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FINAL PROJECT REPORT

Smart Inverter Interoperability Standards and Open Testing Framework to Support High-Penetration Distributed Photovoltaics and Storage

**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.

Smart Inverter Interoperability Standards and Open Testing Framework to Support High-Penetration Distributed Photovoltaics and Storage (Contract Number EPC-14-036) is the final report for the project conducted by the SunSpec Alliance. 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](http://www.energy.ca.gov/research/) (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

Distributed energy resources, typically consisting of solar photovoltaic and energy storage systems on homes and commercial buildings, are a growing source of power on the electric grid. Paired with smart inverters, distributed resources have vast potential as a controllable resource for the grid. This report describes the framework of deploying and integrating California Rule 21-compliant smart inverters into the grid. The project successfully demonstrated that smart inverters could achieve more than 100 percent distributed energy resources penetration of peak distribution circuit load. This result shatters the Institute of Electrical and Electronics Engineers' (IEEE) national 15-percent-distributed resources ceiling standard guideline, which is observed by utilities nationwide. Kitu Systems, a project subcontractor and system integrator, provided IEEE 2030.5/CSIP network software, a communications aggregation platform, saving utilities from micro-managing thousands of residential distributed energy resources, and enabling distributed energy resource providers (for example, solar companies) to easily onboard their installations and comply with Rule 21 requirements.

The financial analysis of smart inverters shows a value of \$640 million to \$1.4 billion per year of smart inverters' benefits, in addition to showing improvements in the areas of reliability, power quality, energy delivery efficiency, dispatchable resources, and avoided or deferred transmission and distribution upgrades.

Keywords: solar, photovoltaic, PV, distributed energy resources, DER, smart grid, smart inverter, Rule 21, value proposition analysis, testing, standardization, cybersecurity, energy storage, grid economics

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EXECUTIVE SUMMARY

California has aggressive goals for achieving a low-carbon future. Recent passage of Senate Bill 100 (de León, Chapter 312, Statutes of 2018) mandates that 100 percent of the state's electricity come from renewable-energy resources and zero-carbon resources by the year 2045. Smart inverters enabled by standard data communication will play an integral role in reaching California's 100 percent clean-electricity goal by providing grid support and enhancing grid flexibility.

The following factors have so far stood in the way of even more accelerated progress towards California's ambitious goals:

- The Institute of Electrical and Electronics Engineers IEEE 1547-2003 standard limits distributed energy resources penetration to 15 percent of peak feeder load.
- The value of solar photovoltaic (PV) was unclear because of a mismatch between the PV production curve and the load demand. Ramping exacerbates with increasing PV penetration and may result in sub-optimal grid performance and grid instability.
- Non-smart inverters are associated with negative effects of reverse energy flow and thermal problems that pose safety issues at high penetration levels.
- The revision of IEEE 1547 national standard was proceeding slowly, prompting the State to update its own California Rule 21 regulation to hasten achievement of its clean-energy goals. This state regulation redefines new electrical capabilities and communication functions normally addressed in the IEEE 1547 standard.

Project Purpose

This project developed, demonstrated, and evaluated new smart-inverter standards that enable high photovoltaic penetration beyond the 15 percent peak-feeder-load guideline in the IEEE 1547.2-2008 standard.

Project Approach

Researchers engaged and assembled a team including smart-inverter manufacturers, OSIsoft, the University of California at San Diego's smart-inverter-testing laboratory, Southern California Edison, Kitu Systems, Strategen Consulting, and QualityLogic. This project team created a smart-inverter test framework and open-source software tools that allowed both rapid product development and compliance testing. The project team also developed a trial field network and collected empirical data that validated power-flow models and proved data communication compatibility.

The team maintained a flexible schedule to make sure the project stayed on track throughout the inevitable ups and downs of the standards and regulatory development processes, an evolving mix of partners and contractors, and technical setbacks and breakthroughs.

Project Results

The project accomplished its goals by enabling a collection of smart-inverter brands to comply with California Rule 21, using a SunSpec Modbus communication interface. This interface is low cost and scalable across distributed energy resource system sizes, resulting in plug-and-

play-compatible solutions. This capability fills a critical technology gap, improves grid stability, enables grid operators to effectively monitor and control distributed energy resources asset costs, and ultimately enables distributed energy resource systems to participate in ancillary-services energy markets.

The project delivered the following direct results:

- Developed and deployed a low-cost, standard test-lab platform for smart inverters using standard communication interfaces and conformance validation procedures to prove California Rule 21 compliance. Leveraging open-test software developed by the project, the team developed the test-lab platform based upon open specifications ready to implement in any commercial or academic setting.
- Five smart-inverter manufacturers successfully demonstrated support to California Rule 21 Phase 1 autonomous functions, including settings changes through Rule 21's Phase-2-compliant networks.
- Demonstrated and deployed California Rule 21, Phase 2 compliant networks, including IEEE 2030.5 protocols.
- Demonstrated cost reductions of \$500 per distributed energy resource system using a standard communication interface.
- Demonstrated that distributed energy resource systems enabled by smart inverters can safely generate 100 percent of circuit load (for example, 100 percent distributed energy resource grid penetration). By demonstrating that 100% DER grid penetration is possible, this project shatters the 15% DER ceiling currently enforced by utilities across the country and unlocks the potential of DERs for California.
- The project performed Smart Inverter Value Proposition Analysis to quantify grid benefits and projected an annual savings of \$640 million to \$1.4 billion when using smart inverters.
- The project leveraged close to 2-million dollars of in-kind contributions from industry.
- Kitu Systems, a subcontractor and system integrator, provided IEEE 2030.5/CSIP network software for the project, a communications aggregation platform, saving utilities from micro-managing thousands of residential DERs, and enabling DER providers (e.g. solar companies) to easily onboard their installations and comply with Rule 21 requirements.

Technology Transfer and Market Adoption

The project's technology-transfer activities began at its inception and continued throughout. Five of the seven smart-inverter companies have successfully completed their performance and interoperability testing. Hundreds of individuals participated in SunSpec-hosted webinars on smart inverters. Many hundreds more attended in-person events, and more than 150 completed a project-supported university-level course on the subject. The project team also created a working group of 350 individuals to develop cyber-security standards that support this initiative.

Benefits to California

The value and benefits from smart inverters to California and its electric-grid infrastructure are significant. To define a specific economic value, the project performed the *Smart Inverter Value Proposition Analysis* to quantify grid benefits. The results of this analysis show savings of \$640 million to \$1.4 billion per year from smart inverters (Table ES-1).

Table ES-1: Value of Smart Inverters

Benefit	Low Case	High Case
Reliability	\$290,000,000	\$660,000,000
Power Quality	\$30,000,000	\$100,000,000
Energy Delivery Efficiency	\$30,000,000	\$70,000,000
Dispatchable Resources	\$270,000,000	\$530,000,000
Avoided/Deferred T&D Upgrades	\$20,000,000	\$70,000,000
Total	\$640,000,000	\$1,430,000,000

Source: SunSpec Alliance

In addition, the project delivered or facilitated the following additional benefits:

1. 152-time return on investment under the state’s 2012 EPIC program
2. \$500-per- distributed energy resource system savings from standardization
3. Annual cost savings of \$1.7 billion from reducing greenhouse gas emissions by 112 million metric tons by generating 100 percent-renewable electricity
4. California Rule 21 reform, jump started by this project, hastened development and ratification of IEEE’s 1547-2018 standard. In summary, this project has demonstrated that smart inverters can enable distributed energy resource systems to operate at penetration rates of 100 percent of circuit load, and has additionally developed a streamlined and standardized smart-inverter platform that enables 100 percent distributed energy resource grid penetration. SunSpec’s smart-inverter platform created a networked energy environment, with distributed energy resources serving multiple purposes and providing multiple benefits to the grid and, ultimately, to California.

CHAPTER 1:

Introduction

Distributed energy resources (DERs), typically solar photovoltaic (PV) and energy storage systems on homes and commercial buildings, are a growing source of electricity on the electric grid. Paired with smart inverters, DERs have vast potential as clean, renewable, and controllable resources for the grid. The goal of this project was to develop, demonstrate, and evaluate a smart-inverter standardization and go-to-market solution to enable high-PV penetration beyond the Institute of Electrical and Electronics Engineers' (IEEE) national 15-percent-maximum guideline. The project demonstrated the safe installation of smart inverters at penetration levels of 100 percent or more, and showed a pathway for DERs to achieve critical mass and contribute their electricity to the electric transmission grid. The project standardized a collection of inverter brands that support both California Rule 21 smart-inverter functions and the open SunSpec communication interface standard. This interface, now incorporated into IEEE 1547-2018, is a plug-and-play-compatible solution that is both low cost and scalable from residential to large-scale commercial systems. It fills a critical technology gap, enables grid operators to monitor and control DER costs effectively, improves grid stability, and will enable DERs to participate in ancillary services generation markets.

The project had five specific objectives:

- Provide a standards-ready test and certification framework for timely execution that supports California Rule 21 updates.
- Reduce DER engineering costs by 10 percent from current baseline costs by integrating existing standards and providing plug-and-play interoperability across manufacturers.
- Demonstrate mitigation of increased PV penetration impacts on feeder circuits above the IEEE-mandated 15 percent limit through seamless communication between California Rule 21-compliant smart inverters and a utility, using standard communication protocols.
- Demonstrate the ability of smart inverters to support the power grid during system disturbances and increase overall power grid reliability.
- Identify new revenue models for DER investors and operators by enabling standards-compliant systems to participate in ancillary energy markets, accelerating achievement of SB X1-2 renewable resources goals.

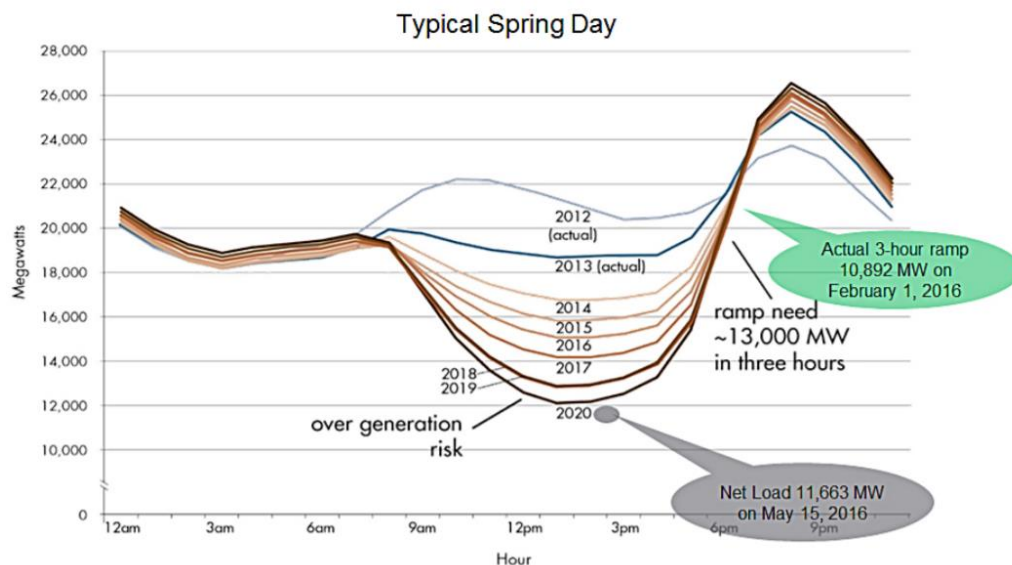
Smart inverters will most effectively leverage their capabilities when part of an integrated DER solution. This chapter presents the current and future state of the DER market, as well as policies influencing implementation of DER.

Current State of Distributed Energy Resources Market

This section discusses the status quo of the current DER market. With a minimal penetration of smart-inverter DERs, this section describes what has been spent on integrating DERs as the basis for identifying further saving opportunities with smart inverters.

Current discussions of DERs mainly focus on solar PV since about half of expected DER capacity additions will come from distributed PV.¹ While a valuable source of renewable energy, the grid impact and value of solar PV is a particularly contentious resource because of its intermittency and production curve. This is clearest in the infamous California Independent System Operator (California ISO) duck curve (Figure 1), which shows the ramp in the “neck” of the duck caused by the mismatch between the PV production curve and load demand. Ramping exacerbates with increasing PV penetration and may result in sub-optimal grid performance and grid instability.

Figure 1: California Independent System Operator Duck Curve



Source: California Independent System Operator

To limit negative effects, the IEEE 1547.2 's 15 percent rule caps penetration of DER at 15 percent of the peak feeder load.² In practice, even lower levels of penetration can trigger feeder-impact studies or even distribution-capacity upgrades within utilities. Both can extend the commissioning and installation process for DER and significantly increase developer costs.

For example, in the highly penetrated grid of Hawaii, the Hawaii Public Utilities Commission decided to end the net-metering program in 2015, citing difficulties with maintaining grid stability. This led to a 52 percent drop in PV permitting from 2016 to 2017.³

¹ (John, 2018)

² (Anderson Hoke, 2012)

³ (Wesoff, 2017).

Since the start of this project, new policies have been introduced to encourage or mandate the growth of DER development. The California Public Utilities Commission (CPUC) has published two landmark bills:

1. AB 2514, which directs the Commission to set targets for utilities to procure grid-connected energy-storage systems, and also directs electric utilities to adopt appropriate storage targets
2. AB 2868, which requires the Commission to direct utilities to implement programs and investments to accelerate deployment of distributed energy storage, with a total goal of 500 MW in addition to targets, set forth in AB 2514.⁴ While not explicitly requiring additional DER capacity, Federal Energy Regulatory Commission (FERC) Order 841 contains language allowing simultaneous retail and wholesale market DER participation, paving the way to greater usage and deployment of DERs on the grid.⁵

SB 100, *California Renewables Portfolio Standard Program*, enacted in September 2018 ahead of then-Governor Jerry Brown's Global Climate Action Summit, mandates that 60 percent (from 50 percent) of California's electricity come from renewable generation by 2030 and establishes the future goal of 100 percent clean energy by 2045.⁶

Evolved State of the Distributed Energy Resources Market

Solar PV and storage contribute to California's renewable energy policy goals. Smart inverters will play an integral role in reaching the 100 percent clean energy goal by enabling and enhancing distribution system flexibility.

Eliminating the national IEEE 15-percent-limit rule can provide substantial benefits to the health and operation of the grid. Unlike the traditional grid structure, with centralized generation providing power to loads through the transmission and distribution network, DERs allow additional generation resources throughout these networks. The addition of DERs on the grid, with the correct grid architecture supporting them, enables bidirectional, or two-way power-flow operation, and allows ratepayers to become both providing and consuming power.

As generation resources, DERs represent added power capacity that supports the grid. DER storage is particularly useful for this application, as it represents not only additional power capacity but also a stored and deployable energy capacity. With the proper regulation, DERs can participate in both local retail markets and regional wholesale markets. Therefore, DERs present a significant opportunity for both utilities and the California ISO as a market resource.

Large networks of DERs can provide alternative transmission solution (ATS) or alternative distribution solutions (ADS) that support the changing electric grid. For example, as

4 (California Energy Commission, 2018).

5 Federal Energy Regulatory Commission. 2018. *Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators*. Department of Energy. 162 FERC ¶ 61,127.

6 (Koseff, 2018).

distribution loads grow, there is always a need for capacity upgrades such as additional power lines and transformers to support increased power flows from centralized generation to the distribution network. DERs can defer upgrades or even avoid them because of the additional generation resources provided by DERs. The California ISO's Transmission Planning Process (TPP) extensively studied DER solutions through which ATS are decided and implemented for the transmission network.⁷

This potential, however, comes with caveats and requirements. In order to deploy DERs at scale, the supply chain must be improved, including creating and enforcing operating standards that ensure DERs adhere to those standards. If DERs are not properly visible to either the California ISO or to distribution system operators, or if their coordination is insufficient, or if DER participation is not adequately compensated, controlled, or managed, increasing DERs on the grid could become difficult and lead to increased operational challenges that could drive up system costs.

Smart inverters, along with the results delivered in this project, represent an important component in mitigating these issues and allowing greater DER participation and its benefits for the electric grid.

7 (Kerinia Cusick, 2019)

CHAPTER 2: Project Approach

Project researchers took the following approach in their efforts to achieve project goals to develop, demonstrate, and evaluate a smart-inverter standardization and go-to-market solutions that allow high PV penetration beyond the 15 percent IEEE rule.

Assemble a World-Class Team

The project engaged a diverse team of stakeholders including smart-inverter manufacturers, utilities, laboratories, DER system integrators, software developers and UC San Diego as an academic partner as shown below (Figure 2). The project team also included a technical advisory committee and the project participants.

Figure 2: Organizations Involved with Project



Source: SunSpec Alliance

Engage with Inverter Manufacturer Product-Development Organizations

The project joined product development teams of smart-inverter manufacturers to standardize support for the California Rule 21 smart-inverter functions and the open SunSpec communication interface standard. IEEE 1547-2018 specified SunSpec interface as a low-cost, plug-and-play compatible solution scalable from residential to large-scale commercial systems. This fills a critical technology gap, while enabling grid operators to monitor and control DER asset costs effectively, improves grid stability, and will enable DER systems to participate in ancillary electric markets.

Execute and Iterate

To ensure the project stays on track throughout the inevitable difficulties of standards and regulatory development processes, an evolving partner/contractor mix, and technical setbacks and breakthroughs, the project team adopted a complex but exacting management approach.

Sub-groups within the team met weekly and aligned their short-term objectives with tasks completed in three-week sprints. The larger group met less frequently but often joined market outreach activities. The team had a rigorous financial management system based on timely delivery, in-kind contribution accounting, and precise record keeping.

The shared commitment to the importance and timeliness of the work to the State of California shaped all project activities.

Develop Interlocking Technologies to Validate Theory

The smart inverters in this project, complemented by a smart-inverter test framework and open-source software tools, enabled rapid product development and compliance testing. To estimate grid impacts, the project team developed power-flow models to emulate target-feeder conditions. To validate the power flow models and to prove data communication interoperability, the project team deployed a field trial network that collected empirical data. The project team assimilated and analyzed data collected during lab tests and field pilot to demonstrate the validity of the predicted benefits described in the project goals. Finally, the project developed a financial model to estimate the economic impact of introducing smart inverters at scale.

CHAPTER 3:

Project Results

This project resulted in many significant achievements in smart-inverter research, conformance testing, standardization, cyber security, and education. This chapter describes these results and their deliverables. Each section covers a single project result and describes both the delivered result and its significance to the smart inverter and to the DER industry.

Smart Inverters Enable 100 Percent-Plus Penetration of Distributed Energy Resources

This project successfully demonstrated that smart inverters could achieve DER penetration of more than 100 percent of peak distribution circuit load. This successful result is illustrated in the report *Smart Inverter Performance Testing to UL 1741 SA and California Rule 21 Criteria: Results from the UC San Diego Smart Inverter Laboratory*,⁸ *Smart Inverters for High PV Penetration: Analysis of functionality and behavior*,⁹ and the “*SunSpec 2030.5/CSIP Field Trial Results Report*.”¹⁰ These results are additionally supported by the *Integration of Big Data for Advanced Automated Customer Load Management*,¹¹ by Southern California Edison.

This result shatters IEEE’s national 15-percent-DER ceiling standard guideline, which is observed by utilities nationwide. It also further achieves California’s energy policy goals described in SB 100. Other benefits include reduced greenhouse gas emissions, improved air quality, enhanced consumer choice, and expanded use of renewable energy and electric vehicles.

8 Lloyd Cibulka, Bob Fox, Tom Tansy, Suzanne Martinez, Jan Kleissl. (University of California San Diego). 2018. *Smart Inverter Performance Testing To UL 1741 SA and CA Rule 21 Criteria: Results From the UC San Diego Smart Inverter Laboratory*. California Energy Commission.

9 Zack Pecenek, Vahid R. Disfani, William V. Torre, Jan Kleissl, Anil Pochiraju, Bob Fox, Thomas Tansy. (University of California, San Diego). 2016. *Smart Inverters for High PV Penetration: Analysis of functionality and behavior*. California Energy Commission.

10 Tom Tansy, Bob Fox, Suzanne Martinez, Glenna Wiseman. SunSpec Alliance. 2019. *SunSpec 2030.5/CSIP Field Trial Results Report*. California Energy Commission.

11 Joshua McDonald. (Southern California Edison). January 2019. *Integration of Big Data for Advanced Automated Customer Load Management*. California Energy Commission.

Smart-Inverter Value Proposition Analysis Results

Smart inverters, combined with standardized communication protocols, establish a new class of controllable and highly responsive resources on the grid. Increasing the number of smart inverters allows grid support on both local and regional scales beyond the support maintained or managed with traditional energy resources. Smart-inverter functions, both autonomous and controlled, enable ratepayers, DER owners, and other stakeholders to access new and emerging market opportunities. The project developed a value proposition analysis model that assesses smart-inverter capabilities and value. This model is available for inspection and review in the document *Smart Inverter Value Proposition Analysis Spreadsheet*,¹² and described in the report *Networked DER Value Proposition Report*.¹³

The model analysis methodology was leveraged before the Energy Commission funded work on Distribution Automation (DA) impacts (Navigant, 2009).¹⁴ The project used the DA report analysis as the framework to evaluate benefits to utilities, customers, and the environment. The high-level quantification of smart-inverter benefits is a combination of published data, data from the previous Navigant report, and professional assumptions. The authors identified sensitive inputs and varied them to create a range of expected benefits.

This analysis shows a value of \$640 million to \$1.4 billion per year of smart inverters' benefits, in addition to showing improvements in the areas of reliability, power quality, energy delivery efficiency, dispatchable resources, and avoided or deferred transmission and distribution upgrades (Table 1).

These benefits are from enhanced operation and improved performance of the grid by smart inverters, as well as from avoided-energy losses and grid-upgrade costs. The benefits are a result of analyzing the California energy policy goals and the capabilities and functions of smart inverters.

12 Ron Nelson, Kevin Moy. January 2019. [Smart Inverter Value Proposition Analysis Spreadsheet](https://www.sunspec.org) (https://www.sunspec.org). California Energy Commission.

13 Ron Nelson, Kevin Moy. January 2019. [Networked DER Value Proposition Report](https://www.sunspec.org). (https://www.sunspec.org). California Energy Commission.

14 California Energy Commission. [The Value of Distribution Automation](https://www.energy.ca.gov/2007publications/CEC-500-2007-103/CEC-500-2007-103.PDF). 2007. (https://www.energy.ca.gov/2007publications/CEC-500-2007-103/CEC-500-2007-103.PDF)

Table 1: Smart Inverter Value Proposition

Benefit	Low Case	High Case
Reliability	\$290,000,000	\$660,000,000
Power Quality	\$30,000,000	\$100,000,000
Energy Delivery Efficiency	\$30,000,000	\$70,000,000
Dispatchable Resources	\$270,000,000	\$530,000,000
Avoided/Deferred T&D Upgrades	\$20,000,000	\$70,000,000
Total	\$640,000,000	\$1,430,000,000

Source: SunSpec Alliance

California Rule 21 Technical Specifications and Test Criteria

California Rule 21 defines a framework for DER retail market participation including interconnection, operation, and metering requirements. The current revision of Rule 21 allows utilities to incorporate DER to support grid stability (allowing the control of DER for frequency and Volt-VAr regulation at the retail level) by dispatching or curtailing participating DER facilities.

SunSpec Alliance led the design of key technical specifications to ensure that smart inverters achieve full capability and usage within the boundaries of California Rule 21. SunSpec operates working groups that maintain and update these documents, which are published, open and royalty-free, on SunSpec’s website.

Common Smart-Inverter Profile

SunSpec Alliance, working with industry and utility participants, was a key contributor to development of the *Common Smart-Inverter Profile (CSIP)*.¹⁵ This document is an implementation guide for IEEE 2030.5-2018 Standard for Smart Energy Profile Application Protocol, as applied to Rule 21, and is now on the SunSpec website. CSIP allows manufacturers, DER operators, system integrators, and DER aggregators to properly design products and systems that are Rule-21 compliant, enabling smart inverters to perform to the full extent of Rule 21 capabilities.

¹⁵ SunSpec Alliance. March 2018. [Common Smart Inverter Profile \(CSIP\) version 2.1](https://sunspec.org/download/) (https://sunspec.org/download/).

Open Test Procedure for IEEE 2030.5/CSIP

SunSpec Alliance developed the SunSpec CSIP conformance test procedures¹⁶, an open royalty-free document that describes how to document smart inverters' adherence to Rule 21 requirements for compliance to IEEE 2030.5-2018 Standard for Smart Energy Profile Application Protocol, as described in the CSIP. The project funded development of Rule 21 Phase 1 test procedures, including tests for autonomous function behavior and communication interface settings support.

Smart-Inverter Communication Go-To-Market Platform

The project developed and established a low-cost means for smart-inverter manufacturers to test hardware for compliance with Rule 21. This includes:

- An open smart-inverter test lab specification, used in UCSD's smart-inverter test lab.¹⁷
- Royalty-free test scripts for IEEE 2030.5/CSIP client and SunSpec Modbus protocol conformance.¹⁸
- Updates to SunSpec System Validation Platform (SVP)¹⁹ to automate test scripts.

This work provides a framework for manufacturers to build testing laboratories with the necessary hardware and software components for Rule 21 compliance testing, and allows any organization, including buyers or interested third parties, to establish their own facilities for evaluating smart inverters.

Confirmation of Smart Inverter California Rule 21 Conformance

The project tested and verified conformance of smart-inverter products from five manufacturers to Rule 21 specifications at UCSD's smart-inverter test lab using SunSpec's platform.²⁰ This work proved that individual inverters tested are Rule 21 compliant, and demonstrated that any Rule 21 smart inverter could be tested and evaluated, in a standard manner, for compliance with standard open-source tools.

16 SunSpec Alliance. [Common Smart Inverter Profile \(CSIP\) Conformance Test Procedures](https://sunspec.org/download/) (https://sunspec.org/download/)

17 SunSpec Alliance. March 2016. [SunSpec Advanced Function Inverter Test Lab Specification](https://sunspec.org/download/) (https://sunspec.org/download/).

18 SunSpec Alliance. 2015-2019. [SunSpec System Validation Platform open source libraries](https://github.com/sunspec/svp_directories) (https://github.com/sunspec/svp_directories).

19 SunSpec Alliance. 2015-2019. [SunSpec System Validation Platform](https://www.sunspec.org) (https://www.sunspec.org).

20 Lloyd Cibulka, Tom Tansy, Bob Fox, Suzanne Martinez, Dr. Jan Kleissl. (2018). "Smart Inverter Performance Testing to UL 1741 SA and CA Rule 21 Criteria: Results from the UC San Diego Smart Inverter Laboratory." California Energy Commission.

Influencing Relevant Distributed Energy Resource Source Standards

The development of a Rule 21 testing and conformance platform led to an understanding of how smart inverters should communicate. The project used this to inform and influence other standards and protocols with practical knowledge acquired during this development process. These include:

- Opening a Project Action Request (PAR) and revising the IEEE 2030.5 standard to reflect lessons learned from this project, including cyber security.
- Successfully leading the effort to ratify IEEE 1547-2018 communication requirements.
- Managing updates to the SunSpec IEEE 2030.5/CSIP test procedure.
- Managing updates to the CSIP requirements document.
- Managing public reviews of test procedure and CSIP requirements document updates.
- Convening a workgroup to process inputs, drive workgroup consensus, and release update of compliance documents in concert with the Energy Commission and the CPUC.
- Updating SunSpec (Modbus) Models to reflect current California Rule 21 requirements.

This broad, ongoing work in standardization ensures that smart inverters will follow a strict set of operational and communications protocols, facilitating the growth of networked DER systems that comply with Rule 21 requirements.

Improvements of Cybersecurity Practices and Infrastructure

Smart inverters, as communicating devices, must implement and comply with cyber-security standards. To investigate this topic, researchers launched the SunSpec/Sandia DER Cybersecurity Workgroup. This workgroup comprises approximately 350 professionals from the DER/cyber security industry, and includes stakeholders across the all aspects of the industry. The workgroup has met consistently since 2017 and published three best-practices papers on the topic, all of which are available free to download from the SunSpec website.²¹

Consistent with the SunSpec/Sandia DER Cybersecurity Workgroup mission, the group promoted its first cyber security best practices document as the foundation of the UL 2900-2-2 specification (Software Cybersecurity for Network-Connectable Products, Part 2-2: Particular Requirements for Industrial Control Systems). UL accepted this proposal and the process of establishing the UL 2900-2-2 Standards Technical Panel started in Feb 5, 2019. Kenneth Boyce, an engineering fellow with UL, is championing this effort, along with Jay Johnson, senior researcher at Sandia, and Tom Tansy of SunSpec. Key contributors include Danish Salem, researcher at NREL, and Cedric Carter, researcher at MITRE Corporation.

²¹ [SunSpec Cybersecurity Workshop](https://sunspec.org/sunspec-cybersecurity-workgroup/) (https://sunspec.org/sunspec-cybersecurity-workgroup/)

SunSpec, Sandia, and others jointly authored a scientific paper on issues associated with digital security and public key infrastructure ²² titled *Recommendations for Trust and Encryption in DER Interoperability Standards – SAND2019-1490*.²³ This paper is foundational to understanding DER cyber security and its evolving communication standards.

Communication Interface Certification Program

To establish uniform performance criteria for communicating smart inverters, the SunSpec Alliance launched SunSpec’s certified program. This program includes a network of SunSpec authorized testing laboratories, the SunSpec CSIP conformance test procedures, test results reporting standard,²⁴ and the SunSpec public key infrastructure that establishes a benchmark for the industry.

The project has established a network of seven SunSpec authorized testing laboratories: five nationally recognized testing laboratories capable of both IEEE 2030.5/CSIP communication testing and UL 1741 SA smart-inverter electric function testing, as well as two testing laboratories that specialize in IEEE 2030.5/CSIP communication testing.

To identify smart-inverter products that have successfully passed this testing, SunSpec developed a SunSpec-certified branding and marking program for IEEE 2030.5/CSIP-conformant products. The SunSpec-certified program will soon feature a SunSpec product listing web service and API, based on the Orange Button²⁵ taxonomy, to enable Authority Having Jurisdictions (AHJ)²⁶ to publish customized product listings.

This service will allow authority-having jurisdictions including the Energy Commission, to maintain a database of approved smart-inverter models to install within jurisdictions. As new smart inverters are approved and added to the SunSpec product-listing service, the hardware-selection process will become easy for developers within the jurisdiction.

²² Public Key Infrastructure is the preferred method of authentication for networked ecosystems due to its strength and scalability.

²³ James Obert, Patricia Cordeiro, Jay Johnson, Gordon Lum, Tom Tansy, Max Pala, Ronald Ih. 2019. “Recommendations for Trust and Encryption in DER Interoperability Standards - SAND2019-1490.” (<https://sunspec.org/wp-content/uploads/2020/01/Recommendations-for-Trust-and-Encryption-in-DER-Interoperability-Standards-SAND2019-1490.pdf>)

²⁴ SunSpec Alliance. 2019. [SunSpec IEEE 2030.5/CSIP Conformance Test Procedures Results Reporting](https://www.sunspec.org) (<https://www.sunspec.org>).

²⁵ SunSpec Alliance and U.S. Department of Energy. 2018. [Orange Button: Solar Financial Data Exchange Standard](https://sunspec.org/orange-button-initiative/) (<https://sunspec.org/orange-button-initiative/>).

²⁶ Authority Having Jurisdiction (AHJ): means an organization, office or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

SunSpec Public Key Infrastructure

SunSpec established the SunSpec official public key infrastructure (PKI) program²⁷ to provide security services for SunSpec-certified products and announced Kyrio, a subsidiary of CableLabs®, as SunSpec's official PKI provider.²⁸ This service is foundational for a smart grid communication infrastructure in California that will integrate smart inverters, energy storage, and electric vehicles. It provides highly secure communications between DER systems, aggregators, and utilities that address industry needs.

Education and Outreach

The project developed and implemented a suite of programs and seminars to disseminate knowledge about smart inverters, DER data communication, and the roll-out of California Rule 21. Components of this program include industry events, media outreach and articles, university-accredited education programs, and informational webinars.

In September 2018, SunSpec held the Gridvolution Conference, an affiliated event at the Global Climate Action Summit.²⁹ The event attracted 65 attendees and featured speakers from 17 companies. It furthered collaboration and learning between DER stakeholders working to digitize both information and the interoperability of energy facilities.³⁰

SunSpec established a SunSpec Rule 21 education program³¹ that includes both technical and executive tracks. This program was a collaboration between SunSpec, the University of California San Diego, QualityLogic, and Kitu Systems. SunSpec promoted the courses through email, web postings, social media, and included it in UCSD's extension course catalog.

Byron Washom, the director of the Strategic Energy Initiatives program at UCSD, recognized the Rule 21 technical training course as "one of most successful market transitions from lab to curriculum in UCSD history." The 9-module online course was offered in the fall of 2018 with

²⁷ [SunSpec Public Key Infrastructure Program](https://sunspec.org/sunspec-public-key-infrastructure-pki-program/) (https://sunspec.org/sunspec-public-key-infrastructure-pki-program/).

²⁸ ["SunSpec Alliance Announces Kyrio as Official PKI Provider"](https://sunspec.org/sunspec-alliance-announces-kyrio-official-pki-provider/) (https://sunspec.org/sunspec-alliance-announces-kyrio-official-pki-provider/).

²⁹ ["Gridvolution: SunSpec Solar and Storage Finance Summit"](https://sunspec.org/gridvolution/) (https://sunspec.org/gridvolution/).

³⁰ ["SunSpec Alliance to Convene Global Technology Leaders to Discuss The "Electricity Grid in Evolution" on September 12, 2018"](https://sunspec.org/sunspec-alliance-convene-global-technology-leaders-discuss-electricity-grid-evolution-september-12-2018/) (https://sunspec.org/sunspec-alliance-convene-global-technology-leaders-discuss-electricity-grid-evolution-september-12-2018/).

³¹ <https://sunspec.org/wp-content/uploads/2018/03/SunSpec-Rule21-EdProgram-Sellsheet-2018-08-press-nocrops.pdf>

17 students and again in winter of 2018-2019³² with nearly double that number. The course was offered again in the spring and fall terms of 2019.

The Rule 21 executive workshops were similarly successful, with over 110 solar and DER executives participating in this training track. This track started in March 2018 and has included training workshops conducted at Intersolar North America³³, Solar Power International³⁴, and UCSD.³⁵

SunSpec and Sandia hosted a cyber-security webinar in December 2018 with nearly 200 registrations. The webinar covered security requirements of IEEE 2030.5 as they apply to California DER networks, as well as topics in cryptography, credential management, revocation, the general concept of trust chains, and global supply-chain implications.³⁶

These courses, workshops, and events are crucial for the development of smart inverters going forward. They allow for the spread of knowledge and experience gained during the term of this project, and also encourage further collaboration and discussion within the smart-inverter industry.

32 "[SunSpec Alliance and UC San Diego Extension Announce Winter 2019 CA Rule 21 and Secure Communication Networking Courses](https://sunspec.org/sunspec-alliance-uc-san-diego-extension-announce-winter-2019-ca-rule-21-secure-communication-networking-courses/)" (<https://sunspec.org/sunspec-alliance-uc-san-diego-extension-announce-winter-2019-ca-rule-21-secure-communication-networking-courses/>).

33 California Rule 21 Market Opportunity (<https://sunspec.org/california-rule-21-market-opportunity-executives/>).

34 "[SunSpec Alliance Annual Member Meeting and Digital Energy Summit](https://sunspec.org/sunspec-alliance-annual-member-meeting-digital-energy-summit/)" (<https://sunspec.org/sunspec-alliance-annual-member-meeting-digital-energy-summit/>).

35 "[The California Rule 21 Market Opportunity for Executives](https://sunspec.org/california-rule-21-market-opportunity-executives/)" (<https://sunspec.org/california-rule-21-market-opportunity-executives/>).

36 "[Cybersecurity Webinar: Securing California Rule 21 Networks](https://sunspec.org/cybersecurity-webinar-securing-california-rule-21-networks/)" (<https://sunspec.org/cybersecurity-webinar-securing-california-rule-21-networks/>).

CHAPTER 4:

Technology Transfer and Market Adoption

Knowledge gained from this project is available to inverter manufacturers, aggregators, end users, utilities, regulatory agencies, other SunSpec members, and members of the public; it uses methods that promote adoption of the project's best practices, standards, procedures, services, and open-source software.

Technical Advisory Committee

The project also formed a technical advisory committee from parties not directly associated with the project to provide guidance to the project team. The advisory group met twice and provided key input from:

- Tom Herbst, Sr. Director Vertical Lead, Utilities and Energy at ARM Holdings.
- James Mokri, lecturer in mechanical engineering at San Jose State University specializing in solar and electric vehicle charging infrastructure.
- Denver Hinds, Smart Energy Systems Engineer, Sacramento Municipal Utility District.
- TJ Vargas, R&D Engineer, Sacramento Municipal Utility District.

Licensing Strategy

Specifications and related documents delivered by this program are royalty-free under a Massachusetts Institute of Technology (MIT) open-source license. These documents are available on the SunSpec website.

Policy Impact

All project artifacts (specifications, documents, and software) will be disseminated to non-profit organizations involved in state-level policy development (e.g., Technet, Silicon Valley Leadership Group, Clean Coalition, and the Interstate Renewable Energy Council), and SunSpec's more than 100 member companies with the goal of promoting open communication about how open communication standards can positively impact the grid.

Outreach

The knowledge gained from the project is available to inverter and DER manufacturers, aggregators, end users, utilities, regulatory agencies, and other members of the public via SunSpec Alliance distribution channels including its website, newsletters, educational events, media outreach, and promotional events.

Here is a sampling of outreach done to date:

- SunSpec IEEE 2030.5/CSIP Test Procedures announced:
 - Coverage by Solar Power World: "[SunSpec Releases Smart Inverter Test Procedures for California Rule 21](https://www.solarpowerworldonline.com/2018/05/sunspec-releases-smart-inverter-test-procedures-for-ca-rule-21/)," (https://www.solarpowerworldonline.com/2018/05/sunspec-releases-smart-inverter-test-procedures-for-ca-rule-21/).

- Kitu announces adoption: "[Kitu Systems Announces Rule 21 Compliance Software Suite](https://www.solarpowerworldonline.com/2018/07/kitu-systems-announces-rule-21-compliance-software-suite/)" (https://www.solarpowerworldonline.com/2018/07/kitu-systems-announces-rule-21-compliance-software-suite/)
- Certification program announced: "[Seven SunSpec Alliance Authorized Test Laboratories Announced](https://sunspec.org/seven-sunspec-alliance-authorized-test-laboratories-announced-2/)" (https://sunspec.org/seven-sunspec-alliance-authorized-test-laboratories-announced-2/).
- SunSpec Authorized Testing Laboratories program announced: 9/18/18: "[SunSpec Announces RFPs for Certified Test Lab and PKI Programs](https://sunspec.org/sunspec-announces-rfps-certified-test-lab-pki-programs/)" (https://sunspec.org/sunspec-announces-rfps-certified-test-lab-pki-programs/)
- Partners announce support for SunSpec Authorized Testing Laboratory program
 - Solar Builder: "[SunSpec Alliance Partners with 7 Test Labs](https://solarbuildermag.com/news/sunspec-alliance-partners-with-7-test-labs-to-certify-products-for-its-solar-storage-communication-standards/)" (https://solarbuildermag.com/news/sunspec-alliance-partners-with-7-test-labs-to-certify-products-for-its-solar-storage-communication-standards/).
 - Solar Power World: "[SunSpec Alliance Announces First Authorized Solar System](https://www.solarpowerworldonline.com/2019/01/sunspec-alliance-first-seven-authorized-test-labs/)" (https://www.solarpowerworldonline.com/2019/01/sunspec-alliance-first-seven-authorized-test-labs/).
 - Kyrio: "[Kyrio Offers SunSpec Alliance Certification Testing](https://kyrio.com/blog/kyrio-sunspec-alliance-certification-testing?utm_campaign=Security%20|%20SunSpec%20|%20Awareness&utm_content=83402580&utm_medium=social&utm_source=twitter&hss_channel=tw-3682198094)" (https://kyrio.com/blog/kyrio-sunspec-alliance-certification-testing?utm_campaign=Security%20|%20SunSpec%20|%20Awareness&utm_content=83402580&utm_medium=social&utm_source=twitter&hss_channel=tw-3682198094).
 - SGS: "[SunSpec Alliance Welcomes SGS as an Authorized Test Laboratory \(ATL\) Partner](https://www.sgs.com/en/news/2019/01/sunspec-alliance-welcomes-sgs-as-an-authorized-test-laboratory-atl-partner)" (https://www.sgs.com/en/news/2019/01/sunspec-alliance-welcomes-sgs-as-an-authorized-test-laboratory-atl-partner).
- [SunSpec Official PKI provider announced 2/13/19:](https://sunspec.org/sunspec-alliance-announces-kyrio-official-pki-provider/) (https://sunspec.org/sunspec-alliance-announces-kyrio-official-pki-provider/)
- SunSpec Announced California Rule 21 Deadline Extension: "[SunSpec Market Bulletin: CA Rule 21 Smart Inverter Communications Requirements February 22, 2019 Deadline Extended to August 22, 2019](https://sunspec.org/sunspec-market-bulletin-ca-rule-21-smart-inverter-communications-requirements-february-22-2019-deadline-extended-august-22-2019/)" (https://sunspec.org/sunspec-market-bulletin-ca-rule-21-smart-inverter-communications-requirements-february-22-2019-deadline-extended-august-22-2019/).
- SunSpec Gridvolution conference held With Global Climate Action Summit:
 - 65 attendees
 - Seventeen speakers including representatives from: Blue Banyan Solutions, CableLabs, California Public Utilities Commission, Chapman and Cutler LLP, Clean Power Research, Electric Power Research Institute (EPRI), Fronius USA, kWh Analytics, Salesforce.com, SMA Solar Technology AG, Sandia National Laboratories, Sunrun, Texas Instruments, Tigo Energy, Wells Fargo, Wivity Inc. and XBRL, US.
 - Agenda: "[Gridvolution: SunSpec Solar and Storage Finance Summit](https://sunspec.org/gridvolution/)" (https://sunspec.org/gridvolution/).

- Press release and quotes: "[SunSpec Alliance to Convene Global Technology Leaders to Discuss The "Electricity Grid in Evolution" on September 12, 2018](https://sunspec.org/sunspec-alliance-convene-global-technology-leaders-discuss-electricity-grid-evolution-september-12-2018/)" (https://sunspec.org/sunspec-alliance-convene-global-technology-leaders-discuss-electricity-grid-evolution-september-12-2018/).
- Media: "[111: Gridvolution, Tom Tansy Of SunSpec Alliance](https://sunspec.org/111-gridvolution-tom-tansy-sunspec-alliance/)" (https://sunspec.org/111-gridvolution-tom-tansy-sunspec-alliance/).
- SunSpec Launches Educational Program 2/21/18:
 - Program outline: [California Rule 21 Educational Program](https://sunspec.org/wp-content/uploads/2018/03/SunSpec-Rule21-EdProgram-Sellsheet-2018-08-press-nocrops.pdf) (https://sunspec.org/wp-content/uploads/2018/03/SunSpec-Rule21-EdProgram-Sellsheet-2018-08-press-nocrops.pdf)
 - Update of program: "[SunSpec Alliance and UC San Diego Extension Announce Winter 2019 CA Rule 21 and Secure Communication Networking Courses](https://sunspec.org/sunspec-alliance-uc-san-diego-extension-announce-winter-2019-ca-rule-21-secure-communication-networking-courses/)" (https://sunspec.org/sunspec-alliance-uc-san-diego-extension-announce-winter-2019-ca-rule-21-secure-communication-networking-courses/).
- California Rule 21 Executive Workshop Results:
 - March 5, 2018: 65 attendees
 - [Intersolar 2018](https://sunspec.org/executive-track-california-rule-21-market-opportunity-executives-2/): 35 attendees (https://sunspec.org/executive-track-california-rule-21-market-opportunity-executives-2/).
 - [Solar Power International](https://sunspec.org/sunspec-alliance-annual-member-meeting-digital-energy-summit/): 39 attendees (https://sunspec.org/sunspec-alliance-annual-member-meeting-digital-energy-summit/).
 - [UCSD Workshop January 2019](https://sunspec.org/california-rule-21-market-opportunity-executives/) : 29 attendees – UCSD based: (https://sunspec.org/california-rule-21-market-opportunity-executives/).
- California Rule 21 Engineering Online Course at UCSD Extension Results:
 - Fall 2018 session: 17 students
 - Winter 2019 session: 31 students
- Cybersecurity Program Results
 - 30+ workgroup sessions, 350 participants
 - December 2018 webinar: [Securing California Rule 21 Networks webinar](https://sunspec.org/cybersecurity-webinar-securing-california-rule-21-networks/) (https://sunspec.org/cybersecurity-webinar-securing-california-rule-21-networks/).
 - Forbes coverage: [Cybersecurity: The Hackers are Already Through the Utilities' Doors, so What's Next?](https://sunspec.org/cybersecurity-hackers-already-utilities-doors-whats-next/) (https://sunspec.org/cybersecurity-hackers-already-utilities-doors-whats-next/)

Composite Outreach Statistics

A composite view of the 2018 results for outreach and promotional activities includes:

- **Audiences Reached, 2018**
 - SunSpec – unique website visitors, 23,515
 - SunSpec – all mailing lists, 9,940
 - SunSpec – newsletter subscribers, 1,680

- SunSpec – web event registrants, 486
- SunSpec – member company employees, 1,045
- SunSpec – Cybersecurity work group members, 353
- SunSpec – Inverter work group members (added per year), 88
- **Email Campaigns Referencing IEEE 2030.5**
 - Campaigns targeting Inverter and cyber-security experts, total campaigns, 13; messages sent, 46,983
 - Other campaigns targeting DER market participants, total campaigns, 47; messages sent, 261,028
- **Web Events Referencing IEEE 2030.5**
 - Web events targeting Inverter and cyber-security experts: total web events, 3; total web event registrants, 313
 - Other web events targeting DER market participants: total web events, 5; total web event registrants, 283
- **SunSpec Live Events and Activities**
 - SolarPlaza Asset Management North America 2018 (multiple presentations), 300+
 - SunSpec Executive Summit on California Rule 21 in SF, 64
 - Intersolar North America 2018 workshop on California Rule 21, 68
 - Gridvolution @ Solar Power International 2018, 100+
 - SunSpec 2018 annual member meeting, 87
 - SunSpec online engineering at UC San Diego, fall term: Secure Communication Networking for DER, 17
 - SunSpec IEEE 2030.5 test procedure downloads, 528

Media Statistics

Media coverage related to SunSpec California Rule 21 initiatives includes:

- Number of media coverage pieces, 8
- Online readership of publications, 109 million
- Estimated coverage views, 102,000
- Social shares from coverage, 433

CHAPTER 5:

Conclusions and Recommendations

Lessons Learned

This complex project involved more than a dozen corporate stakeholders operating across multiple technical disciplines. Due to the length of the project and the dynamic nature of the industry during the contract period, several significant adjustments were required including replacing the sub-awardee responsible for the field trial and wholesale market participation project. With these adjustments came the following valuable lessons:

- Sustaining long-term engagement of vendors with limited roles is challenging: Though vendor enthusiasm remained high throughout the project, some vendors were not ready for testing, which forced the project team to recruit replacements. The primary reasons for lack of vendor readiness were the late resolution of technical and regulatory requirements.
- Reliance on a single sub-awardee to lead multiple phases of a project is risky: Another significant challenge for the project was the withdrawal of the sub-awardee responsible for the field trial and wholesale market validation portions of the project. Both of these program elements required months of advance planning to secure the circuit density required for the evaluation conditions. When the sub-awardee withdrew, the project suffered a setback in achieving the right density, and program objectives needed some adjustments.
- Bridging retail and wholesale energy markets will take more work: This project demonstrated that manipulating smart inverters with a standard communication interface could provide a wide array of grid support functions. This was the precise mechanism needed in order for DERs to participate in the wholesale electricity market, and yet it is still insufficient. As described in the wholesale market analysis report included in this project,³⁷ recent studies performed by Lawrence Berkeley National Laboratory showed a lack of economic feasibility for the wholesale market because of the low profitability of DER services when operating under different retail and wholesale tariff structures³⁸. Rather than attempt to replicate the laboratory's work, further analysis was required for the feasibility of integrating the wholesale and retail markets with Rule 21 as the framework that is the basis of the wholesale market analysis report for this project.
- New methods to evaluate the economic benefits of DERs and smart inverters: The most recent Energy Commission-approved economic models for evaluating the value of an automated distribution infrastructure, including DERs, are more than 10 years old. The

37 Analysis Report of Wholesale Energy Market Participation by Distributed Energy Resources (DER) in California

38 Black, Douglas, Jason MacDonald, Nicholas DeForest, and Christoph Gehbauer. Lawrence Berkeley National Laboratory. 2017. *Los Angeles Air Force Base Vehicle-to-Grid Demonstration*. California Energy Commission. Publication Number: CEC-500-2018- 025.

global market has evolved dramatically since then and much has changed in terms of equipment capabilities, value streams, and use cases. For proper analysis of the value proposition of DERs and smart inverters, a new analysis framework was needed. This project developed that framework and now offers it as a new benchmark for the industry.

Considerations for Further Development

The results presented in this report expose some of the regulatory and market barriers that prevent smart inverters and DERs from reaching their full potentials. The following recommendations represent actions to mitigate those barriers.

Market Considerations

As discussed in the Wholesale Market Report³⁹ included in this project, in order to realize the full benefits of smart-inverter DERs there is a crucial need for consistent retail and wholesale market tariffs. In January 2019 Greentech Media published an article citing issues with a wholesale market based on legacy generation resources. That article added that the relative ease of installing and commissioning energy storage (versus traditional generation resources) presents a significant advantage.⁴⁰ The testing infrastructure and standardization presented in this report validates and further enhances this benefit for DERs as a wholesale market resource.

While this project focused on the prospect of solar PV and energy storage-enabled bypass, using electric vehicles (EVs) as DERs also has growth potential.⁴¹ According to the Auto Alliance, more than 162,000 plug-in EVs were registered in California as of 2019.⁴² Assuming an average battery of 50 kWh, this represents over eight GWh of capacity. While the same principles of PV storage and smart inverters apply, more work is needed to standardize EV systems as a grid resource — for example, by making a distinction between a charging station interfacing with the grid and a mobile EV, and classifying EVs based on whether they have onboard inverters. Like stationary storage, charge management also needs standardization to balance grid resource needs with EV owner needs. However, if properly standardized and controlled, EVs provide vast opportunities to add to smart-inverter DER capacity.

39 Tom Tansy, Ron Nelson, Kevin Moy, Suzanne Martinez. 2018. Analysis Report of Wholesale Energy Market Participation by Distributed Energy Resources (DERs) in California. https://sunspec.org/wp-content/uploads/2015/08/4.0EPC-14_036AnalysisReportofWholesaleEnergyMarketParticipationbyDERinCA.pdf.

40 (Gimon, 2019)

41 Chris Nelder, James Newcomb, and Garret Fitzgerald, [Electric Vehicles as Distributed Energy Resources](#), Rocky Mountain Institute, 2016, www.rmi.org/pdf_evs_asDERs.

42 (Auto Alliance, 2019)

System Cost and Compensation

For DER owners who traditionally interact only with the retail market, the issue of compensation is critical for their participation in the wholesale market. The location and functionality of a smart inverter within the distribution grid greatly affects its value and compensation potential⁴³. However, designing a locational value tariff presents significant technical, regulatory, and political challenges.⁴⁴ A coordinated retail and wholesale energy market will help address these challenges by creating a unified platform to support this new value infrastructure.

For electricity providers, significant investment is required to develop control schemes across the smart grid. For example, the PG&E EPIC 2.02 Report, which details its efforts to develop a DER management system, recommends more investment into these systems' control infrastructures including "improved data quality, modeling, forecasting, communications, cyber security, and a DER-aware advanced distribution management system."⁴⁵ While results from this report demonstrated capabilities on the individual smart-inverter level, these capabilities require proper support from the grid infrastructure.

For adequate and accurate benefits of DERs and grid modernization, and from a regulatory standpoint, design processes for both individual DER systems and a future DER-enhanced grid should consider the advanced capabilities of smart inverters. For example, verification and authorization of smart-inverter telemetry data as utility production meter-quality data would help avoid AMI redundancies and lower installation costs while providing the same critical data to system owners and utilities that maintain stable grid operating conditions. Restrictions on distribution circuits for DER penetration beyond IEEE's mandated 15 percent needed re-evaluation to reflect the operational benefits and avoided costs of smart-inverter DERs.

Consumer Impacts and Protections

Depending on the settings, California Rule 21 smart-inverter functions can reduce DER system generation at certain locations. This could affect consumer investment and project economics; due diligence is therefore needed to avoid any impacts to customers by the required settings. Since the performance of voltage regulation functions depend on a customer's location on the grid (as well as factors outside the customer's control such as utility voltage regulation practices), introducing these functions may complicate system performance, potentially reducing a consumer's expected return on investment. Adopting explicit consumer protection provisions may be necessary to ensure that customers are aware of any potential loss of generation over time, and that recourse exists if a single customer experiences a disproportionate amount of generation loss. Similarly, DER system designers need to

43 (Dave Gahl, 2018)

44 (Spector, 2019)

45 (Pacific Gas and Electric Company, 2019)

understand and model the effects of the new functions on DER output to convey accurate information to customers regarding anticipated lifetime generation.⁴⁶

Future Capabilities of Smart Inverters

The results of this project will help shape the future of smart inverters and DERs on the grid. By adopting functional and communications standards, original equipment manufacturers avoid the lengthy and costly R&D required by one-of-a-kind solutions. For the DER owner, standardization of the electric functional interface and the communication interface of smart inverters eliminate “switching” costs associated with using one brand or another.

By providing standardized functional requirements and testing platform tools, development time will be dramatically shorter while product quality will be increased, allowing quicker integration of DERs on the grid. The SunSpec System Validation Platform reduces testing time by one to two orders of magnitude as compared with current practices.⁴⁷ New smart inverters with 10 times the functionality of non-smart inverters require less testing time.

Given a coordinated and unified retail and wholesale market for DERs as described in this project, the IEEE 2030.5 infrastructure for the retail market could extend to the wholesale market. This will allow access to smart-inverter DERs for simultaneous operation in both markets.

Indeed, activity in other markets shows promise for DER wholesale market participation. In February 2019, Independent System Operator-New England became the first capacity market to accept an aggregated residential solar-plus-storage bid, awarding Sunrun 20 MW of distributed grid capacity to come online in 2022.⁴⁸

The capabilities of smart inverters may also reduce or eliminate the need for duplicate equipment or functionality on the grid. For example, smart inverters can collect and transmit production-related information to utilities and eliminate the need for production meters, in certain instances. With smart inverters providing the functions of a production meter, the cost of using advanced rate designs for DERs could fall dramatically. Given that smart inverters are required equipment, their ability to collect and transmit data grid-wide may displace utility investments in equipment with similar functionality.

The recent wildfires throughout the state have placed an emphasis on grid resiliency. PG&E has recently published its wildfire mitigation plan, which accounts for planned mandatory grid outages during unsafe fire conditions (e.g. high winds under dry conditions).⁴⁹ Microgrids have been proposed as a solution to maintain power to certain loads during these shutdown events. Smart inverters, given their autonomous and controllable characteristics, would be a key

46 Lydic, Brian and Sara Baldwin, January 2019. “Making the Grid Smarter”. Interstate Renewable Energy Council.

47 Johnson, Jay, October 2015. Presentation at Energy Storage North America, San Diego.

48 (Gheorghiu, 2019)

49 (Pacific Gas and Electric Company's Wildfire Mitigation Plan, 2018)

component of these microgrids and could help reduce electricity costs associated with reducing wildfire risks.

Additional work is needed to incorporate smart inverters into such a microgrid. A local energy management system would be required to coordinate smart-inverter operation along with other system components. Smart-inverter settings would need reconfiguration to accommodate microgrid operation modes, while existing communication protocols do not yet provide the means to systematically reconfigure smart inverters for this operation. This additional operational mode would also need to be reconciled with other operational modes. For example, the primacy of events as established by Rule 21 would need to account for local conditions, such as a grid outage, and prevent non-microgrid support operations on the inverter. In short, just as aggregation and communications have standards for smart inverters in CSIP and Rule 21, microgrid operations would also need to be standardized.

Conclusion

This project successfully demonstrated that smart inverters compliant with California Rule 21 (Phase 1 and Phase 2) requirements, are ready to be installed safely at penetration levels of 100 percent or higher while eliminating the reverse energy flow and thermal problems associated with non-smart inverters. As a result, there are no known technical barriers imposed by smart inverters that would preclude California from reaching its 100 percent renewable electricity goals.

This project also includes a framework that enables easy deployment and integration of Rule 21-compliant smart inverters into the grid. SunSpec's combined results in lab and theoretical testing, technology dissemination, education, verification, and certification for smart inverters provide a pathway for DERs to achieve critical mass, enabling DERs to provide non-wires grid support solutions throughout California.

In summary, SunSpec has developed a streamlined smart-inverter standardization platform for 100 percent DER penetration. SunSpec's smart-inverter platform enables a networked energy environment, with DER serving multiple purposes and providing multiple benefits to the grid and to California.

CHAPTER 6:

Benefits to Ratepayers

This project represents a four-year intensive investment of the EPIC program and in-kind industry support from educational institutions, smart-inverter companies, utility and grid companies, research institutions, and subject matter and domain experts. Over the course of the project, from creating the testing environment and tools, to inverter testing and reporting through field trials and market analysis, quantitative and qualitative benefits emerged that affect a broad range of California stakeholders. While this final report, along with other related reports addresses core project results, this project essentially produced 11 key benefits, described here.

Smart-Inverter Value Proposition Analysis

By demonstrating that 100 percent DER grid penetration is possible, this project disproves the necessity of IEEE’s 15 percent DER ceiling currently practiced by utilities across the country. This report includes a smart-inverter value proposition analysis that quantifies these benefits. The following table shows a value of \$640 million to \$1.4 billion attributed to smart inverters.

Table 2: Smart-Inverter Value Proposition

Benefit	Low Case	High Case
Reliability	\$290,000,000	\$660,000,000
Power Quality	\$30,000,000	\$100,000,000
Energy Delivery Efficiency	\$30,000,000	\$70,000,000
Dispatchable Resources	\$270,000,000	\$530,000,000
Avoided/Deferred T&D Upgrades	\$20,000,000	\$70,000,000
Total	\$640,000,000	\$1,430,000,000

Source: SunSpec Alliance

The values calculated accrue annually to the general customer population. (Note: while some benefits may first accrue to the utility, such as avoided and deferred transmission and distribution upgrades, eventually the decreased costs would also flow to customers through rate-case proceedings. In addition, not all values flow equally to all customers, such as reliability values that accrue in larger portions to commercial and industrial customers).⁵⁰ While the benefits are not discrete and therefore may be related and overlap, the calculation intentionally omits benefits that are almost entirely duplicative, such as the benefit of bill reductions reflected through avoided wholesale and infrastructure costs.

50 Ron Nelson, Kevin Moy. January 2019. [Networked DER Value Proposition Report](https://www.sunspec.org). California Energy Commission. Available at <https://www.sunspec.org>.

We note that there is considerable overlap between smart-inverter benefits and the benefits of DER generally. However, as smart inverters approach 100 percent DER penetration and are indeed required of DER generation in current policy, it is difficult to decouple these benefits from one another.

152 Times Return on Investment to California Stakeholders

With \$2 million funding from California and in-kind contributions of \$2.2 million from industry (\$4.2 million total), assuming that the low end of the value proposition number (\$640 million) is achieved, this project will return \$152 to California stakeholders for every \$1 invested through the EPIC program.

\$500 per Distributed Energy Resource System Savings Due to Standardization

With adoption of a standardized IEEE 2030.5/CSIP network approach, several areas of cost savings could be realized.

System Redesign Cost Reduction

Every constructed DER system begins as a system design made up of components that are specifically selected for that installation. Prior to the availability of smart inverters, inverter designs were considered unique and required special engineering consideration in every case.

With smart inverters standardized, system designers are free to choose among an array of manufactured products that are electrically and logically similar. This similarity enables designers to pick smart inverters based on price, availability, or other factors—even after the system design is complete. Given a labor cost of \$100 per hour and a redesign time requirement of two hours per design, about \$200 can be saved in this process. Supply chain savings add further economies.

Total estimated system redesign savings: \$200.

Network Gateway Cost Reduction

Contemporary network gateways are comprised of off-the-shelf components and are often built by hand. With likely order volumes in the hundreds of thousands of units per year (California will install about 250,000 new smart-inverter-based systems per year), residential gateway original equipment manufacturers (OEM) that are currently paying \$200 to \$300 per unit for gateway compute devices can expect to save half that amount (\$100 to \$150 per unit) by going to “system on chip” (“SOC”) designs.

Inverter OEM’s can count on saving another \$25 to \$50 per unit by embedding the gateway computer device in the inverter chassis and another \$100 in installation labor (versus the cost of installing an external gateway).

Total estimated network gateway system savings: \$200.

Monitoring/Management Cost Reduction

Monitoring is a de facto requirement for commercial installations and a common feature of residential installations. Standardization dramatically reduces monitoring costs in both installation types.

Monitoring is typically sold as a bundle of proprietary monitoring equipment (i.e. network gateway and sensors) and proprietary portal software offered under an annual software-as-a-service agreement.

With IEEE 2030.5/CSIP networks required, telemetry can be delivered as a by-product of interconnection. This means that monitoring hardware, which is often priced at \$500 for residential customers and up to \$5,000 for commercial installations, is eliminated in many cases.

With telemetry now “free,” monitoring portals will naturally gravitate toward using that data service. This will cause monitoring companies to compete with one another for existing installations—which was virtually impossible with bundled hardware/software solutions—and for new software entrants coming into the market.

Total estimated monitoring/management system savings: \$100.

Table 3: Cost Reduction Opportunities from Interoperability Standardization

Savings Description	Estimated Savings
System redesign cost reduction	\$200
Network gateway cost reduction	\$200
Monitoring/management cost reduction	\$100
Total estimated savings	\$500

Source: SunSpec Alliance

Supporting California Clean Energy and Environmental Initiatives

The project supports the Energy Commission’s commitment to help the State reach its ambitious targets for transitioning its generation to renewable energy to limit the effects of climate change.

When the project started in 2015, SB X1-2⁵¹ was California’s foundational renewable energy legislation. DERs supported by interoperable smart inverters contribute to the State’s clean energy and environmental initiatives. Over the last five years, the State has enacted increasingly proactive mandates to reach 100 percent clean energy. Smart inverters, by supporting 100 percent penetration of DERs on the grid, advance these mandates.

A chronological list of how California’s clean energy legislation has positively impacted and supported DER systems, enabled by smart inverters, follows.

⁵¹ California’s Governor Jerry Brown signed Senate Bill (“SB”) X1-2 on Tuesday requiring California’s electric utilities to procure 33% of their energy from renewable resources by 2020.

2011 Senate Bill X1-2: California Renewable Energy Resources Act

This law, enacted in 2011, required California’s electric utilities to generate or obtain at least 33 percent of their electricity from renewable resources by the year 2020. At the time, this mandate was considered to be the most aggressive renewable portfolio standard in the country.⁵²

2016 California Public Utilities Commission Distributed Energy Resources Action Plan

The California Public Utilities Commission’s 2016 DER Action Plan – updated in 2017⁵³ – created a roadmap for the CPUC in distributed energy resource planning within the context of greenhouse-gas-emission reductions and the “reform of utility distribution planning, investment, and operations.”

A range of actions to implement the plan was developed within three initiatives:

1. Rates and Tariffs
2. Distribution Grid Infrastructure, Planning, Interconnection, and Procurement
3. Wholesale DER Market Integration and Interconnection

The CPUC recognizes value in DERs and concludes its action plan with a commitment to develop market opportunities and remove barriers to DERs.

2017 California Rule 21

In 2017, the CPUC brought in new requirements for inverters in solar projects through its Electric Tariff Rule 21. The Rule 21 interconnection requirements apply to any DER that connects to the electric grid. Their purpose is to maintain the safety and reliability of the distribution and transmission systems.⁵⁴

2018 Senate Bill 100: The 100 Percent Clean Energy Act of 2018

California’s Governor Jerry Brown hosted the Climate Action Summit in September 2018 to bring people from around the world to build on commitments made in the Paris Agreement and take stronger action toward zero greenhouse-gas emissions by midcentury. To kick off the summit, Governor Brown signed SB 100, the 100 Percent Clean Energy Act of 2018,⁵⁵ which both accelerates the pace at which electricity providers in the State must achieve renewable energy goals and establishes a state mandate to provide 100 percent clean generation by 2045. At the same time, Executive Order B-55-18 to Achieve Carbon Neutrality was signed, also with a 2045 target.

52 [Senate Bill X1-2](http://www.leginfo.ca.gov/pub/11-12/bill/sen/sb_0001-0050/sbx1_2_cfa_20110214_141136_sen_comm.html) (http://www.leginfo.ca.gov/pub/11-12/bill/sen/sb_0001-0050/sbx1_2_cfa_20110214_141136_sen_comm.html).

53 [Distributed Energy Resource Action Plan](http://www.cpuc.ca.gov/General.aspx?id=6442458159) (<http://www.cpuc.ca.gov/General.aspx?id=6442458159>).

54 [California Rule 21](http://www.cpuc.ca.gov/Rule21/) (<http://www.cpuc.ca.gov/Rule21/>).

55 [Senate Bill 100](https://focus.senate.ca.gov/sb100) (<https://focus.senate.ca.gov/sb100>).

SB 100 requires:

- Eligible renewable energy and zero-carbon resources to supply 100 percent of retail sales of electricity to California’s end-use customers and 100 percent of electricity procured to serve all state agencies by 2045.
- Fifty percent renewable resources by 2026 and 60 percent by 2030 (up from 25 percent of retail sales by 2016, 33 percent by 2020, 40 percent by 2024, 45 percent by 2027, and 50 percent by 2030).

These policy requirements promote benefits beyond achieving carbon neutrality including stable retail rates for electric service. Other anticipated benefits to Californians include:

- Jobs and economic growth throughout California.
- Reduced local pollution from reduced fossil-fuel generation.
- Cleaner, healthier air and less pollution in vulnerable communities where power plants are often located.

The demonstration of the viability of 100 percent DER utilization on the grid supports California’s climate and clean energy legislation, including SB 100. This project provided significant public benefits to California’s electric utility ratepayers by confirming that smart inverters can support PV penetration up to and exceeding 100 percent of demand. This single attribute will lower costs for electricity, create reliable electricity supply, and reduce emissions.

2018 California’s Fourth Climate Change Assessment

The State of California’s Fourth Climate Change Assessment⁵⁶ presents climate projections and analyses of anticipated impacts in a format useful for local decision makers. Hundreds of researchers from state and federal agencies, universities, the private sector, and other stakeholder groups contributed to the report. The Energy Commission was one of the lead coordinating agencies.

The report states that, “Changing climate conditions will affect the energy system in several ways: by changing energy demand, changing performance of the energy delivery system, and by direct risks to infrastructure.”

An example is rising electricity demand for air conditioning due to hotter temperatures, particularly during peak demand in late afternoons in the hottest months. The CPUC is considering strategies for the challenge of matching electricity generating capacity with this higher demand, as well as other climate adaptation needs. Climate-related-sea-level rise and storm events increase flood and wildfire risk to energy infrastructure, particularly Northern California’s portion of the grid and substations in low-lying areas.

Possible response measures suggested for areas where demand outstrips capacity include additional substation capacity, DERs, or load shifting. The main adaptation suggestion for areas with damaged grid infrastructure is greater use of non-generating DERs such as energy storage or smart-charging electric vehicles.

⁵⁶ [California’s Fourth Climate Change Assessment](http://www.climateassessment.ca.gov/state/overview/) (http://www.climateassessment.ca.gov/state/overview/).

California Rule 21 jumpstarts California's IEEE 1547-2018 Standard Compliance.

Concurrent with this project, the U.S. national standard (IEEE 1547) was further developed and refined, updated in large part by knowledge generated by SunSpec Cybersecurity Workgroup experts in California.

When IEEE 1547-2018 was ratified, it specified that each DER must support at least one standard communication interface. The standard communication interface options provided by IEEE 1547-2018 were SunSpec Modbus, IEEE 2030.5-2018, and IEEE 1815; these aligned well with California Rule 21 requirements.

IEEE 1547-2018 is expected to take effect in 2020. The specific implementation date will be determined by the availability of IEEE 1547.1 conformance test procedures. These procedures are nearing the end of development and are being reviewed at the time of this writing. The IEEE 2030.5/CSIP test procedures, delivered as part of this project, ensure DER communication interoperability and are compatible with IEEE 1547-2018, the new national standard.

California's leadership exhibited by this project and the California Rule 21 tariff serve to jumpstart compliance of the DER marketplace to IEEE 1547, making the California grid smarter through networked and interoperable DER system components.

Grid Benefits: Greater Reliability, Improved Capacity Optimization and Flexibility

A pilot installation of 15 solar DERs and storage solutions, networked according to California Rule 21 Phase 1 and 2 requirements, provided operational data that enabled important insights into DER commissioning and data networking processes. This in turn facilitated higher levels of renewable penetration and provided greater flexibility to local capacity, with increased reliability.

Improved power delivery reliability: The smart inverters tested showed that higher levels of renewable generation penetration can be achieved, reducing the need for conventional sources, while enhancing reliability with DERs. This created savings by reducing the need to build new power system infrastructure, (e.g., voltage support, spinning reserves), to accommodate higher levels of renewable generation.

Improved capacity optimization and flexibility: Integrating energy storage with PV provides greater flexibility to local capacity and increases reliability through improved capacity optimization. Energy storage can help reduce loads and provide services like ramping and voltage support to maintain reliability.

Increased Ratepayer Safety

Groups or nodes, with storage, can control smart inverters within the California Rule 21 tariff. DER systems supporting medical necessities and larger systems for critical loads can be programmed for active operation during fires or other natural disasters. Systems with battery backup play an outsized role in maintaining critical service. Available solar generation provides power to these critical services even if the grid is down.

Smart inverters acting as the internal programming function with microgrids could also keep individual systems active when the overall grid is down.

Economic Development

High penetration potential of DERs, supported by smart inverters, has the added benefit of stimulating economic development on several fronts.

While this project does not include a scope of work that quantifies economic development benefits, it does indicate qualitative economic development benefits.

- Job Development - By stimulating solar, energy storage and related DER system expansion in California through the elimination of challenges related to the national 15 percent DER grid penetration limit, the project points to job development in the following areas:
 - Growth of construction jobs from DER system growth.
 - Software and service jobs.
 - Export of California-originated DER expertise to other regions where California-based companies could leverage that expertise to accelerate DER expansion in other parts of the country.
- Workforce Development - Training both new industry entrants and existing workers in DER data communications, network IT and cyber security⁵⁷ is happening now. This training includes educating existing line engineers about the new IT parameters and training others to bridge the existing skilled-worker gap in the renewables industry. Community colleges can also serve as centers for this training.
- Accelerate and Increase the State's Manufacturing Base – Incorporating lessons learned into California's manufacturing base will increase penetration of smart inverters locally and support grid stability. The rollout of smart inverters and storage is happening globally, and the lessons learned through this project will significantly support California smart-inverter manufacturers, energy-storage providers, and data communication industries.
- Cost-Effective Replication of Project in Other California Locations - Given the complexity of testing California Rule 21 functionality, development and delivery of the open SunSpec SVP software to the market is one of the project's most important outcomes. The availability of this open platform means that DER vendors, owners, operators, and academic institutions (including the State's universities, state colleges, and junior colleges) can adopt the technology to develop their own DER research facilities and train the next generation of workers as the market expands.

Research into the effects of DERs is still in its infancy, and this project delivered a new technology (smart-inverter test automation) that will be practiced in California for years to come. With project breakthroughs in the areas of capital equipment cost reductions for smart-

⁵⁷ SunSpec Alliance, partnering with the University of California San Diego, offers a three-unit course on the topic of the intersection of power engineering and data communication. For more information see [California Rule 21 Educational Program](https://sunspec.org/wp-content/uploads/2018/03/SunSpec-Rule21-EdProgram-Sellsheet-2018-08-press-nocrops.pdf) (<https://sunspec.org/wp-content/uploads/2018/03/SunSpec-Rule21-EdProgram-Sellsheet-2018-08-press-nocrops.pdf>).

inverter testing, DER simulation, and test automation, it is conceivable that smart-energy laboratories may one day be in high schools or even junior high schools.

Greenhouse Gas Emissions Reduction

High penetration distributed PV and storage would reduce greenhouse gas emissions by 112 million metric tons⁵⁸ annually for cost savings of \$1.7 billion.⁵⁹ The most recent figures for California's greenhouse gas emissions are from 2016. That year, the State's total greenhouse gas emissions were 429.4 million metric tons of CO₂ equivalent (MMTCO₂e). The electricity sector accounted for 16 percent of that, or 68.95 million metric tons.⁶⁰

An earlier report from this project (*Smart Inverter for High PV Penetration: Analysis of Functionality and Behavior*, San Diego, California. Pecanek, Zack et al., California Energy Commission, October 2016) demonstrated that typical feeder circuits in the San Diego Gas and Electric grid could be loaded with PV, and that with storage, PV plus storage systems by up to 200 percent of load while reducing the number of system faults and load tap operations (i.e. improving grid health).

In both the lab testing at UCSD and field-testing on the SCE grid, this project was able to prove that smart-inverter devices respond identically to simulated devices when given control signals via communication networks. Given this promising result, we can conclude that grid penetration levels of 100 percent or greater are technically feasible.

As a result, it is reasonable to estimate that cost savings associated with supplying 100 percent of statewide energy requirements with low-cost-solar energy could reduce greenhouse gas emissions by 112 million metric tons.⁶¹

Reducing Criteria Air Pollutants

The non-energy benefits, namely from pollutant emission reductions, are equally important to California. While not within the scope of this project's quantitative benefits study, the project team can qualitatively state that DERs do reduce criteria air pollutants.

An August 2007 analysis by the National Renewable Energy Laboratory (NREL), *Energy, Economic, and Environmental Benefits of the Solar America Initiative*,⁶² found that widespread

58 [California Greenhouse Gas Emission Inventory](https://www.arb.ca.gov/cc/inventory/data/data.htm). California Air Resources Board. (https://www.arb.ca.gov/cc/inventory/data/data.htm).

59 [The Footprint of US Carbon Pricing Plans](https://rhg.com/research/the-footprint-of-us-carbon-pricing-plans/) (https://rhg.com/research/the-footprint-of-us-carbon-pricing-plans/).

60 [California Greenhouse Gas Emission Inventory](https://www.arb.ca.gov/cc/inventory/data/data.htm). California Air Resources Board. (https://www.arb.ca.gov/cc/inventory/data/data.htm).

61 Ibid.

62 [Energy, Economic, and Environmental Benefits of the Solar America Initiative](https://www.nrel.gov/docs/fy07osti/41998.pdf) (https://www.nrel.gov/docs/fy07osti/41998.pdf).

DER and solar adoption would significantly reduce nitrous oxides, sulfur dioxide, and particulate matter emissions, all of which can cause health problems. NREL found that, among other health benefits, solar power results in fewer cases of chronic bronchitis, respiratory and cardiovascular problems, and lost workdays related to health issues.⁶³

Distributed Energy Resources Systems Contribute to Energy Security

Energy security in the context of this qualitative project benefit has two dimensions: availability of energy and the security of DERs on the grid.

Energy security, as defined by Wikipedia, is “the association between national security and the availability of natural resources for energy consumption. Access to (relatively) cheap energy has become essential to the functioning of modern economies.⁶⁴” In this context, installation of greater amounts of DER generation on the grid and the resiliency and reliability benefits of smart-inverter-enabled DER reduce the overall need to generate or import energy from centralized and other fossil-fuel sources.

The second dimension of energy security, to which this report contributed, is DER cyber security. The California Rule 21 DER installation landscape, moving forward, will be informed by and encompass the SunSpec Certified™ Program⁶⁵ out of which the SunSpec Public Key Infrastructure Program⁶⁶ flows. This program is designated as the method of authentication used for IEEE’s Standard (IEEE Std.) 2030.5 and is therefore the method to use for authenticating and securing communications for SunSpec-certified products and services.

SunSpec is working with organizations such as Sandia National Laboratories, which also work on the coordination and standardization of DER cyber security through its Cybersecurity Workgroup.⁶⁷

The mission of the SunSpec DER Cybersecurity Working Group is to support the expansion of DERs by defining best practices in cyber security and driving their best practices into both national and international standards. This work is constrained by requirements adopted by states that are already rolling out advanced DER regulations, including California (Rule 21) and Hawaii (Rule 14H).

The following are some of the international standards referenced or influenced by this project:

- The Institute of Electrical and Electronics Engineers
- The International Electrotechnical Committee

63 [The Health and Environmental Benefits of Solar Energy](https://news.energysage.com/health-environmental-benefits-of-solar-energy/) (https://news.energysage.com/health-environmental-benefits-of-solar-energy/).

64 [Wikipedia](https://en.wikipedia.org/wiki/Energy_security) (https://en.wikipedia.org/wiki/Energy_security).

65 [SunSpec IEEE 2030.5 / CSIP Certification](https://sunspec.org/sunspec-ieee-2030-5-csip-certification/) (https://sunspec.org/sunspec-ieee-2030-5-csip-certification/).

66 [Public Key Infrastructure Program](https://sunspec.org/sunspec-public-key-infrastructure-pki-program/) (https://sunspec.org/sunspec-public-key-infrastructure-pki-program/).

67 [Cybersecurity Workgroup](https://sunspec.org/sunspec-cybersecurity-workgroup/) (https://sunspec.org/sunspec-cybersecurity-workgroup/).

- The Internet Engineering Task Force
- The American National Standards Institute
- The International Standards Organization
- The National Institute of Standards and Technology, Internal/Interagency Reports
- The North American Electric Reliability Corporation
- The CIGRE (International Council on Large Electric Systems) Reports
- The Federal Information Processing Standard and The Department of Homeland Security
- The Industrial Control Systems Cyber Emergency Response Team
- The Information Security Forum

GLOSSARY

Term	Definition
AHJ	Authority Having Jurisdiction: An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.
AMI	Advanced Metering Infrastructure typically refers to the full measurement and collection system that includes meters at the customer site, as well as communication networks between the customer and a service provider.
API	Application Programming Interface in this document refers to a web API, which allows sharing of content between different stakeholders via a defined set of protocols and definitions.
California Rule 21	Rule 21 is a tariff that describes the interconnection, operating and metering requirements for generation facilities to be connected to a utility’s distribution system. Each investor-owned utility is responsible for administration of Rule 21 in its service territory and maintains its own version of the rule.
CSIP (California Smart Inverter Profile)	The California Smart Inverter Profile describes configuration requirements for how an IEEE 2030.5 interface can be implemented to satisfy the California Rule 21 requirements.
DER	Distributed Energy Resource
DSO	Distribution System Operator
EPIC	Electric Program Investment Charge, established by the CPUC in 2011, funds clean energy research and projects that support the state's climate and energy goals while also promoting greater reliability, lower costs, and increased safety.
FERC	The Federal Energy Regulatory Commission, or FERC, is an independent agency that regulates the interstate transmission of electricity, natural gas, and oil.
IEEE	Institute of Electrical and Electronics Engineers
IEEE 1547	The technical specifications for, and testing of, the interconnection and interoperability between utility electric power systems and distributed energy resources are the focus of this standard.
IEEE 2030.5	A communications standard that provides an interface between the smart grid and its users. It is the default communications

Term	Definition
	interface in California for grid integration of DER as described in CSIP.
IOU	Investor-Owned Utilities
ISO	Independent System Operator
Modbus	Modbus is a set of communications protocols used between components in process automation systems.
Penetration	Penetration refers to the amount of power capacity added to the grid by DER. It is often reported as a percentage, which represents the ratio of peak DER output to the peak consumption of the distribution feeder on which the DER are located.
PKI (Public Key Infrastructure)	Public key infrastructure (PKI) is a set of roles, policies, and procedures needed to manage digital certificates and public-key encryption. It is required for activities where proof is required to confirm the identity of the parties involved in the communication and to validate the information being transferred.
Smart Grid	Smart grids enable real-time data collection concerning electricity supply and demand during the transmission and distribution process, making monitoring, generation, consumption and maintenance more efficient.
Smart Inverter	As defined in Rule 21, smart inverters are inverters with advanced capabilities to report, manage power quality, and power flow. Smart inverters are able to perform these tasks either autonomously or by a set of commanded controls.
UL 1741 SA	UL 1741: Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources” is the test standard by which inverters are certified for interconnection to the grid, with particular respect to grid voltage and grid frequency. It is intended to supplement and support IEEE 1547.

REFERENCES

- Anderson Hoke, R. B. (2012). "Maximum photovoltaic penetration levels on typical distribution feeders." National Renewable Energy Laboratory, 14.
- Auto Alliance. (2019). "Autos Drive California Forward." Retrieved from Auto Alliance - Driving Innovation: <https://autoalliance.org/in-your-state/ca/>
- Black, Douglas, Jason Macdonald, Nicholas DeForest, and Christoph Gehbauer (2017). Lawrence Berkeley National Laboratory, "Los Angeles Air Force Base Vehicle-to-grid Demonstration." California Energy Commission. Publication number: CEC-500-2018- 025
- California Energy Commission. (2018). "Tracking Progress - Energy Storage." California: California Energy Commission.
- Common Smart Inverter Profile Working Group. (March 2018) "[Common Smart Inverter Profile, IEEE 2030.5 Implementation Guide for Smart Inverters.](https://sunspec.org/get-csip-test-procedure/)" (https://sunspec.org/get-csip-test-procedure/)
- Chris Nelder, James Newcomb, and Garrett Fitzgerald. (2016). "Electric vehicles as distributed energy resources." Rocky Mountain Institute: https://rmi.org/wp-content/uploads/2017/04/RMI_Electric_Vehicles_as_DERs_Final_V2.pdf
- Dave Gahl, K. L. (2018). "Getting more granular: how value of location and time may change compensation for distributed energy resources." Solar Energy Industries Association (SEIA).
- Federal Energy Regulatory Commission (2018). "Electric storage participation in markets operated by regional transmission organizations and independent system operators." Department of Energy. 162 FERC ¶ 61,127.
- Fox, Bob, Gene Hartsell, Steve Kang, Gordon Lum, James Mater, Tom Tansy. (2018). "[SunSpec Common Smart Inverter Profile \(CSIP\) Conformance Test Procedures.](https://sunspec.org/get-csip-test-procedure/)" (https://sunspec.org/get-csip-test-procedure/)
- Gheorghiu, J. (2019, Feb 8). "Residential Solar+Storage Breaks New Ground as Sunrun Wins ISO-NE Capacity Contract." Retrieved from Utility Dive: <https://www.utilitydive.com/news/residential-solarstorage-breaks-new-ground-as-sunrun-wins-iso-ne-capacity/547966/>
- Gimon, E. (2019, Jan 24). "How Market Rules Are Holding Back Energy Storage." Retrieved from Greentech Media: <https://www.greentechmedia.com/articles/read/energy-storage-wholesale-market-rules>
- Hawaiian Electric Companies Motion for Approval, docket no. 2014-0192. (Public Utilities Commission of the State of Hawai'i Jan 20, 2015).

- James Obert, Patricia Cordeiro, Jay Johnson, Gordon Lum, Tom Tansy, Max Pala, Ronald Ih. (2019). "Recommendations for Trust and Encryption in DER Interoperability Standards - SAND2019-1490."
- John, J. S. (2018, June 21). "Distributed energy poised for 'explosive growth' on the US grid." Retrieved from Greentech Media: <https://www.greentechmedia.com/articles/read/distributed-energy-poised-for-explosive-growth-on-the-us-grid#gs.14fnb4>
- Kerinia Cusick, J. W. (2019). "Alternative transmission solutions roadmap for CAISO grid." <https://www.center4ri.org/publications: center4ri>.
- Koseff, Alexei (2018), "[California approves goal for 100% carbon-free electricity by 2045](https://www.sacbee.com/news/politics-government/capitol-alert/article218128485.html)", Sacramento Bee (<https://www.sacbee.com/news/politics-government/capitol-alert/article218128485.html>).
- Lloyd Cibulka, Tom Tansy, Bob Fox, Suzanne Martinez, Dr. Jan Kleissl, (2018). "Smart Inverter Performance Testing to UL 1741 SA and CA Rule 21 Criteria: Results from the UC San Diego Smart Inverter Laboratory."
- Lydic, Brian and Baldwin, Sara, (2019), "Making the grid smarter". Interstate Renewable Energy Council.
- Mark Dyson, J. P. (2018). "The non-wire solutions implementation playbook: a practical guide for regulators, utilities, and developers." <https://www.rmi.org/insight/non-wires-solutions-playbook/>: Rocky Mountain Institute.
- Misbrener, K. (2018, Jul 19). "Kitu Systems announces Rule 21 compliance software suite." Retrieved from Solar Power World: <https://www.solarpowerworldonline.com/2018/07/kitu-systems-announces-rule-21-compliance-software-suite/>
- Pacific Gas and Electric Company. (2019). "Electric program investment charge (EPIC) - distributed energy resource management system (EPIC 2.02 DERMS)." California: Pacific Gas and Electric Company.
- Pacific Gas and Electric Company's Wildfire Mitigation Plan, r. 18-10-007 (Public Utilities Commission of the State of California Oct 25, 2018).
- Spector, J. (2019, Mar 11). "Distributed energy still isn't valued properly, report finds." Retrieved from Greentech Media: <https://www.greentechmedia.com/articles/read/distributed-energy-value-properly>
- State of Hawai'i. (2019). "[Hawaii Clean Energy Initiative](http://www.hawaii-clean-energy-initiative.org/)." Retrieved from state of Hawaii (<http://www.hawaii-clean-energy-initiative.org/>).
- Wesoff, E. (2017, Feb 07). "Rooftop solar in Oahu crashes with loss of net metering, lack of self-supply installs." Retrieved from [Greentech Media](#):

(<https://www.greentechmedia.com/articles/read/rooftop-solar-in-hawaii-crashes-with-loss-of-net-metering-lack-self-supply>)