CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Mass-Manufactured, Air-Driven Trackers for Low-Cost, High-Performance Photovoltaic Systems

Gavin Newsom, Governor
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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Mass-Manufactured, Air Driven Trackers for Low Cost, High Performance Photovoltaic Systems is the final report for the Sunfolding project (Contract Number EPC-14-025) conducted by Sunfolding, Inc. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

Sunfolding designs and manufactures simple solar trackers using high volume, low cost manufacturing to create a solar tracking system powered by air. The result is a single-axis tracker that lowers the levelized cost of electricity by making solar power plants easier to design, faster to install, and smoother to operate.

The objectives of this project were to (1) investigate techniques to reduce installation and implementation time and material costs and (2) gather and analyze environmental and operating data to assess manufacturing and system performance. The culmination of the project was a 300-kilowatt demonstration field at Photovoltaics for Utility Scale Applications in Davis, California.

The results demonstrate that the technology has met or exceeded industry standards for tracking accuracy, uptime, and availability. Sunfolding's single-axis tracker features: a modular design that fits into irregular-shaped sites, enabling flexible site layouts that can add up to 20 percent more capacity on a site and lower fixed costs; and only three components, which reduces installation time by half and lowers maintenance requirements by having 95 percent fewer maintenance locations. Using the air-driven technology rather than traditional trackers, Sunfolding's team estimates a 20 percent improvement in the levelized cost of electricity and a 26.7 percent increase in the internal rate of return on a 100-megawatt site. By lowering project costs and the levelized cost of electricity, the air-driven tracker improves project profitability for customers and, by extension, lowers the cost of electricity to ratepayers.

Keywords: solar, photovoltaics, single-axis tracking, modular air-driven trackers, mass-manufacturable trackers

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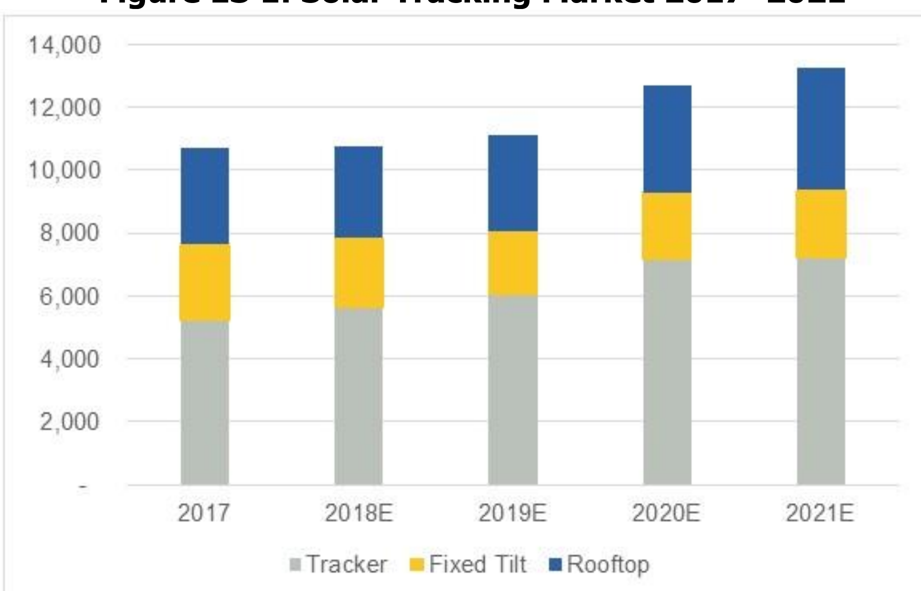
Introduction

California has been committed for decades to reduce the state's greenhouse gas emissions to avoid the effects of climate change. The California Global Warming Solutions Act of 2006 (Assembly Bill 32, Núñez, Chapter 488, Statutes of 2006) set a target of reducing statewide greenhouse gas emissions to 1990 levels by 2020. Ten years later, Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016) put into law a statewide goal to reduce greenhouse gas emissions 40 percent below 1990 levels by 2030. In 2018, then-Governor Edmund G. Brown, Jr. expanded that goal with Executive Order B-55-18 that set a statewide target for carbon neutrality by 2045 and negative greenhouse gas emissions afterward.

Renewable electricity technologies like solar photovoltaics can contribute to achieving these goals. Solar is the fastest growing energy source in the world. Fueled by the dramatic shift in component prices since 2008, solar has become viable in many markets without subsidy and consistently outperforms other energy sources in competitive auctions globally. However, development of more efficient and affordable solar photovoltaic systems is crucial to making solar cost-competitive into the future.

Solar trackers are an important element of solar photovoltaic systems. Trackers are machines that move the solar panels during the day to create the most energy possible, changing the traditional infrastructure of the solar plant. The rapid adoption of trackers by the solar industry in the last few years is a function of economics: with tracking, plants produce 20 to 25 percent more energy from the same panels.

Figure ES 1: Solar Tracking Market 2017–2021



Source: GTM Research, Global Tracker Market Landscape 2017.

In 2014, Sunfolding received funding from the California Energy Commission's Electric Program Investment Charge program to transition its tracking technology from the laboratory into the field. Sunfolding designs and manufactures simple solar trackers using high volume, low cost manufacturing to create a solar tracking system powered by air and composed by fewer components than conventional trackers, which are composed of multiple moving, mechanical parts, such as motors and gearboxes. The result is a single-axis tracker that makes solar power plants easier to design, faster to install, and smoother to operate. This in turn reduces the levelized cost of electricity, which is the present value of the price of the electricity produced considering the economic life of the generating resource and costs of construction, operation and maintenance, and fuel.

The intent of the Sunfolding project was to investigate techniques that reduce installation and implementation time and material costs and to gather and analyze environmental and operational data to assess manufacturing and system performance. The result was successful installation and operation of a 300-kilowatt demonstration field at Photovoltaics for Utility Scale Applications (PVUSA) in Davis, California that met the following project objectives:

- Scale-up, design, and procurement
- Installation
- Testing and verification: As of January 2020, Sunfolding had scaled up production and supplied solar trackers to the United States market, with 26 projects across the country, including 16 projects in California.

Sunfolding Background

Sunfolding is commercializing a new solar tracker that offers a lower levelized cost of solar electricity to customers through a reduction in tracker component costs and an improvement in the project design, construction, and long-term operation of trackers.

Over the last six years, Sunfolding has rigorously tested the product under the supervision of federal and California programs. Sunfolding developed the underlying solar tracking technology with funding from the U.S. Department of Energy Advanced Research Projects Agency – Energy (ARPA-E) under its 2012 Open Funding Opportunity Application and obtained follow-up ARPA-E funding to support further research and development testing. In 2014, Sunfolding obtained an award from the California Energy Commission Electric Program Investment Charge program to design and scale up the tracking technology from the lab to a field setting, to investigate techniques that result in less installation and implementation time and reduce material costs to install, and to obtain operational data to assess manufacturing and system performance. Subsequently, in 2016, the U.S. Department of Energy's SunShot program awarded Sunfolding funds to use advanced United States manufacturing techniques to scale the product.

Sunfolding assembled a team with expertise in renewable energy markets, solar product development, manufacturing, and business development. Collectively, the team deployed in total more than one gigawatt of solar hardware with First Solar, SMA, Schletter, and KACO New Energies.

At this time, Sunfolding has built more than 20,000 trackers with its supplier, has more than 26,000,000 actuator-hours of testing on the current product, and is distributing trackers to customers across the United States.

Sunfolding Tracker Overview

Solar trackers have been a common component in utility photovoltaic power plants for almost a decade. The shift from fixed-tilt arrays to tracked arrays introduced complexity into the solar plant infrastructure that affects nearly all aspects of a solar project from layout, installation, and maintenance to the need for larger and more skilled crews for installation. Traditional trackers use steel and motors, gearboxes, torque tubes, dampers, and other machinery components. Only about one-third of the cost of adding tracking to a plant is the tracker itself — the remaining two-thirds of the cost is a function of the added complexity.

Sunfolding's Single-Axis Tracker is unique in how it performs, with a solution that replaces machinery with air. By combining the functionality of motors, gearboxes, bearings, linkages, and heavy steel torque tubes with a single air-driven part, Sunfolding has reduced tracker installation and implementation time and lowered the cost of installation and implementation without sacrificing energy benefits of tracking.

Project Purpose

The objective of this project was to move Sunfolding's tracking technology from the laboratory to a field setting, with technical tasks culminating in demonstrating performance over a six-month period for a 300-kilowatt demonstration field at Photovoltaics for Utility Scale Applications in Davis, California. This project provided an opportunity for learning how to optimize field layout options, tracking configurations, installation and implementation techniques, and operations and maintenance approaches.

Project Process

The following technical tasks supported the project's objectives:

- Scale-up, design, and procurement: Designed alternative actuator materials and configurations for evaluation in the field and procurement of all components
- Installation: In conjunction with the selected engineering, procurement, and construction partner, developed installation methods and analyzed implementation approaches
- Testing and verification: Performed extensive monitoring and uptime analysis

Project Results

Sunfolding successfully installed the 300-kilowatt field that is currently operating at Photovoltaics for Utility Scale Applications. The team fully instrumented the demonstration field and analyzed the system performance data. The results demonstrate that the technology has met or exceeded industry standards for tracking accuracy, uptime, and availability. Sunfolding produced and tested several generations of the actuator over the life of the project. The team collected data on the full production actuator, and during the six-month testing and verification period, from July 1, 2017 to December 31, 2017, experienced no component failures in the field that would have led to a corrective maintenance event. During that period, Sunfolding also tested for tracker accuracy and found the tracker met International Electrotechnical Commission design qualification standards applicable to solar trackers for photovoltaic systems that may also be used for trackers in other solar applications. The analysis involved data cleaning, correcting wind speed to meet standards, dividing data into high and low wind speed based on a 4 meter-per-second threshold, and filtering data based on nautical twilight.

Technology Transfer Activities

Sunfolding has pursued a variety of forums to connect with partners, customers, policymakers, investors, and other important stakeholders. It participated in conferences and tradeshows, has been featured in broadcast and web interviews and publications, and has released its own videos.

For example, Sunfolding showcased its technology at the annual ARPA-E Innovation Summit in 2016 and 2017, at which Sunfolding was featured in the video "ARPA-E: Guiding Technologies to Commercial Success." Sunfolding exhibited at Solar Power International in 2017 and 2018, providing technology and product demonstrations to several dozen prospective customers and stakeholders each year.

Benefits to California

The innovative tracker's ability to deliver more economical photovoltaic systems supports California's energy goals and accrues benefits to ratepayers.

Tracked systems increase the yield of a solar plant by 15 percent to 25 percent over fixed-tilt systems. This provides additional benefits at the grid level. Unlike fixed-tilt systems, tracked systems deliver the same amount of power regardless of the sun's position and time of day. By capturing west-facing power in the late afternoon, tracked photovoltaic systems can soften, though not eliminate, ramping requirements.

Sunfolding's single-axis tracker (T29) provides benefits to its customers by lowering the end-to-end cost of a solar plant in the following ways:

- In the development phase: The tracker features a modular design that fits into irregular-shaped sites, enabling flexible site layouts that can add up to 20 percent more capacity on a site and lower fixed costs.
- In the construction phase: Traditional trackers use more than 21 components; T29 tracker uses three. Fewer components reduce installation time by half and minimize opportunity for error.
- In the operational phase: Three components, rather than the traditional 21, reduce maintenance and maximize field durability by having 95 percent fewer maintenance locations and limiting regular maintenance to an annual changing of the compressor air filter.

Using the T29 air-driven technology rather than traditional trackers, Sunfolding's team estimates a 20 percent improvement in the levelized cost of electricity and a 26.7 percent increase in internal rate of return on a 100-megawatt site. By lowering project costs and the levelized cost of electricity, the air-driven tracker improves project profitability for customers and, by extension, lowers the cost of electricity to ratepayers.

Conclusions and Next Steps

Sunfolding successfully installed and operated a 300-kilowatt photovoltaic field using its air-driven tracker technology and, based on the analysis of six months' data, exceeded expectations for tracker performance, accuracy, and uptime — all key metrics to meeting solar industry bankability requirements.

Sunfolding is now positioned to leverage high-volume manufacturing techniques to build an inherently low cost, scalable tracker. The company has scaled up production and is supplying trackers to the United States market, including 14 projects in California to date. Sunfolding continues to expand its customer base in the United States and Australia and is adding headcount in operations, sales, and business development. The company continues to invest in ongoing research and development, as well as product revisions that will further reduce the cost of solar with lower product and installation costs. The project team will continue to focus on photovoltaic plant balance-of-system improvements and system-level optimizations.

CHAPTER 1: Scale-Up, Design, and Procurement

The objectives of the scale-up, design, and procurement portion of the project were to develop the test site for installation and develop the design of the trackers for scale-up to demonstration level.

The site is still in use to test potential design variants and to collect performance data.

Test Site Development

The Photovoltaics for Utility Scale Applications (PVUSA) site is a behind-the-fence installation used for testing emerging solar technologies. Historically, the equipment installed there is new technology and understood to have more associated risk than that of fully mature technology.

Sunfolding worked with the PVUSA site owner, Clean Energy Assets LLC, to secure the rights to develop, test, and maintain a 300-kilowatt (kW) test field. The negotiation process began in August 2015 and concluded with a joint development agreement executed in April 2016.

Engineering, Procurement, and Construction Selection

Sunfolding sought an engineering, procurement, and construction (EPC) partner that could install Sunfolding trackers and work closely with the project team to develop best practices guidelines and training materials.

After developing requests for proposals and considering EPCs that were experienced with new technologies, familiar with the PVUSA site, and had knowledge of relevant Authority Having Jurisdiction requirements in Yolo County, Sunfolding selected major subcontractor Blue Oak Energy in November 2015. Blue Oak Energy had provided engineering and/or construction services on 500 distributed generation projects and 700-megawatt (MW) utility-scale projects and had extensive experience building test fields, including a 3MW test site for First Solar.

Site Preparation

Site preparation preceded tracker installation and entailed assessing environmental data for expected output of the site, determining project boundaries, and determining areas that would require regrading and the necessity of a geotechnical report before installation. The site preparation plan also involved removing existing trackers, preparing the operations infrastructure, and establishing a network connection to enable off-site monitoring. Figure 1 shows the project area in the demonstration site (PVUSA).

Figure 1: Project Area

Source: Sunfolding (2019)

PVUSA's area is approximately 2.1 acres. The project was sized to be 300kW-direct current (dc) at 33 percent ground-coverage ratio (GCR), using 18.5 percent efficient modules.

Plant Design

The basic plant layout for this project consisted of 44 trackers mounted with 96-cell modules from manufacturer SunPower, with 16 four-post trackers and 28 five-post trackers.

Installation of the test field was carried out in multiple phases to allow for testing and evaluation of different designs and configurations.

Figure 2 depicts the design of the PVUSA plant overlay.

Figure 2: PVUSA Plant Overlay

Source: Sunfolding (2019)

Tracker Design

Development of the tracker involved a rigorous product development process, internally referred to as Sunfolding's New Product Introduction (NPI). Given the extreme lifetimes and scale of deployment for solar power plants, Sunfolding's NPI is a stringent product development process that borrows from aerospace and space deployment processes. The NPI details Sunfolding's process and plan for new product launch manufacturing and commercialization, with an overall goal of low product issues once the product reaches customers. The NPI follows four phases, which begin following the completion of research. To advance to the next stage, the product must pass a "stage gate" that includes a strict set of technical and business criteria and requires cross-functional buy-in.

CHAPTER 2: Installation

The goal of the installation portion of the project was to install the test field, work closely with the selected EPC, Blue Oak Energy, and related experts and advisors to develop the installation method and best practices for installation, and develop the official installation method for future deployments and product launch.

Installation Process

The test field was installed in several segments, which enabled Sunfolding team to evaluate the installation process during each phase of the New Product Introduction.

As noted in Chapter 1, the installation plan was structured to give Sunfolding flexibility in how the tracker subsystems were configured and installed, while requiring fewer total EPC mobilizations. The first mobilization at PVUSA entailed working with Blue Oak to develop the design and foundation location plan, complete survey and place markers for foundations, install all foundations, and install the equipment pad for the compressor and the ancillary power panel. The rest of the installations took place as part of engineering verification tests prescribed by the NPI process.

Sunfolding documented the installation, recording elements with video, and soliciting feedback from Blue Oak Energy when the installation was complete to inform content of the installation manual, construction guides, and additional training materials.

Documentation

Installation instructions are critical to the long-term integrity of the solar power plant, as well as activation of product warranties and guarantees.

Installation Manual

The installation manual outlines the steps, sequential and non-sequential, to install the tracker, with detailed instructions and images.

Sunfolding staff continually revise and update installation materials, including how-to videos and simplified construction guides, to reflect lessons learned in the field. The project team submitted the first revision of the Installation Manual to the California Energy Commission (CEC). The Installation Manual is now on its fourth revision.

Construction Documents

The construction documents that were generated for the PVUSA installation include site layout drawings, post drawings, row layout drawings, and tracker installation drawings.

CHAPTER 3: Testing and Verification

The objective of the testing and verification phase of the project was to install and validate performance using next generation solar trackers that have the simplicity and flexibility of tracker-less plants. Sunfolding installed a 300kW demonstration field at PVUSA in Davis, California, which provided an opportunity for learning about and proving out different variations and aspects of Sunfolding's tracker, specifically investigating manufacturing options, field layout options, tracking configuration, and operations and maintenance (O&M) approaches.

Sunfolding Test Program

Sunfolding operates a comprehensive reliability program, the Sunfolding Test Standard, developed under the scrutiny of the Department of Energy Advanced Research Projects Agency – Energy (ARPA-E). The Sunfolding Test Standard is a detailed regimen that evaluates key sub-components, namely the actuator and the pneumatic system. This standard has basic existing photovoltaic (PV) tracker standards, but is designed to be relevant to Sunfolding's particular system and specifications. The test standard consists of 11 tests that evaluate pressure, ultraviolet (UV), abrasion, loading, creep, and mechanical and thermal cycling. Under this test regime, the full production actuator has performed to specification or beyond.

Field Testing

The goals were to fully instrument the site and monitor and characterize and assess performance after collecting six months of data on the full 300kW field. The PVUSA site was instrumented with sensors, cameras, and data collection equipment. Distributed position sensors were installed to gather temporal positioning and provide tracker consistency data. High accuracy air pressure sensors were deployed to assess pneumatic performance, and a video monitoring system was installed to enable remote visual monitoring.

The team collected data from the built-out 300kW site starting on June 23, 2017.

Instrumentation

To conduct the required analysis, the test site was instrumented as shown in Table 1.

Table 1: Instrumentation Overview

Instrumentation	Description	Purpose
Inclinometers	Angles of slope or tilt	Tracking accuracy
Video monitoring	Internet-enabled camera	Remote visual inspection
Pressure sensors	Measurement of air pressure	Pneumatic monitoring and FMEA
UV sensors	UV exposure under normal operation	Product lifetime testing
Anemometer	Measurement of wind speed	Monitor environmental conditions, evaluate tracker accuracy
Temperature sensors	Measurement of temperature	Temperature rise throughout the day relative to ambient

Source: Sunfolding (2019)

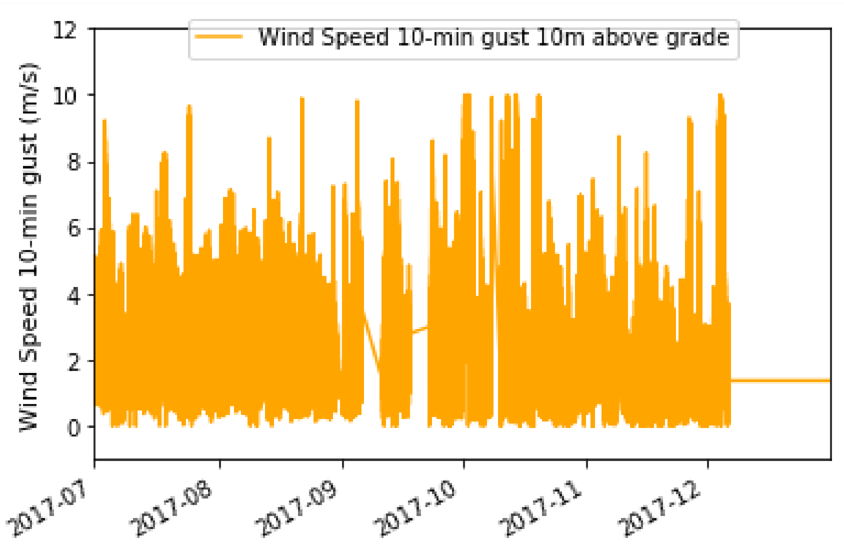
Environmental Data Collection

This section reviews environmental data that was collected including wind, UV, and temperature data.

Wind

The research team installed an anemometer on the site and collected wind speed data. For the purposes of this technical task, the team used wind speed data to evaluate tracker accuracy and consistency, as shown in Figure 3.

Figure 3: Wind Data Collected at PVUSA Over Six-Month Period



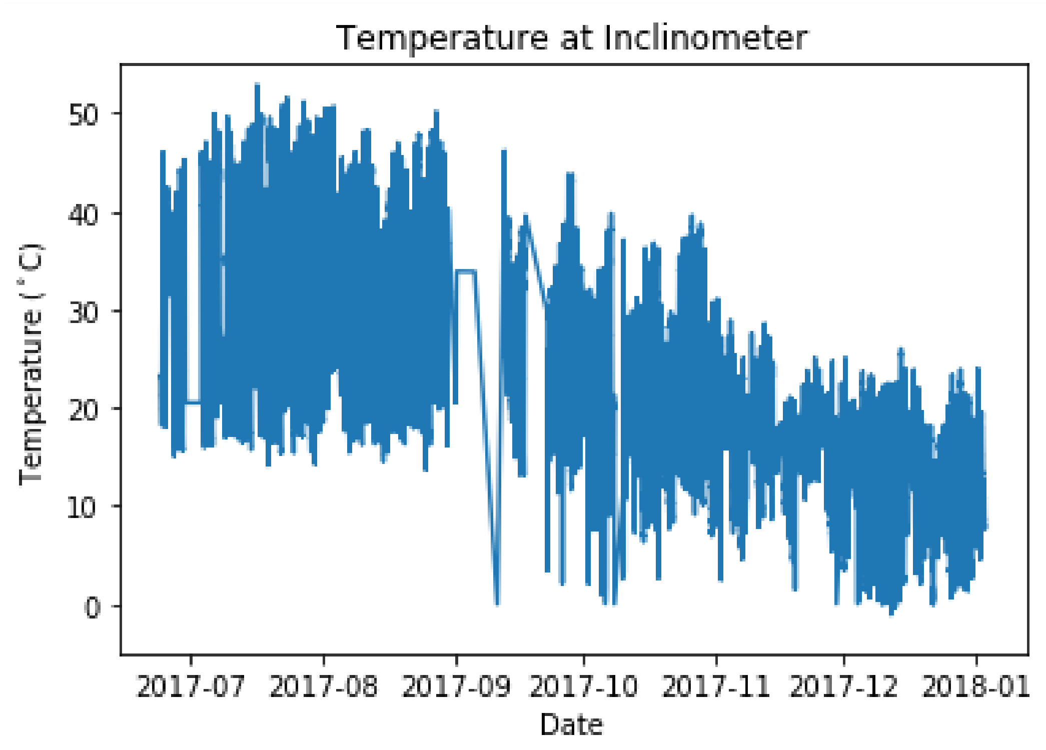
Source: Sunfolding (2019)

Temperature

Temperature sensors were implemented in the field to determine the temperature rise throughout the day relative to ambient. One temperature sensor was placed on the bellows cap closest to the solar panel and was expected to have the highest temperature rise. The temperature rise is only an average of 35.6 degrees Fahrenheit (2 degrees Celsius) higher than ambient, and all within 51.8 degree Fahrenheit (11 degrees Celsius). This measurement is also used to inform product accelerated lifetime testing.

Figure 4 shows the data collected from the inclinometer during the pilot demonstration activities.

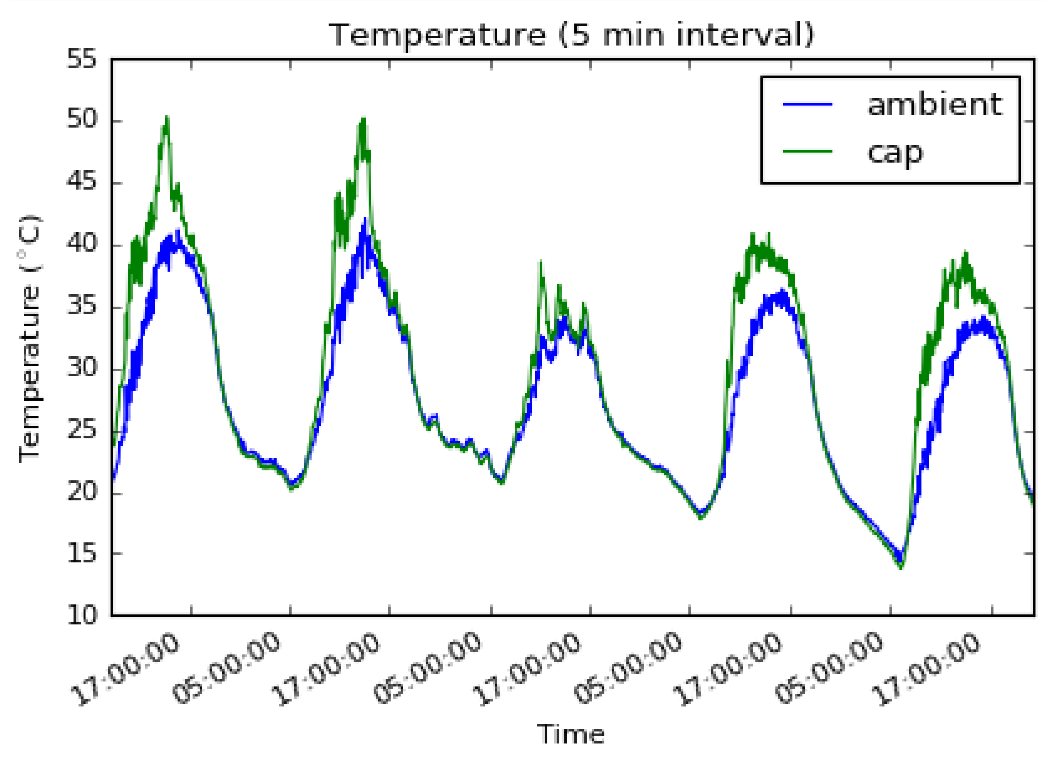
Figure 4: Temperature at Inclinometer During Six-Month Period



Source: Sunfolding (2019)

Figure 5 illustrates the temperature of bellows during the test period.

Figure 5: Temperature of Bellows Relative to Ambient



Source: Sunfolding (2019)

Ultraviolet

Sunfolding evaluated the amount of UV the Sunfolding tracker would experience using UV sensors installed throughout the field. These tests have strongly improved Sunfolding's understanding of the amount of UV the Sunfolding tracker is exposed to under normal operation.

Pneumatic System Characterization

Sunfolding evaluated the pneumatic system using pressure sensors and a series of tests in the field and in simulations. These tests have strongly improved Sunfolding's understanding of the system and the effect of changes in pressure and position on tracker performance.

Assessment of 300kW Field Performance

Failure Rates

During the testing period, no component failures were observed in the 300kW site; no corrective maintenance events occurred.

Sunfolding has produced and tested several generations of the actuator over the life of the project. Sunfolding collected data on the full production actuator for the testing and verification period July 1, 2017 – December 31, 2017, during which no component failures were experienced in the field that led to a corrective maintenance event.

Tracker Performance

Tracker accuracy meets International Electrotechnical Commission (IEC) 62817 Ed. 1.0 b section 7.4 standards, and its accuracy was calculated based on those standards.

The analysis involved data cleaning, correcting wind speed to meet standards, dividing data into high and low wind speed based on a 4 meter-per-second (m/s) threshold, and filtering data based on nautical twilight. The project team used data acquired at the 300kW site from July 1, 2017 to December 31, 2017.

Uptime/Availability

The project objective is to assess uptime of field, which is the percentage of time the system is operational. Uptime refers to the measure of reliability or stability of a system. For the 300kW site over a six-month period, Sunfolding calculated availability from July 1, 2017 to December 31, 2017.

The Sunfolding test site at PVUSA was fully instrumented and improved the team's understanding of the system and its subcomponents in the field. Based on its analysis following six months of data collection, Sunfolding finds the system is exceeding expectations in terms of tracker performance, accuracy and uptime, which are key metrics to meeting solar industry bankability requirements.

CHAPTER 4: Evaluation of Project Benefits

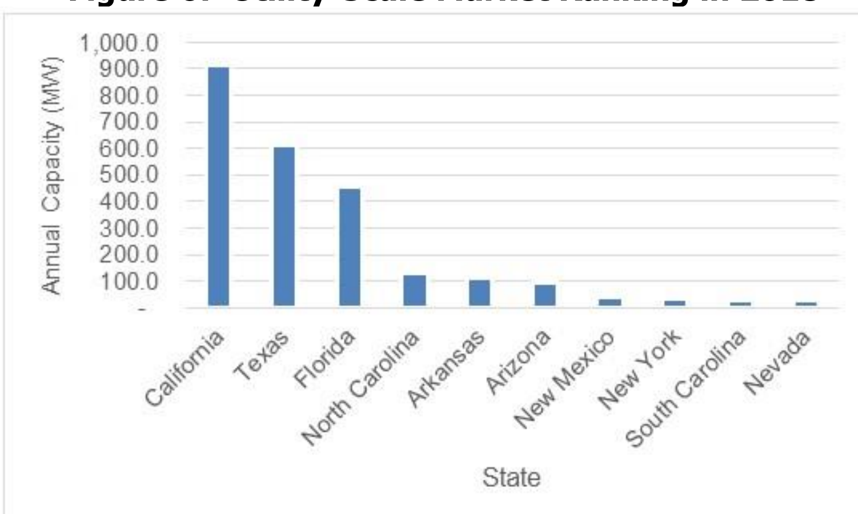
This Sunfolding technology helps address several of the state's energy policy goals: 1) the cost of renewables, 2) late afternoon peak demand, and 3) operational challenges associated with high penetration renewables in the long-term.

With the recent passage of Senate Bill 100, the California Clean Energy Act, California has set itself apart as a global clean energy leader with the aim to reach a goal of 100 percent zero-carbon electricity by 2045. Sunfolding's air-driven tracker technology and its ability to deliver PV systems with a lower levelized cost of electricity (LCOE) bring benefits to California that address state energy goals and accrue to ratepayers and the grid.

Benefits to Customers

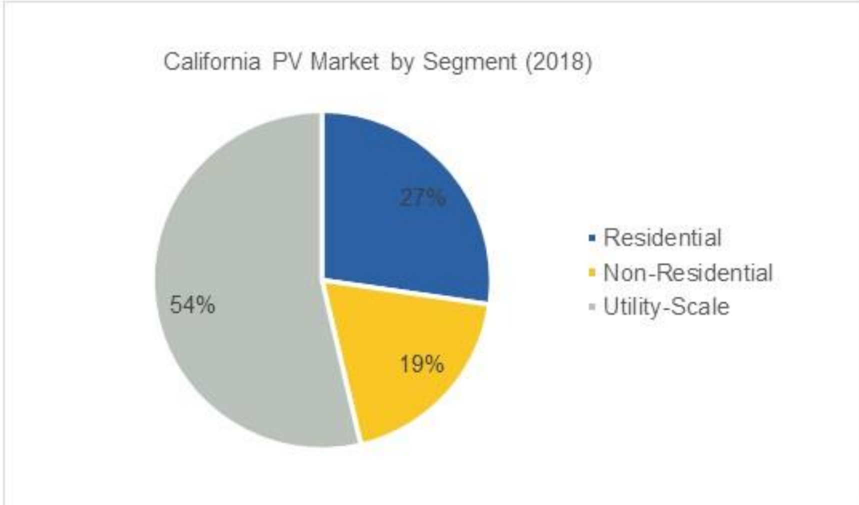
California is the top solar PV market in the United States and has the highest percentage of electricity generation from solar at 15.6 percent, as shown in Figure 6. Figure 7 shows how utility-scale projects constitute the majority of new capacity additions on the grid in California. According to GTM Research, California has 12.5 gigawatts (GW) of utility-scale solar plants currently operating and a forecast of 7.3 GW to be added by 2023.

Figure 6: Utility-Scale Market Ranking in 2018



Credit: Solar Energy Industries Association (SEIA). U.S. Solar Market Insight. Dec 2018.

Figure 7: California Photovoltaic Market by Segment (2018)

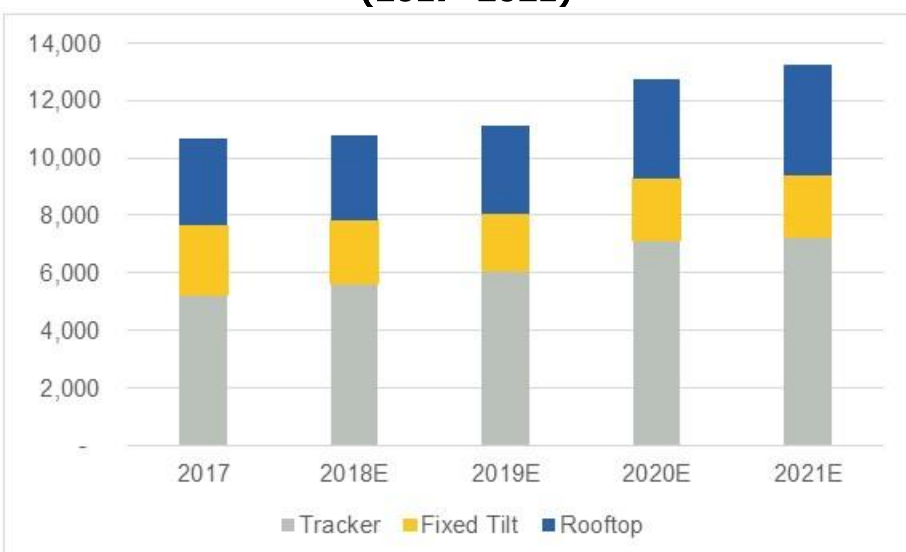


Credit: Solar Energy Industries Association (SEIA). U.S. Solar Market Insight. Dec 2018.

All components of a photovoltaic system other than the photovoltaic panels, known as the structural balance of systems (SBOS), consists of mounting and racking for rooftops, carports, and fixed-tilt and tracked-ground mount systems. The SBOS market is dominated by single-axis tracking.

Figure 8 shows the estimates of annual capacity of solar PV technologies in the United States.

Figure 8: United States Racking Market Annual Capacity in Megawatts (2017–2021)



Credit: GTM Research, Global Tracker Market Landscape 2017.

Trackers are the backbone of a majority of PV power plants in California and the rest of the United States. Sunfolding's tracker can be used in ground-mount applications in non-residential and utility-scale markets. Ground-mount systems are installed in approximately 75 percent of the utility-scale market, with the rest being fixed tilt. Non-residential systems are primarily on rooftops, with a smaller portion being ground-mount. While trackers are a relatively modest percentage of the non-residential market, gains are being made because of community solar and corporate purchases.

On a 100MW site, Sunfolding's team estimates a 20 percent improvement in LCOE over traditional trackers and a 26.7 percent increase in internal rate of return (IRR) based on the assumptions shown in Table 2.

Table 2: Project Levelized Cost of Energy Assumptions

	Fixed Tilt	Traditional 1-Axis	Sunfolding
Capital Cost ($/W)	$0.85	$0.95	$0.87
Capacity Factor	20%	25%	25%
Fixed O&M Cost ($/MW-year)	$1,000	$5,000	$1,000
Analysis Period (years)	30	30	30
Discount rate (%)	7%	7%	7%

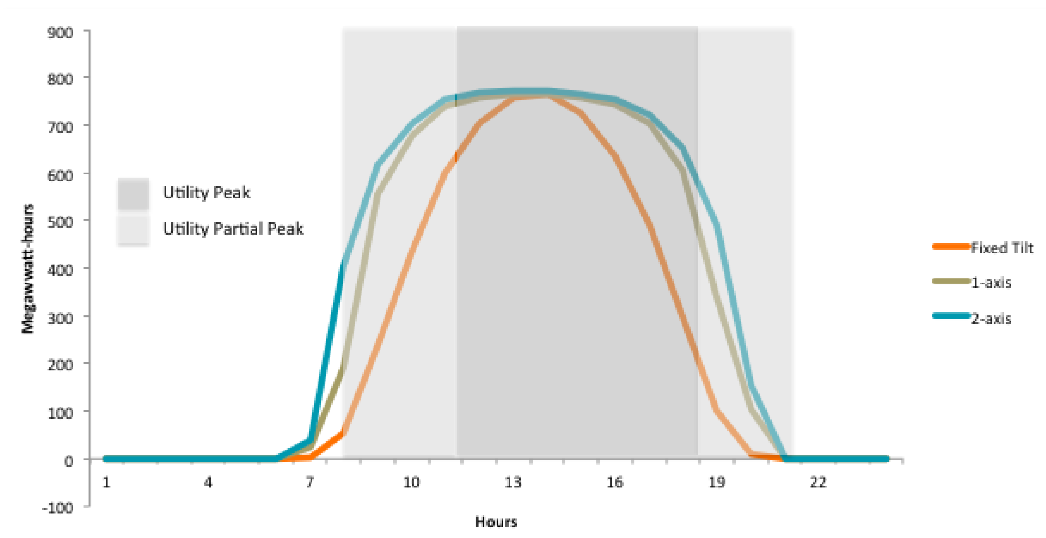
Source: Sunfolding (2019)

Impact on Reliability

Peak Demand

There is a mismatch between when much of California's solar generation occurs and when the utility system's demand is at its highest, though only by a few hours. Figure 9 compares the production from a fixed-tilt PV system to a one-axis and two-axis tracked PV system in Pacific Gas and Electric (PG&E) territory.

Figure 9: Daily Solar Production Profile for a 1MW PV System in August in Sacramento



Source: Sunfolding (2019)

When the utility experiences high demand on the grid, one-axis trackers still produce considerable power relative to their noontime peak output. Solar production that is available later in the day will mean less air pollution from gas-fired generators during peak periods. Table 3 compares peak solar output during early evening hours in a typical August.

Table 3: Comparison of Solar Output for Fixed Tilt and 1-Axis

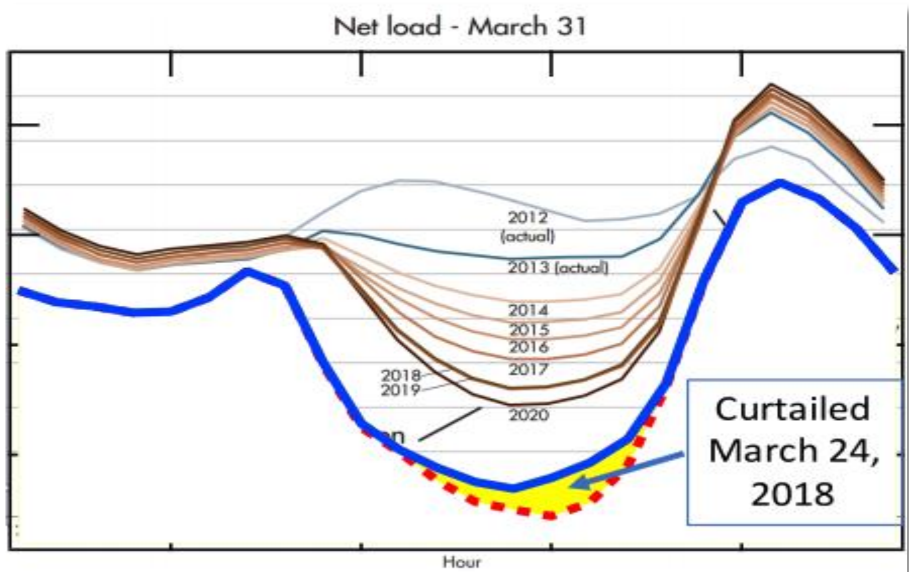
Percent of Solar Output @ 12pm	Fixed Tilt	1-Axis
@ 5pm	39%	79%
@ 6pm	13%	44%
@ 7pm	1%	13%

Source: Sunfolding (2019)

Grid Integration

The "duck curve" caused by "net peak load" has been identified as a serious challenge to the grid under a high renewable penetration scenario. Adding flexibility to the system (for example, through fast-ramping storage and curtailment) will be key to dealing with the issue. Capturing the sun in the late afternoon can soften the steep upward curve that is the result of moving from over-generation during the middle of the day to the systemwide peak demand in the evening[1], as shown in Figure 10.

Figure 10: Duck Curve in California



Source: National Renewable Energy Laboratory (2018)

Effect on Jobs

Working in close collaboration with companies like Dupont and tapping into established automotive supply chains, Sunfolding is creating jobs in California and the United States through design and manufacturing. It has modeled the job creation benefits using National Renewable Energy Laboratory's Jobs and Economic Development Impact model and finds that the work supports approximately 860 jobs per GW, which – given the growth in the tracker market, Sunfolding's differentiation, and ability to scale – the Sunfolding team expects to surpass within a few years of commercialization.

[1] NREL Q4 2017/Q1 2018 Solar Industry Update, May 2018. National Renewable Energy Laboratory, Publication NREL/PR-6A20-7149, https://www.nrel.gov/docs/fy18osti/71493.pdf

Qualitative or Intangible Benefits to Ratepayers

There are environmental and human health benefits that accrue to California ratepayers over the 30-year life of the project. Annual emissions reductions associated with a 100MW single-axis Sunfolding system are estimated below based on California's 2016 electricity mix. Table 4 illustrates the emissions avoided by installing a 100 MW PV Plant.

Table 4: Emissions Avoided By a 100 MW PV Plant in California Over 30 Years

Type	CO_2	CH_4	N_2O	CO_2e	NOx	SO_2
Metric Tons	14,595	1	0	14,651	16	1

Source: Sunfolding (2019)

Calculation assumptions:

- 1 MW direct current generates 2,208 MWh/MW alternative current
- Source: U.S. Environmental Protection Agency (U.S. EPA) Power Profiler

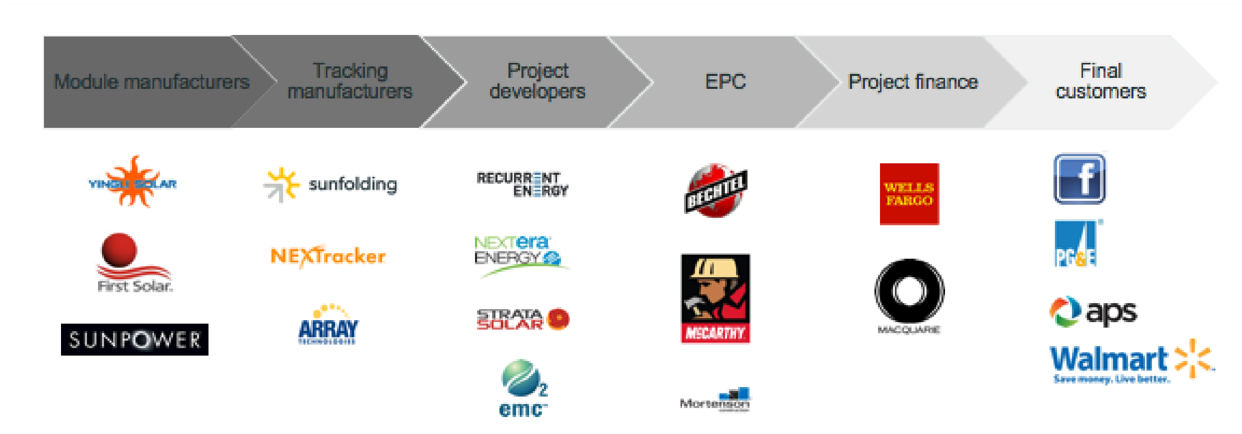
There are intangible health benefits associated with improved air quality from reduced emissions from conventional power plants. According to the U.S. EPA, improving air quality reduces the adverse public health effects that result from exposure to air pollution and reduce the costs of associated public health risks. These risks include premature mortality and exacerbation of health conditions such as asthma, respiratory disease, and heart disease.

CHAPTER 5: Technology Transfer Activities

Path to Market

Solar trackers are upstream in the solar value chain, along with modules and inverters, because are engaged in manufacturing. Project developers specify whether projects include trackers, while the bidding and procurement is typically left to solar integrators and engineering, procurement, and construction firms. Figure 11 shows the solar value chain and major players.

Figure 11: Photovoltaic Value Chain



Source: Sunfolding (2019)

One of the Sunfolding's initiatives to take the solar tracking technology to the market was the preparation of a sales and marketing plan that included prioritizing markets, geographies, and customers based on its value proposition and commercialization timeline. Sunfolding has scaled up production and is supplying trackers to the United States market. Sunfolding has installed 12 projects in the California Central Valley with an agricultural co-op, and has 16 projects operating as of December 2018. Sunfolding broke ground on a 39-MW project in March 2019 in California. Sunfolding also has several projects on the East Coast, in Pennsylvania, South Carolina, and Georgia.

During the sales lifecycle, customer stakeholders include personnel from supply chain, procurement, engineering, construction, operations, maintenance, finance, and sales. As the team receives feedback from various customer stakeholders, Sunfolding continually refines its core value proposition by customer type and market. Sunfolding is also developing new sales and marketing collateral (case studies and white papers) while evolving existing materials (product datasheet, product brochure, sales deck) to address the various stakeholders. Table 5 lays out the types of materials developed for potential customers and key stakeholders.

Table 5: External Stakeholder Information Transfer Summary

Sunfolding Department	Information Transferred	External Stakeholder
Engineering	Construction Documents Installation Manual Technical Application Notes	Developers EPCs
Supply Chain	Part specifications	Suppliers
Marketing	Brochures Videos Case studies White papers Promotional materials Website	Developers EPCs Banks/Finance
Sales	Product datasheet Sales deck Project proposals Project layouts Supporting documentation	Developers EPCs Asset owners
Customer Care	Training materials O&M manual Replacement parts lists	EPCs O&M firms Asset owners

Source: Sunfolding (2019)

Additional Technology Transfer Activities

Sunfolding has participated in a number of forums to connect with partners, customers, policymakers, investors, and other important stakeholders. Table 6 includes technology transfer activities including conferences, tradeshows, web, social media, and earned and owned media.

Table 6: Technology Transfer Activities

Date	Channel	Name	Description
February 2016	Conference	ARPA-E Energy Innovation Summit	Sunfolding showcased its technology at the annual ARPA-E Energy Innovation Summit. The team had the honor of speaking with many energy and policy leaders at the event, including former Vice President, Al Gore. 
June 2016	Conference	Clean Energy Ministerial (CEM7)	Sunfolding was invited to participate in the Clean Energy Ministerial (CEM7) in San Francisco. CEO Leila Madrone was featured in a CBS news story
September 2016	Tradeshow	Solar Power International	Attended Solar Power International, hosting technology demonstrations for more than 20 prospects
February 2017	Conference	ARPA-E Energy Innovation Summit	Sunfolding had a good presence at the ARPA-E Energy Innovation summit, with Sunfolding co-founder, Saul Griffith, as a keynote speaker, Sunfolding showcasing its technology as an exhibitor, and ARPA-E featuring Sunfolding in the video "ARPA-E: Guiding Technologies to Commercial Success." https://bit.ly/2WcwsRY

Date	Channel	Name	Description
September 2017	Conference	Solar Power International	Exhibited at Solar Power International with an 800-square-foot booth. Provided technology and product demonstrations for more than 40 prospects. 
December 2017	Conference	CEC/ARPA-E	Presentation to CEC/ARPA-E on commercialization challenges in Sacramento, California.
February 2018	Conference	CEC EPIC Symposium	Presented a poster at the CEC EPIC Symposium in Sacramento, California.
May 2018	Conference	NREL Industrial Growth Forum	Sunfolding wins NREL Best Venture Award. https://bit.ly/2D2zIbI 

Date	Channel	Name	Description
June 2018	Earned Media	Greentech Media	Leila Madrone’s Watt It Takes interview with Powerhouse airs on GTM Media’s “The Energy Gang” podcast. https://bit.ly/2F6cJ1Q 
	Website	Sunfolding video	Released a video about Sunfolding’s approach to tracking. https://bit.ly/2Q20UL6
July 2018	Earned Media	Venture Beat	Sunfolding accepted into Macquarie Capital Venture Studio as part of first cohort. https://bit.ly/2AQDIdI
August 2018	Earned Media	ASME Mechanical Engineering Magazine	Featured in ASME’s Tech Gadget (print only) 

Date	Channel	Name	Description
September 2018	Earned Media	Macquarie Capital	Macquarie Capital article "Follow the sun: The air-powered technology that is boosting the economics of solar energy." http://macq.co/kjB9
	Earned Media	Macquarie Capital	Macquarie Capital video "Spotlight on Sunfolding." https://bit.ly/2S8UxKi
	Earned Media	San Francisco Business Times	Sunfolding accepted into Elemental Excelerator's 2019 Cohort. https://bit.ly/2Qd2ysW
	Tradeshow	Solar Power International	Exhibited at Solar Power International with a 600-square-foot booth. Provided technology and product demonstrations for more than 60 prospects.
October 2018	Social Media	First Solar	First Solar Interview of Sunfolding at SPI video. https://bit.ly/2R9Urhr
	Website	Sunfolding	Sunfolding releases new video on approach to manufacturing and reliability. https://bit.ly/2yEyKiV
	Earned Media	Forbes	*Forbes* article covers Sunfolding's approach to bankability. https://bit.ly/2EW3lh8
November 2018	Earned Media	Green Biz	Green Biz coverage of Sunfolding at Global Energy Forum at Stanford University. https://bit.ly/2OtVC9F
December 2018	Earned Media	CleanTechnica	CleanTechnica article covers Sunfolding's 39-MW project. https://bit.ly/2QjM5TH

CHAPTER 6: Production Readiness Plan

Production Readiness Overview

The Sunfolding T29 is designed at the Sunfolding headquarters facility located in San Francisco, California. Manufacturing and fabrication of the individual components of the Sunfolding T29 is conducted by a network of qualified suppliers in the United States. As a result of the testing and validation activities, Sunfolding is in full production with the Sunfolding T29, supplying customers since 2016 and scaling up.

T29 system uses mass manufacturing and high-lifetime polymers coupled to streamlined structural components, resulting in a low-cost, low-weight, low-part-count, and robust tracker. Its manufacturing processes scale to high volume with established manufacturing equipment, removing traditional supply constraints.

Sunfolding has established a world-class supply chain with partners that are behind some of the most dependable material applications in the world, including air brakes used in big rig trucks and suspension systems for trains and industrial lifts. With partners, Sunfolding team leverages materials and manufacturing processes with decades of operating experience.

Sunfolding believes it is strategically superior, given current market conditions, to manufacture T29 bellows and actuators within the United States for a number of reasons, including reduced shipping costs, reduced lead times, reduced installation risks, ease of supplier collaboration during production ramp-up, ease of factory inspections and satisfying customer expectations that want to boost the local, regional, and national economies.

Key Suppliers

The T29 supply chain primarily involves suppliers for actuator, controller, and metal racking systems; pneumatic hardware and components are typical, off-the-shelf sources. The manufacturing facilities are located in the United States and were selected for their excellence in quality control and scaling similar products. Figure 12 illustrates the manufacturing of T29 parts.

Figure 12: Repurposed Automotive Factory Assembling Sunfolding Parts

Source: Sunfolding (2019)

Descriptions of Sunfolding's major suppliers follow.

Bellows Material

DuPont is a publicly traded (NYSE: DD) conglomerate, founded in the United States in 1802. In the 20th century, DuPont developed many polymers and has become the world's fourth largest chemical company based on market capitalization, and eighth based on revenue. Its stock price is a component of the Dow Jones Industrial Average. DuPont is a Fortune 500 company, ranked 87th on the list in 2015. DNV GL views DuPont's expertise in the polymer industry as a significant advantage to Sunfolding. DuPont also works closely with the Sunfolding engineering team to help ensure manufacturability of parts and proper material selection for different worldwide manufacturing markets.

Actuator Assembly

Martinrea International Inc. develops and produces metal parts, assemblies, modules, fluid-management systems and complex aluminum parts, primarily for the automotive sector. The company is headquartered in Vaughan, Ontario, Canada and has more than 14,000 employees at over 50 manufacturing and engineering facilities in North America, South America, Europe and Asia. With reported revenues of $3.9 billion (CAD) in 2016, Martinrea has the technical ability, engineering expertise, and company strength needed to supply the actuator assembly for the Sunfolding T29.

Control Components

LeeMah Electronics Inc. is a global electronics manufacturing service company founded in 1971. They have locations in California, Texas, and China, all which have been certified to ISO 9001:2008.

Racking Components

OMCO Solar is a division of OMCO Holdings, the largest custom-roll metal former in the United States according to their website. OMCO has been producing highly engineered metal shapes for a wide range of industries since 1955. OMCO Solar was established in 2009 in order to enter into the expanding solar industry by producing custom mounting structures. OMCO Solar claims their products have been used in nearly 7 GW of deployed solar installations.

Pneumatic Components

Atlas Copco is a large multi-national manufacturer and distributor of compressors, vacuum equipment, air treatment systems, power tools, and construction and mining equipment. The company's global reach spans about 180 countries, including operations in more than 90 countries. Manufacturing is mainly concentrated in Belgium, Sweden, Germany, the United States, India and China.

CHAPTER 7: Conclusions/Recommendations

Sunfolding successfully installed and operated a 300-kilowatt photovoltaic field using its air-driven tracker technology and, based on the analysis of six months' data, exceeded expectations for tracker performance, accuracy, and uptime—all key metrics to meeting solar industry bankability requirements.

As a result of the CEC's EPIC funding, Sunfolding is now positioned to leverage high-volume manufacturing techniques to build an inherently low cost, scalable tracker. The company has scaled up production and is supplying trackers to the United States market, with 26 projects as of January 2020, 16 of which are in California, including 39-MW project in operation. Sunfolding continues to expand its customer base in the United States and Australia and is adding headcount in operations, sales, and business development. The company continues to invest in ongoing research and development, as well as to work on product and installation revisions that will further reduce the cost of solar. The project team will continue to focus on PV plant balance-of-system improvements and system-level optimizations.

LIST OF ACRONYMS

Term	Definition
ARPA-E	Department of Energy Advanced Research Projects – Agency
U.S. DOE	U.S. Department of Energy
CEC	California Energy Commission
EPC	Engineering, Procurement, and Construction
EPIC	Electric Program Investment Charge
EPA	U.S. Environmental Protection Agency
GCR	Ground-Coverage Ratio
IEC	International Electrotechnical Commission
kW	Kilowatt
MW	Megawatt
O&M	Operation and Maintenance
PV	Photovoltaics
SBOS	Structural Balance of Systems
SEIA	Solar Energy Industries Association
UV	Ultraviolet

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