_ga=2.212930327.2069708652.1534295143-439395501.1532895894)

## SOLAR READY SCOPE

**Table 1 GENERAL SCOPE SOLAR READY FEATURES**

ROOF	ELECTRICAL	SERVICE PANEL	OTHER
Solar Zone on the roof	Junction box on or near the roof	Busbar ampacity rating suitable for PV backfeed	Consumption monitoring
Structural design load	Chase from electrical service panel area to the roof	Space in the service panel dedicated for solar PV	EV-charger Ready
Other rooftop components, with integrated flashing/waterproofing	Chase from electrical service panel area to exterior	Solar PV breakers installed in the service panel	Hard-wired network port near electrical
	Space for the inverter (outside or inside)		Additional safety components
	Junction box near the electrical service panel /		

**Table 2 SAFETY SCOPE SOLAR READY FEATURES**

ROOF	ELECTRICAL	OTHER
Permanet anchor points	Signage indicating service panel specifications	Documentation of Solar Ready features
Roof pitch less than 6:12	Ease of access to grounding electrode	
Roof materials that are safe		
Low slope roof: parapet walls		
No skylights in the "solar zone"		
No trip hazards in the "solar zone"		
No nearby overhead powerlines		

**Table 3 SOLAR ZONE: Solar Ready Scope for Rooftops**

South-facing roof section dedicated to PV array (roof orientation between 90° E and 270° W or more southerly constraints)
Free of skylights, vents, conduits, HVAC equipment and other obstructions
Structural design capable of supporting PV load (typ. 2.5 lb/sq ft)
Roof pitch less than 6:12
Capped sleeve terminated in an all-weather rated junction box integrated with finished roof
Indicate setbacks from roof edges (minimum 3' to edges, 1' to ridge)
Indicate other fire-code requirements (per local AHJ regulations)

<b>Table 4 ENERGY CHASE: Solar Ready Scope for Electrical Systems</b>	
Junction box on or near the roof	Service panel busbar ampacity rating suitable for PV backfeed
Chase from electrical service panel area to the attic / near the roof	Space in the service panel dedicated for solar PV
Chase from electrical service panel to (planned inverter location	Dedicated space for future inverter (outside or inside)
Chase from electrical service panel to exterior location [auxiliary equipment]	Other components
Junction box near the electrical service panel / inverter location	

<b>Table 5 DOCUMENTATION: Solar Ready Scope for Documentation</b>	
Roof structural load bearing capacity	Busbar ampacity / Max backfeed amperage
Planned chase and conduit routing	Permanent signage dedicated PV breaker space
Solar Zone layout	Inverter location
	Other components

### ***Boulder, CO energy conservation code***

This building code is derived from the International Code Council and includes provisions for the core areas of Solar Ready: solar zone, chase for a conduit run, electrical and documentation. Notable provisions include:

- **C406.2.2 Orientation** The orientation of the solar zone for sloped roofs is tailored to Colorado's geographic position.
- **C406.2.4 Structural design loads on construction documents** Documentation must include structural design loads for roof dead load and roof live load. The structural design need not consider a PV system, in line with fact that most PV systems fall within the design margins of 10%.
- **406.3 Interconnection pathways** There is no requirement for stubbed conduits, conduit runs, etc... Instead, documentation is to include pathways for the future routing among PV panels (on the roof), inverter location, electrical service panel (point of interconnection) and metering equipment. This design philosophy accounts for additional components (metering, remote-disconnect, EV-charging) while avoiding the possible issues that sometimes present themselves when a conduit is pre-installed by another contractor.<sup>2</sup>
- **406.4 Documentation** Documentation requirements consist solely of the solar zone on the roof (with structural design loads) and the prescribed interconnection pathways. There is no requirement for permanent signage, which may be an onerous requirement for non-solar contractors.

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<sup>2</sup>Bad workmanship and miss-specification are among the issues that can stem from pre-installed electrical components.

## ***Energy Trust of Oregon: EPS Solar Ready***

EPS is not a building code but an incentive program.<sup>3</sup> The program includes several energy-efficiency measures that supersede the code minimums. Energy-efficiency upgrades are validated through a computer-simulation. The Solar Ready incentive is validated by an independent auditor. Notable provisions include:

- **1.1** Designation of eligibility by service territory. This could be a pre-cursor to an interconnection pre-approval, discussed below.
- **1.2** The only Solar Ready provision to specify a performance standard.
- **1.10** The solar zone must meet prescribed roof-pitch and orientation. The upper limit of the roof pitch is 12/12, higher than what many installers would consider safe. The orientation is appropriate for Oregon's geographic position.<sup>4</sup>
- **1.12** Designates setbacks for the solar zone, with respect to firefighters and local fire and life safety codes.

The most notable aspect of the EPS is the incentive structure. As a whole and for the Solar Ready component, it provides a direct monetary incentive to builders that might otherwise not have any motivation to build "above code." This incentive program could serve as a model for other authorities that want to incentivize builders to invest in energy-efficiency and Solar Ready improvements.

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<sup>3</sup>Energy Trust of Oregon. (2014). Solar Ready Residential Installation Requirements. Retrieved from [https://insider.energytrust.org/wp-content/uploads/sle\\_rq\\_solarreadyreq.pdf](https://insider.energytrust.org/wp-content/uploads/sle_rq_solarreadyreq.pdf)

<sup>4</sup>Compared to Colorado, Oregon is at a more northerly latitude and PV benefits from a more southerly orientation.

## **Purpose**

Planning ahead for the installation of a solar electric system by creating a residence that is solar ready can be a significant benefit to future homeowners. This Solar Ready Installation Requirements document details the requirements and minimum criteria for solar electric components installed by builders or solar trade allies through Energy Trust of Oregon's New Homes program.

The purpose of these installation requirements is to ensure that preliminary work done to make a home solar ready is in compliance with Energy Trust's full solar installation requirements, and will result in an easier and more accessible installation of solar in the future. As a result, these specifications may differ from those of a manufacturer or exceed applicable codes.

Any variations from these solar ready installation requirements must receive prior approval from Energy Trust.

## **General**

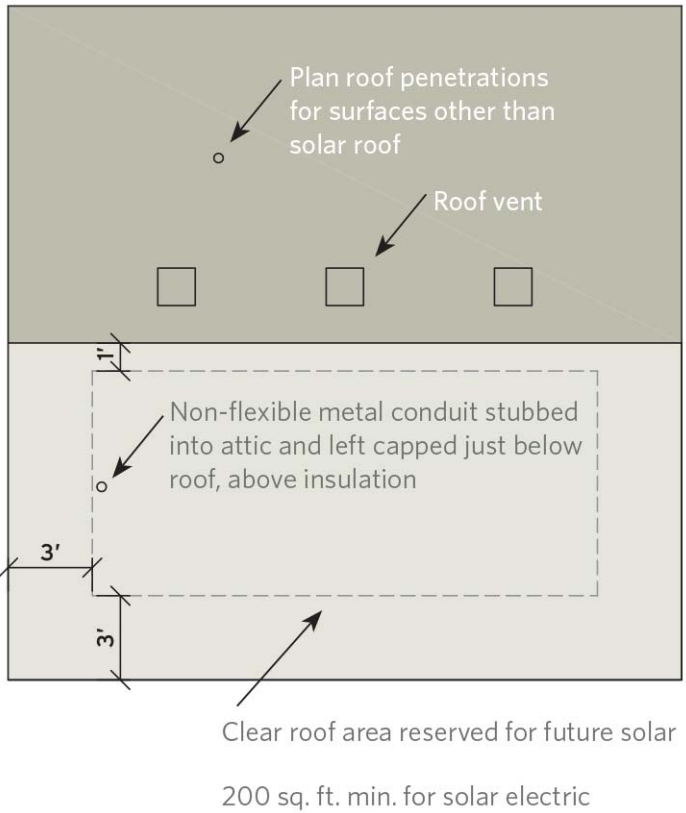
- 1.1 Installation site must be grid-connected and installed on real property in Oregon that receives electrical service directly from Portland General Electric or Pacific Power.
- 1.2 The installation must be of industry standard and workmanlike quality.
- 1.3 Equipment installers must be licensed according to the Oregon Building Codes Division and required to work for a contractor that is licensed according to the Oregon Construction and Contractors Board.
- 1.4 Dissimilar metals that have galvanic action (such as aluminum and steel) must be isolated from one another using industry standard practices (such as brass unions or nipples, non-conductive shims, washers or other methods).
- 1.5 Aluminum must not be placed in direct contact with concrete materials.
- 1.6 All installed system components must be new.
- 1.7 All components must be mounted securely.
- 1.8 Equipment must not be modified such that it voids the listing or manufacturer warranty.

## **Solar Access & Solar Roof Area**

- 1.9 The proposed future location on the roof of the solar modules (Solar Roof Area) must be included in the plan set or documented with a roof diagram that accurately describes the following:
  - Area reserved for the solar electric (photovoltaic, PV) array;
  - Location of the pre-installed conduit;
  - Set-backs from eaves or peaks, as required by Oregon Solar Installation Specialty Code (OSISC).

- 1.10 The Solar Roof Area must be located such that it can utilize 80 percent or more of the solar resource available at the site. This must be demonstrated using one of the following methods:
- Total Solar Resource Fraction, TSRF, method: There must be no less than 80 percent TSRF at the Solar Roof Area, as verified with an Energy Trust sun chart or approved shading analysis tool as described on the Energy Trust [trade ally sun chart web page](#)<sup>1</sup>.
  - Prescriptive method: Solar Roof Area must have a roof pitch between 0/12 and 12/12, an orientation between East-Southeast (113°) and West-Southwest (248°), and be completely unshaded between the hours of 9 a.m. and 4 p.m. year-round.
- 1.11 The Solar Roof Area must be free from all obstructions that would interfere with the placement of panels, including, but not limited to, chimneys, plumbing stacks, skylights, roof vents, gables, nearby overhangs, landscaping and future home construction.
- 1.12 To allow for local requirements for firefighter roof access pathways, the designated Solar Roof Area must be set back at least three feet from roof edges and one foot from ridges and roof valleys. When installed, the actual system may be located within this setback if allowed by code.

**Figure 1. Sample Solar Roof Area Best Practices**

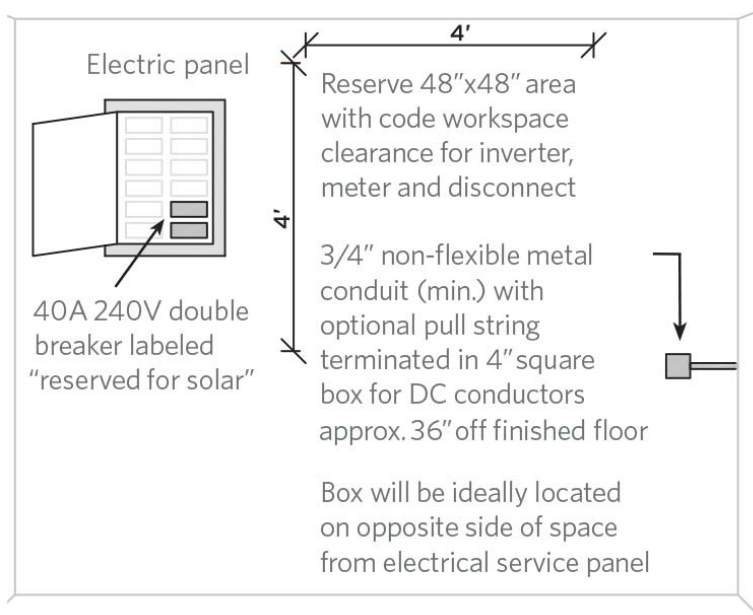


<sup>1</sup> <http://energytrust.org/shared-resources/calculating-shading>. For more information, contact Energy Trust's New Homes solar support at 503.347.0541.

## Solar Ready Electric

- 1.13 A minimum of two hundred square feet of obstruction-free roof space must be reserved for the Solar Roof Area, taking into consideration real dimensions of solar modules.
- 1.14 A 48" x 48" area of wall space as near the electrical panel as possible must be reserved for the future mounting of an inverter, meter and disconnect. If on the exterior of the house, this area must be protected from sun exposure.
- 1.15 All cables, conduit, and electrical boxes must be labeled, secured and supported according to code requirements and in accordance with their performance ratings. Conduit should have three or fewer 90 degree turns from the attic to the termination near the electric panel.
- 1.16 ¾" or larger nonflexible metal conduit must be installed from an accessible attic/roof area at the Solar Roof Area to the space reserved for the inverter near the electrical panel. Each end of this conduit must be terminated in a 4" x 4" recessed metal box with a metal cover clearly labeled "Reserved for Solar".<sup>ϕ</sup>
- 1.17 Electrical panels must be sized to accommodate a minimum 40 amp solar feed, and room must be reserved for a 40 amp double pole breaker on the opposite end from the main service feeder for the future solar feed. The reserved breaker space must be clearly labeled "Reserved for Solar."<sup>ϕ</sup>
- 1.18 A sign or label must be clearly posted on or near the electrical panel indicating that the home is "Solar Ready".<sup>ϕ</sup>

**Figure 2. Solar Ready Best Practices for Photovoltaic Systems**



<sup>ϕ</sup> Label will be provided by New Homes program and affixed by solar ready installer.

## ***Additional provisions***

### *Safety*

A model Solar Ready standard will include safety features that mitigate the fall hazards that solar workers are exposed to when working from heights. These features should be in alignment with other applicable codes. They will differ for low-slope roofs and sloped roofs. For low-slope roofs, it will require OSHA-compliant parapet walls, eliminating the need for additional fall-protection for solar installers and other workers that operate on rooftops. For sloped roofs (greater than 2/12), this provision will offer several options:

- solar zone of the roof to have a slope less than 6/12
- installation of permanent anchor points on the rooftop ridge adjacent to the solar zone. There will be at least 1 rooftop anchor for every 20' of linear roof edge.

### *Interconnection pre-approval*

The interconnection application and approval is a critical step for grid-tied PV systems. The PV system cannot operate without a connection to the utility grid. Creating a pre-approval process during new construction may benefit both the building occupant and the electrical utility. The building occupant might enjoy a faster interconnection process at the time of PV installation. The electric utility will have a register of buildings that are Solar Ready. This may help the utility in planning for future load and production capacities. Since new buildings typically request a new utility connection as a part of the permitting process, this process might be amended to include information about the Solar Ready scope for the building.