

Energy Research and Development Division  
**FINAL PROJECT REPORT**

# **EPC-14-036 Final Report**

**California Energy Commission**

Gavin Newsom, Governor

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## PREFACE

The California Energy Commission's 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 California Energy Commission 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 Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increased 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.

EPC-14-036 Final Report is the final report for the *Smart Inverter Interoperability Standards and Open Testing Framework to Support High-Penetration Distributed Photovoltaics and Storage* project (EPC-14-036) conducted by the SunSpec Alliance. The information from this project contributes to Energy Research and Development Division's EPIC Program.

All figures and tables are the work of the author(s) for this project unless otherwise cited or credited.

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

## ABSTRACT

Distributed Energy Resources (DER), typically consisting of solar PV and energy storage systems on homes and commercial buildings, are a growing source of power on the electric grid. Paired with Smart Inverters, DER have vast potential as a controllable resource for the grid. This project demonstrates that Smart Inverters compliant with CA Rule 21 Phase 1 and Phase 2 requirements can be installed safely at penetration levels of 100% or more while simultaneously eliminating reverse energy flow and mitigating thermal problems associated with non-Smart Inverters. A financial analysis of this proposition shows a value of \$640 million to \$1.4 billion per year due to the benefits of Smart Inverters.

This project describes a framework that enables CA Rule 21 compliant Smart Inverters to be deployed and integrated into the grid. The results of this project—in lab testing, cybersecurity, education, verification, and certification for Smart Inverters—provide a pathway for DER to achieve critical mass and enable solutions throughout the California grid.

**Keywords:** *Distributed Energy Resources, DER, smart grid, smart inverter, CSIP, CA Rule 21, Rule 21, value proposition analysis, testing, standardization, cybersecurity, solar, energy storage, grid economics*

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# CHAPTER 1:

## Executive Summary

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California SB-100 legislation declares that 100% of the state's electricity needs must soon be met by solar PV and other renewable energy sources. Smart Inverters enabled by standard data communication capabilities will play an integral role in helping California reach its the 100% clean energy goal by providing grid support mechanisms and enhancing grid system flexibility.

Two primary factors have stood in the way of California achieving its electricity goals:

- The Institute of Electrical and Electronics Engineers (IEEE) 1547-2003 standard limits the amount of DER that can be installed at 15% of peak feeder load.<sup>1</sup>
- Due to the mismatch between when solar energy is harvested (during daylight hours) and used (24 hours per day), combined with the inability of non-smart inverters to mitigate their own negative grid impacts, the value of solar PV is a contentious issue.

Noting that achievement of its goals and the revision of the IEEE 1547 national standard was going slowly, California took it upon itself to update the CA Rule 21 regulation. This regulation change included defining new electrical capabilities and communication functions that are normally covered in the IEEE 1547 standard.

As the California market was ahead of the rest of the world, the California Energy Commission rightly determined that vendors and utilities were unlikely to solve these problems in the near term and that CEC assistance would be required. Hence, this project was funded and launched.

### Project Purpose

The goal of the EPC-14-036 project was to develop, demonstrate and evaluate a turn-key, Smart Inverter standardization and go-to-market solution to enable high PV penetration beyond the 15% Institute of Electrical and Electronics Engineers (IEEE) 1547.2-2008 guideline.

### Project Approach

The project accomplished its goals by enabling a collection of Smart Inverter brands to be standardized around support of CA Rule 21 Smart Inverter functions and the SunSpec Modbus communication interface<sup>2</sup>. The interface is low-cost and scalable across DER system sizes, and results in plug-and-play compatible solutions. This capability fills a critical technology gap, enables grid operators to monitor and control DER assets cost effectively, improves grid stability, and will enable DER systems to participate in ancillary services markets.

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<sup>1</sup> (Anderson Hoke, 2012)

<sup>2</sup> SunSpec Alliance. 2018. SunSpec Modbus Technology Overview, Information Model Specification, and Information Model Reference. Accessible at <https://sunspec.org/download/>

## Project Results

This project delivered the following direct results:

- Developed and deployed a low-cost, standard test lab platform for Smart Inverters that utilizes standard communication interfaces and conformance validation procedures<sup>3</sup> to prove CA Rule 21 compliance. The test lab platform is based on open specifications<sup>4</sup>, developed in this project, that can be implemented in any commercial or academic setting. It leverages the open test software that was also developed in this project<sup>5</sup>.
- Demonstrated that five Smart Inverter manufacturers support CA Rule 21 Phase 1 autonomous functions and settings changes via CA Rule 21 Phase 2 compliant networks<sup>6</sup>.
- Demonstrated that CA Rule 21 Phase 2 compliant networks, including the IEEE 2030.5 protocols, can be deployed and implemented as intended<sup>7</sup>.
- Demonstrated, via laboratory testing and field verification, that the cost of DER deployment can be reduced by \$500 per system by using a standard communication interface.
- Demonstrated, via simulation and field verification, that Smart Inverters enable DER systems to safely generate 100% of circuit load (i.e. 100% DER grid penetration).
- Developed a new valuation model that projects Smart Inverters provide between \$640 million and \$1.4 billion per year in value to California.<sup>8,9</sup>
- Delivered the project on time and on budget while leveraging \$2.2 million in in-kind contributions from industry.

By demonstrating that 100% DER grid penetration is possible, this project shatters the 15% DER ceiling currently enforced by utilities across the country unlocks the potential of Distributed Energy Resources for California.

## Technology Transfer and Market Adoption

By design, technology transfer in this project was constant, from inception to conclusion. Seven Smart Inverter companies started this project and five successfully finished performance and interoperability testing; hundreds of individuals attended SunSpec-hosted webinars on Smart inverter networking, hundreds attended in-person events, and more than 150 people attended a project-supported university-level course on the topic; 350 people met (and still meet) to

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<sup>3</sup> SunSpec Alliance. 2018. Common Smart Inverter Profile (CSIP) Conformance Test Procedures. California Energy Commission. Available at <https://www.sunspec.org>.

<sup>4</sup> SunSpec Alliance. 2016. Advanced Function Inverter Test Lab Specification. Available at <https://www.sunspec.org>.

<sup>5</sup> SunSpec Alliance. 2015-2019. SunSpec System Validation Platform open source libraries. Available at [https://github.com/sunspec/svp\\_directories](https://github.com/sunspec/svp_directories).

<sup>6</sup> 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.

<sup>7</sup> Tom Tansy, Bob Fox, Suzanne Martinez, Glenna Wiseman. SunSpec Alliance. 2019. SunSpec 2030.5/CSIP Field Trial Results Report. California Energy Commission.

<sup>8</sup> Ron Nelson, Kevin Moy. January 2019. Smart Inverter Value Proposition Analysis Spreadsheet. California Energy Commission. Available at <https://www.sunspec.org>

<sup>9</sup> Ron Nelson, Kevin Moy. January 2019. Networked DER Value Proposition Report. California Energy Commission. Available at <https://www.sunspec.org>

develop cybersecurity standards to support this initiative; and now SunSpec is offering its SunSpec Certified program to validate that Smart Inverters and their associated communication systems comply to CA Rule 21 standards.

## Benefits to California

The resulting value and benefits from Smart Inverters to the state of California and its grid infrastructure are significant. To define a specific economic value, the project performed a “Smart Inverter Value Proposition Analysis” to quantify grid benefits. The results of this analysis show an added value of \$640 million to \$1.4 billion per year from Smart Inverters.

**Table 1. Smart Inverter Value Proposition Analysis Summary.**

### SMART INVERTER VALUE PROPOSITION ANALYSIS SUMMARY

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
<b>Total</b>	<b>\$</b>	<b>640,000,000</b>	<b>\$</b>	<b>1,430,000,000</b>

In addition, the project delivered or enabled these additional benefits:

1. 152X return on EPC-14-036 investment to California stakeholders.
2. \$500 per system savings due to standardization.
3. Annual cost savings of \$1.7 billion from reducing greenhouse gas emissions by 112 million metric tons by moving to 100% renewable energy.<sup>10</sup>
4. CA Rule 21 reform, catalyzed by this project, enabled the IEEE 1547-2018 standard to be developed and ratified.

In summary, this project has demonstrated that Smart Inverters enable DER systems to safely operate at penetration rates of 100% of circuit load and has developed a streamlined standardization Smart Inverter platform to enable 100% DER grid penetration. SunSpec’s Smart Inverter platform enables a networked energy environment, with DER serving multiple purposes and providing multiple benefits to the grid and the state of California.

<sup>10</sup> California Greenhouse Gas Emission Inventory. California Air Resources Board. <https://www.arb.ca.gov/cc/inventory/data/data.htm>

# CHAPTER 2:

## Introduction

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The goal of the EPC-14-036 project was to develop, demonstrate and evaluate a Smart Inverter standardization and go-to-market solution to enable high PV penetration beyond the 15% IEEE guideline. The project accomplished this goal by enabling a collection of Smart Inverter brands to be standardized around support for the CA Rule 21 Smart Inverter functions and the open SunSpec communication interface standard. This interface, now incorporated into IEEE 1547-2018, is low-cost, scalable from residential to large-scale commercial systems, and results in plug-and-play compatible solutions. It fills a critical technology gap, enables grid operators to monitor and control DER assets cost effectively, improves grid stability, and will enable DER systems to participate in ancillary services markets.

The project had five specific objectives:

- Provide a standards-ready test & certification framework that enables timely execution to support CA Rule 21 updates.
- Reduce DER system engineering costs by 10% from current baselines through integration of existing standards and by providing plug-and-play interoperability across manufacturers.
- Demonstrate mitigation of the impact of increased PV penetration on the feeder circuits, above the IEEE-mandated 15% penetration level limit, through seamless communication between CA Rule 21-compliant Smart Inverters and the 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 grid services markets, accelerating the achievement of SB X1-2 goals.

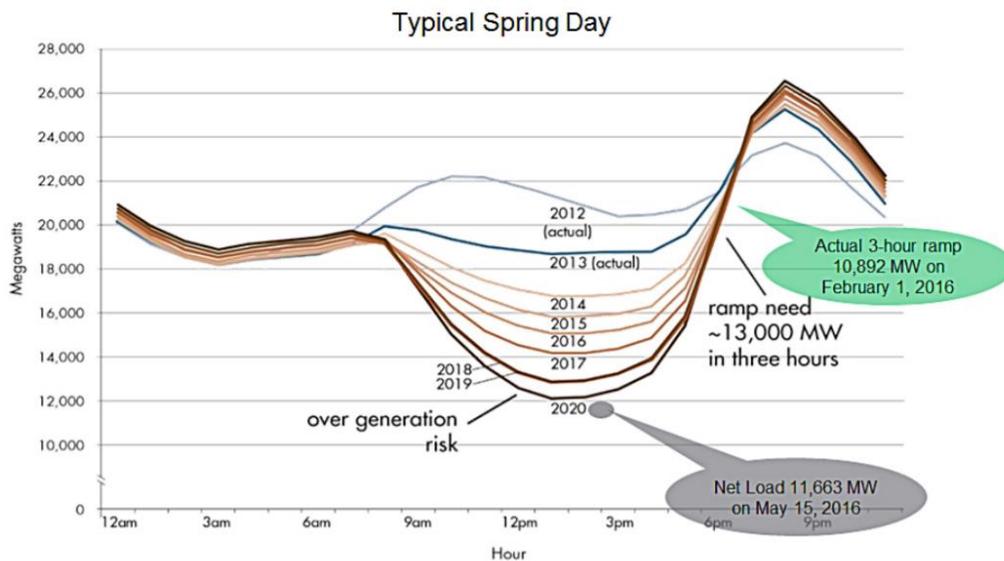
To properly evaluate this project's unique value proposition, sufficient context must be provided pertaining to the role of Smart Inverters as they relate to DER. As DER are uniquely situated on the grid, interspersed throughout the distribution system at the "grid edge," Smart Inverters will most effectively leverage their capabilities when deployed as part of an integrated DER solution. This chapter presents the current and future state of the DER market, as well as the policies influencing the implementation of DER.

## Current State of DER Market

This section discusses the status quo of the DER market as currently implemented. With a minimal penetration of Smart Inverter DER, this section aims to understand what is currently being spent on integrating DER as a basis for identifying further saving opportunities with Smart Inverters.

Current discussions around DER mainly focus on solar PV, as about half of expected DER capacity additions will come from distributed PV.<sup>11</sup> While a valuable source of renewable energy, the grid impact and value of solar PV is also a particularly contentious resource due to its intermittency and production curve. This is most apparent in the infamous California ISO duck curve, which shows the ramp in the “neck” of the duck caused by the mismatch between the PV production curve and the load demand. This ramp exacerbates with increasing PV penetration, and could result in sub-optimal grid performance and grid instability.

**Figure 1. California Independent System Operator Duck Curve**



Credit: California ISO

To limit negative effects, the IEEE 1547.2 “15% Rule” caps the penetration of DER at 15% of the peak feeder load<sup>12</sup>. 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 incur significant costs to developers.

<sup>11</sup> (John, 2018)

<sup>12</sup> (Anderson Hoke, 2012)

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% drop in PV permitting from 2016 to 2017.<sup>13</sup>

Since this project was initiated, new policies have been introduced that encourage or mandate growth of DER deployment. The Commission has published two landmark bills: AB 2514, which directed the Commission to set targets for utilities to procure grid-connected energy storage systems and directed IOUs to adopt appropriate storage targets, and AB 2868, which requires the Commission to direct the IOUs to implement programs and investments to accelerate deployment of distributed energy storage, with a total goal of 500 MW in addition to the targets set by AB 2514.<sup>14</sup> While not explicitly requiring additional DER capacity, FERC Order 841 includes language that allows for simultaneous retail and wholesale market participation by DER, enabling further usage and deployment of DER on the grid.<sup>15</sup>

SB 100, California Renewables Portfolio Standard Program, enacted in September 2018 ahead of Governor Brown's Global Climate Action Summit, legislates an increase to 60 percent (from 50 percent) of California's electricity portfolio to renewables by 2030 and establishes a further goal to have an electric grid that is entirely powered by clean energy by 2045.<sup>16</sup>

## Evolved State of the DER Market

DER comprised of solar PV and storage will address the California policy goals stated above. Smart Inverters will play an integral role in reaching the 100% clean energy goal outlined by SB 100 by enabling and enhancing flexibility on the distribution system.

With the "15% Rule" eliminated, DER 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, DER allow for additional generation resources throughout these networks. The addition of DER on the grid, with the correct grid architecture to support it, enables "bidirectional" or "two-way" power flow operation and allows ratepayers to become "prosumers,"<sup>17</sup> both providing and consuming power.

As generation resources, DER represent added power capacity to support the grid. Storage DER are particularly useful for this application, as they represent not only additional power capacity but a stored and deployable energy capacity. With the proper regulation, DER can be utilized to participate in both local retail markets and regional wholesale markets. Therefore, DER present

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<sup>13</sup> (Wesoff, 2017)

<sup>14</sup> (California Energy Commission, 2018)

<sup>15</sup> 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.

<sup>16</sup> (Koseff, 2018)

<sup>17</sup> U.S. Department of Energy. Accessed May 2018. Consumer vs Prosumer: What's the Difference? Accessed at <https://www.energy.gov/eere/articles/consumer-vs-prosumer-whats-difference>

a significant opportunity for both utilities and Independent System Operators (ISOs) as a market resource.

Large networks of DER can provide alternative transmission or distribution solutions (ATS or ADS) to support a changing grid. For example, as distribution loads grow, capacity upgrades such as additional power lines and transformers are needed to support the increased power flow from the centralized generation through the distribution network. With DER, these upgrades can be deferred and even avoided due to the additional generation resources DER provide in the distribution network.<sup>18</sup> Such DER solutions have also been extensively studied in the context of California ISO's Transmission Planning Process (TPP), through which ATS are decided and implemented for the transmission network.<sup>19</sup>

This potential, however, comes with some caveats and requirements. In order to deploy DER at scale, the supply chain must be improved, including creating and enforcing operating standards, as well as ensuring that DER conform to those standards. If DER are not properly visible to the ISO or Distribution System Operator (DSO), ISO-DSO coordination is not sufficient, or DER are not properly incentivized, controlled or managed, then increasing the penetration of DER on the grid becomes difficult, leading to increased operational challenges that could incur further system costs.

Smart Inverters, along with the results delivered in this project, represent an important component in mitigating these issues and allow for the proliferation of DER and their benefits throughout the grid.

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<sup>18</sup> (MARK DYSON, 2018)

<sup>19</sup> (Kerinia Cusick, 2019)

# CHAPTER 3:

## Project Approach

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The goal of the EPC-14-036 project was to develop, demonstrate and evaluate a Smart Inverter standardization and go-to-market solution to enable high PV penetration beyond the 15% IEEE guideline.

### Assemble a World-Class Team

To achieve the program goals, the SunSpec Alliance engaged with a team of Smart Inverter manufacturers (ABB, Advanced Energy, Enphase Energy, Fronius International, Ideal Power, Kaco New Energy, Pika Energy, Outback Power, SMA, and Tabuchi Electric); OSISOft for their application software, the University of California San Diego, operator of the Smart Inverter test laboratory where Smart Inverters were evaluated; Southern California Edison, the Investor Owned Utility where the networked PV+storage field trial was performed; Kitu Systems, the system integrator and provider of IEEE 2030.5/CSIP network software for the project; an extended team of DER system installers and cybersecurity experts who helped us discover the realities of deploying DER systems with secure communication in a production environment; Strategen Consulting, a professional services company that specializes in market development for a decarbonized grid and that provided economic analysis and research support; and QualityLogic, a test tool vendor that supported curriculum development.

**Figure 2. Organizations involved with the project**



## **Engage with Inverter Manufacturer Product Development Organizations**

The project engaged with the product development teams of Smart Inverter manufacturers to standardize support for the CA Rule 21 Smart Inverter functions and the open SunSpec communication interface standard. The SunSpec interface is specified by IEEE 1547-2018, low-cost, scalable from residential to large-scale commercial systems, and results in plug-and-play compatible solutions. It fills a critical technology gap, enables grid operators to monitor and control DER assets cost effectively, improves grid stability, and will enable DER systems to participate in ancillary services markets.

## **Develop Interlocking Technologies to Validate the Theory**

The Smart Inverters in this project were complemented by a Smart Inverter test framework and open source software tools to enable 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 and collected empirical data. The project team assimilated and analyzed the data collected during the lab tests and field pilot to demonstrate the validity of the predicted benefits specified in the project goals. Finally, the project developed a financial model to estimate the economic impact of deploying Smart Inverters at scale.

## **Execute and Iterate**

With a project as ambitious and complex as this one, it was clear that a nimble and exacting management approach was needed. To ensure that the project stayed on track throughout the inevitable ups and downs of standards development processes, regulatory development processes, an evolving partner/contractor mix, and technical setbacks and breakthroughs, the project maintained an agile posture.

Sub-groups within the team met weekly and aligned their short-term objectives to tasks that could be accomplished in three-week sprints. The larger group met less frequently, but often came together in conjunction with market outreach activities. Financial management was addressed rigorously, with an emphasis on timely delivery, in-kind contribution accounting, and precise record keeping.

Most importantly, the project was galvanized by the knowledge of the importance and timeliness of the work to the state of California and to the planet.

# CHAPTER 4:

## Project Results

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This project resulted in many significant achievements in Smart Inverter research, conformance testing, standardization, cybersecurity, and education. This chapter details these results and deliverables. Each section covers a single project result, describing the result delivered and its significance to the Smart Inverter and DER industries.

### Smart Inverters Enable 100%+ Penetration of DER

This project successfully demonstrated that Smart Inverters can enable DER penetration of more than 100% of peak instantaneous distribution circuit load. This success is validated by the report titled “Smart Inverter Performance Testing To UL 1741 SA and CA Rule 21 Criteria: Results From the UC San Diego Smart Inverter Laboratory<sup>20</sup>,” “Smart Inverters for High PV Penetration: Analysis of functionality and behavior<sup>21</sup>,” and the “*SunSpec 2030.5/CSIP Field Trial Results Report*<sup>22</sup>.” These results are additionally supported by the “*Integration of Big Data for Advanced Automated Customer Load Management*<sup>23</sup>” report by SCE.

This result shatters the 15% DER ceiling currently enforced by utilities across the country within the IEEE 1547 standard guidelines. It also enables achievement of California energy policy goals described in SB 100, along with other benefits which provide state-wide value including reduced greenhouse gas emissions, improved air quality, enhanced consumer choice, and the spread of renewable energy and electric vehicles within marginalized communities.

### Smart Inverter Value Proposition Analysis Results

Smart Inverters, combined with standardized communication protocols, establish a new class of resources on the grid that are controllable and highly responsive. Increasing the number of Smart Inverters allows for grid support on both a local and regional scale, beyond what can be maintained or managed with traditional resources. Smart Inverter functions, both autonomous and controlled, enable ratepayers, DER owners, and stakeholder to access new value streams.

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<sup>20</sup> 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.

<sup>21</sup> 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.

<sup>22</sup> Tom Tansy, Bob Fox, Suzanne Martinez, Glenna Wiseman. SunSpec Alliance. 2019. SunSpec 2030.5/CSIP Field Trial Results Report. California Energy Commission.

<sup>23</sup> Joshua McDonald. (Southern California Edison). January 2019. Integration of Big Data for Advanced Automated Customer Load Management. California Energy Commission.

To assess the value of Smart Inverters and their capabilities, the project developed a value proposition analysis model. This model is available for inspection and review in the document titled “*Smart Inverter Value Proposition Analysis Spreadsheet*”<sup>24</sup> and described in the report titled “*Networked DER Value Proposition Report*.”<sup>25</sup>

The analysis methodology for the model is based on the prior California Energy Commission funded work on Distribution Automation (DA) impacts (Navigant, 2009).<sup>26</sup> The project used the DA report analysis as a framework to evaluate the benefits of Smart Inverters to the utility, customers, and society at large. The high-level quantification of Smart Inverter benefits was based on 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 due to the benefits of Smart Inverters and is comprised of the improvements in the areas of reliability, power quality, energy delivery efficiency, dispatchable resources, and avoided or deferred transmission and distribution upgrades. A breakdown of savings by type is shown in the table below.

**Table 2. Smart Inverter Value Proposition Analysis Summary.**



**SMART INVERTER VALUE PROPOSITION ANALYSIS SUMMARY**

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
<b>Total</b>	<b>\$</b>	<b>640,000,000</b>	<b>\$</b>	<b>1,430,000,000</b>

These benefits are due to the enhanced operation and improved performance of the grid by Smart Inverters, as well as 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.

<sup>24</sup> Ron Nelson, Kevin Moy. January 2019. Smart Inverter Value Proposition Analysis Spreadsheet. California Energy Commission. Available at <https://www.sunspec.org>

<sup>25</sup> Ron Nelson, Kevin Moy. January 2019. *Networked DER Value Proposition Report*. California Energy Commission. Available at <https://www.sunspec.org>

<sup>26</sup> <https://www.energy.ca.gov/2007publications/CEC-500-2007-103/CEC-500-2007-103.PDF>

## **CA Rule 21 Technical Specifications and Test Criteria**

California Rule 21 defines a framework for retail market participation by DER, for interconnection, operating, and metering requirements. The current revision of Rule 21 was made to allow utilities to utilize 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 assets.

SunSpec Alliance led the design of key technical specifications to ensure that Smart Inverters achieve full capability and usage within California Rule 21. SunSpec operates working groups to maintain and update these documents, which are published, open and royalty-free, on the SunSpec web site.

### **Common Smart Inverter Profile**

SunSpec Alliance, working with industry and utility participants, was a key contributor to the development of the Common Smart Inverter Profile (CSIP)<sup>27</sup>. This document is an implementation guide for IEEE 2030.5-2018 as applied to Rule 21, now hosted 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 the full extent of Rule 21 capabilities.

### **Open Test Procedure for IEEE 2030.5/CSIP**

SunSpec Alliance developed the SunSpec Common Smart Inverter Profile (CSIP) Conformance Test Procedures<sup>28</sup>, an open, royalty-free document that describes how to validate Smart Inverters for adherence to Rule 21 requirements for compliance to the IEEE 2030.5-2018 standard as describe in the Common Smart Inverter Profile. The EPC-14-0336 project funded development of Rule 21 Phase 1 test procedures, including tests for autonomous function behavior and communication interface settings support.

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<sup>27</sup> SunSpec Alliance. March 2018. Common Smart Inverter Profile (CSIP) version 2.1. Accessible from <https://sunspec.org/download/>

<sup>28</sup> SunSpec Alliance. Common Smart Inverter Profile (CSIP) Conformance Test Procedures. Accessible from <https://sunspec.org/download/>

## Smart Inverter Communication Go-To-Market Platform

SunSpec developed and established a low-cost means for Smart Inverter manufacturers to test hardware for compliance with Rule 21. This work was funded by the project and includes:

- An open Smart Inverter test lab specification, used in the UCSD Smart Inverter test lab.<sup>29</sup>
- Open test scripts for IEEE 2030.5/CSIP client and SunSpec Modbus protocol conformance.<sup>30</sup>
- Updates to SunSpec System Validation Platform (SVP)<sup>31</sup> 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 type of organization, including buyers or interested third parties, to establish their own facilities for evaluating Smart Inverters.

## Confirmation of Smart Inverter CA Rule 21 Conformance

SunSpec tested and verified the conformance of Smart Inverter products from five manufacturers to Rule 21 specifications at the UCSD Smart Inverter test lab using the SunSpec platform.<sup>32</sup> This work proves the individual inverters are Rule 21 conformant and demonstrates that any Rule 21 Smart Inverter can be exercised and evaluated, in a standard manner, for compliance to the standard using open source tools.

## Influencing Relevant DER Source Standards

The development of the Rule 21 testing and conformance platform led to an understanding of how Smart Inverters should communicate. This understanding was used by SunSpec to inform and influence other standards and protocols with practical knowledge acquired during this development process. These include:

- Opening Project Action Request (PAR) and revising the IEEE 2030.5 standard to reflect lessons learned from this project, including updating the cybersecurity section.
- 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 CA Rule 21 requirements.

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<sup>29</sup> SunSpec Alliance. March 2016. SunSpec Advanced Function Inverter Test Lab Specification. Accessible from <https://sunspec.org/download/>

<sup>30</sup> SunSpec Alliance. 2015-2019. SunSpec System Validation Platform open source libraries. Available at [https://github.com/sunspec/svp\\_directories](https://github.com/sunspec/svp_directories).

<sup>31</sup> SunSpec Alliance. 2015-2019. SunSpec System Validation Platform. Information available at <https://www.sunspec.org>.

<sup>32</sup> 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.

This broad, ongoing work in standardization ensures that Smart Inverters will follow a strict set of operational and communications protocols, facilitating the proliferation of networked DER systems compliant with Rule 21 requirements.

## **Improvements of Cybersecurity Practices and Infrastructure**

Smart Inverters, as communicating devices, must necessarily implement and comply with cybersecurity standards. To investigate this topic, SunSpec launched the SunSpec/Sandia DER Cybersecurity Workgroup. This workgroup comprises approximately 350 professionals from the DER/cybersecurity industry, and includes stakeholders across the value chain. The workgroup has met consistently since 2017 and has published three best practices papers on the topic, all of which are available for free download from the SunSpec website.<sup>33</sup>

Consistent with the SunSpec/Sandia DER Cybersecurity Workgroup mission, the group promoted its first cybersecurity 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). This proposal was accepted by UL and the process of establishing the UL 2900-2-2 Standards Technical Panel commenced 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.

SunSpec, Sandia, and others jointly authored a scientific paper on issues associated with digital security and Public Key Infrastructure titled “Recommendations for Trust and Encryption in DER Interoperability Standards – SAND2019-1490<sup>34</sup>.” This paper is foundational to understanding the DER cybersecurity topic and to evolving communication standards.

## **Communication Interface Certification Program**

To establish uniform performance criteria for communicating Smart Inverters, the SunSpec Alliance launched the SunSpec Certified program. This program utilizes a network of SunSpec Authorized Testing Laboratories, the SunSpec Common Smart Inverter Profile (CSIP) Conformance Test Procedures, a test results reporting standard<sup>35</sup>, and the SunSpec Public Key Infrastructure to establish a benchmark for the industry.

SunSpec has established a network of seven SunSpec Authorized Testing Laboratories: five Nationally Recognized Testing Laboratories (NRTLs) 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.

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<sup>33</sup> <https://sunspec.org/sunspec-cybersecurity-workgroup/>

<sup>34</sup> 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.”

<sup>35</sup> SunSpec Alliance. 2019. SunSpec IEEE 2030.5/CSIP Conformance Test Procedures Results Reporting. Accessible at <https://www.sunspec.org>.

To easily identify Smart Inverter products that have successfully passed such testing, SunSpec also 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 Button<sup>36</sup> taxonomy, to enable AHJs to publish customized product listings.

This service will allow AHJs, including the California Energy Commission, to maintain a database of approved Smart Inverter models that can be installed within the jurisdiction. The SunSpec product listing service can be easily updated as new Smart Inverters are approved and will ease the hardware selection process for developers within the jurisdiction.

## **SunSpec Public Key Infrastructure (PKI)**

SunSpec established the SunSpec Official PKI Program<sup>37</sup> to provide security services for SunSpec Certified products and announced Kyrio its the official PKI provider.<sup>38</sup> This service is foundational to a California smart grid communication infrastructure that will integrate Smart Inverters, energy storage, and electric vehicles. It provides highly secure communications between DER systems, aggregators, and utilities, and is tailored to the needs of the industry.

## **Education and Outreach**

SunSpec developed and implemented a suite of programs and seminars to disseminate knowledge about Smart Inverters, DER data communication, and the CA Rule 21 roll out. 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.<sup>39</sup> The event attracted 65 attendees and featured speakers from 17 companies, allowing collaboration and learning between DER stakeholders working to digitize information and interoperability of energy assets.<sup>40</sup>

SunSpec established a California Rule 21 education program, which includes a technical track and executive track.<sup>41</sup> This program was developed in conjunction with the University of California San Diego (UCSD), QualityLogic, and Kitu Systems. All courses are promoted by email, web postings, and social media, and in the UCSD Extension course catalog.

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<sup>36</sup> SunSpec Alliance and U.S. Department of Energy. 2018. Orange Button: Solar Financial Data Exchange Standard. Information available at <https://sunspec.org/orange-button-initiative/>

<sup>37</sup> <https://sunspec.org/sunspec-public-key-infrastructure-pki-program/>

<sup>38</sup> <https://sunspec.org/sunspec-alliance-announces-kyrio-official-pki-provider/>

<sup>39</sup> <https://sunspec.org/gridvolution/>

<sup>40</sup> <https://sunspec.org/sunspec-alliance-convene-global-technology-leaders-discuss-electricity-grid-evolution-september-12-2018/>

<sup>41</sup> <https://sunspec.org/sunspec-california-rule-21-educational-program/>

The Rule 21 technical training course was lauded as “one of most successful market transitions from lab to curriculum” in UCSD history, by Byron Washom, the director of the Strategic Energy Initiatives program at UCSD. The 9-module online course was offered in the fall of 2018 with 17 students and again in in winter of 2018-2019<sup>42</sup>, with th headcount nearly doubling to 31 students. The course will be 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 was initiated in March 2018, and has included training workshops conducted at Intersolar North America<sup>43</sup>, Solar Power International<sup>44</sup>, and UCSD<sup>45</sup>.

SunSpec and Sandia hosted a cybersecurity webinar in December 2018 with nearly 200 registrations. The webinar covered the security requirements of IEEE 2030.5 and how 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.<sup>46</sup>

These courses, workshops, and events are crucial for the development of Smart Inverters going forward. They allow for the spread of knowledge acquired and experience gained during the term of this project and encourage further collaboration and discussion amongst the Smart Inverter industry.

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<sup>42</sup> <https://sunspec.org/sunspec-alliance-uc-san-diego-extension-announce-winter-2019-ca-rule-21-secure-communication-networking-courses/>

<sup>43</sup> <https://sunspec.org/executive-track-california-rule-21-market-opportunity-executives-2/>

<sup>44</sup> <https://sunspec.org/sunspec-alliance-annual-member-meeting-digital-energy-summit/>

<sup>45</sup> <https://sunspec.org/california-rule-21-market-opportunity-executives/>

<sup>46</sup> <https://sunspec.org/cybersecurity-webinar-securing-california-rule-21-networks/>

# CHAPTER 5:

## Technology Transfer and Market Adoption

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The knowledge gained from the project is made available to inverter manufacturers, aggregators, end users, utilities, regulatory agencies, other SunSpec members, and members of the public using methods that promote the adoption of the best practices, standards, procedures, services, and open source software resulting from this project.

### Technical Advisory Committee

A Technical Advisory Committee was formed of parties not directly associated with the project to provide guidance to the project team. The advisory group met twice and provided key input.

- 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

The specifications and related documents delivered by this program are offered royalty-free under the MIT open source license. These documents are available from the SunSpec web site.

### Policy Impact

All project artifacts (specifications, documents, and software) will be disseminated to non-profit organizations involved in state-level policy development (i.e. Technet, Silicon Valley Leadership Group, Clean Coalition, and the Interstate Renewable Energy Council) and SunSpec's 100+ member companies and business partners in order to foster dialog regarding how open communication standards are positively impacting the grid.

### Outreach

The knowledge gained from the project is made available to inverter and Distributed Energy Resource manufacturers, aggregators, end users, utilities, regulatory agencies, and other members of the public via SunSpec Alliance distribution channels including 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:  
<https://www.solarpowerworldonline.com/2018/05/sunspec-releases-smart-inverter-test-procedures-for-ca-rule-21/>
  - Kitu announces adoption:  
<https://www.solarpowerworldonline.com/2018/07/kitu-systems-announces-rule-21-compliance-software-suite/>

- Certification program announced: <https://sunspec.org/seven-sunspec-alliance-authorized-test-laboratories-announced-2/>
- SunSpec Authorized Testing Laboratories program announced: 9/18/18: <https://sunspec.org/sunspec-announces-rfps-certified-test-lab-pki-programs/>
- Partners announce support for SunSpec Authorized Testing Laboratory program
  - Solar Builder: <https://solarbuildermag.com/news/sunspec-alliance-partners-with-7-test-labs-to-certify-products-for-its-solar-storage-communication-standards/>
  - Solar Power World: <https://www.solarpowerworldonline.com/2019/01/sunspec-alliance-first-seven-authorized-test-labs/>
  - Kyrio: [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: <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/>
- SunSpec Announced CA Rule 21 Deadline Extension: <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: <https://sunspec.org/gridvolution/>
  - Press release and quotes: <https://sunspec.org/sunspec-alliance-convene-global-technology-leaders-discuss-electricity-grid-evolution-september-12-2018/>
  - Media: <https://sunspec.org/111-gridvolution-tom-tansy-sunspec-alliance/>
- SunSpec Launches Educational Program 2/21/18:
  - Program outline: <https://sunspec.org/sunspec-california-rule-21-educational-program/>
  - Update of program: <https://sunspec.org/sunspec-alliance-uc-san-diego-extension-announce-winter-2019-ca-rule-21-secure-communication-networking-courses/>
- CA Rule 21 Executive Workshop Results:
  - March 5, 2018: 65 attendees
  - Intersolar 2018: 35 attendees - <https://sunspec.org/executive-track-california-rule-21-market-opportunity-executives-2/>
  - Solar Power International: 39 attendees - <https://sunspec.org/sunspec-alliance-annual-member-meeting-digital-energy-summit/>
  - UCSD January 2019: 29 attendees workshop - UCSD based: <https://sunspec.org/california-rule-21-market-opportunity-executives/>
- CA 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/>
- Forbes coverage: <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 is provided here.

**Table 3. Composite outreach statistics for 2018.**

<b>Audiences Reached</b>	<b>2018</b>
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
<b>Email Campaigns Referencing IEEE 2030.5</b>	
Campaigns targeting Inverter and Cybersecurity experts	
Total campaigns	13
Messages sent	46,983
Other campaigns targeting Distributed Energy market participants	
Total campaigns	47
Messages sent	261,028
<b>Web Events Referencing IEEE 2030.5</b>	
Web events targeting Inverter and Cybersecurity experts	
Total web events	3
Total web event registrants	313
Other web events targeting Distributed Energy market participants	
Total web events	5
Total web event registrants	283

<b>SunSpec Live Events and Activities</b>	
SolarPlaza Asset Management North America 2018 (multiple presentations)	300+
SunSpec Executive Summit on CA Rule 21 in SF	64
Intersolar North America 2018 workshop on CA 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 include:

**Table 4. Media statistics for 2018.**

<b>Description</b>	<b>Statistic</b>
Number of media coverage pieces	8
Online readership of publications	109 Million
Estimated Coverage views	102,000
Social Shares from coverage	433

# CHAPTER 6:

## Conclusions and Recommendations

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The EPC-14-036 project was complex and 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 valuable lessons learned.

### **Sustaining long-term engagement of vendors with limited roles is challenging.**

Though vendor enthusiasm remained high throughout the project, some vendors were not ready to test when the time came and had to be replaced. The primary reasons for lack of 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 to be adjusted.

### **Bridging retail and wholesale energy markets will take more work.**

This project demonstrated that Smart Inverters with a standard communication interface can be manipulated to provide a wide array of grid support functions. This mechanism is precisely what is needed in order for DER to participate in the wholesale electricity market and yet it is insufficient. As described in the wholesale market analysis report included in this project<sup>47</sup>, recent studies performed by Lawrence Berkeley National Laboratory showed a lack of economic feasibility for the wholesale market, due to the low profitability of DER services when operating under differing retail and wholesale tariff structures<sup>48</sup>. Rather than attempt to replicate the LBNL work, further analysis was required into the feasibility of integrating the wholesale and retail markets with Rule 21 as a framework, which formed the basis of the wholesale market analysis report for this project.

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<sup>47</sup> Analysis Report of Wholesale Energy Market Participation by Distributed Energy Resources (DER) in California

<sup>48</sup> 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.

## **New methods are needed to evaluate the economic benefits of DER and Smart Inverters.**

The most recent Energy Commission-approved economic models for evaluating the value of automated distribution infrastructure, including DER, were developed more than 10 years ago. The global market has evolved dramatically since then and much has changed in terms of equipment capabilities, value streams, and use cases. In order to properly analyze the value proposition of DER and Smart Inverters, a new analysis framework was needed. The project developed this framework and now offers it as the new benchmark for the industry.

## **Considerations for Further Development**

The results presented in this report expose some of the regulatory and market barriers preventing Smart Inverters and DER from reaching their full potential. The following recommendations present actions to mitigate these barriers.

### **Market Considerations**

As discussed in the Wholesale Market Report<sup>49</sup> included in this project, the harmonization of retail and wholesale market tariffs to create a combined wholesale/retail market will be crucial to realize the full benefits of Smart Inverter DER. Greentech Media published an article in January 2019 citing issues with a wholesale market based on legacy generation resources, but adding that the relative ease of installing and commissioning energy storage (versus traditional generation resources) presents a significant advantage<sup>50</sup>. The Smart Inverter testing infrastructure and standardization presented in this report further enhances this benefit for DER as a wholesale market resource.

While this project focused on the prospect of solar PV and energy storage enabled by Smart Inverters, using electric vehicles (EVs) as DER is a growing potential as well<sup>51</sup>. According to the Auto Alliance, more than 162,000 plug-in EVs are registered in the state of CA<sup>52</sup>. Assuming an average battery of 50 kWh, this represents over 8 GWh of capacity. While the same principles of PV/storage Smart Inverters apply, more work needs to be done to standardize EV systems as a grid resource – for example, by making the distinction between a charging station interfacing with the grid vs. a mobile EV, and classifying EVs based on whether they have an onboard inverter. Similar to stationary storage, charge management also needs to be standardized to balance grid resource needs with EV owner needs. However, if properly standardized and controlled, EVs provide vast opportunity to add to the Smart Inverter DER capacity.

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<sup>49</sup> Tom Tansy, Ron Nelson, Kevin Moy, Suzanne Martinez. 2018. Analysis Report of Wholesale Energy Market Participation by Distributed Energy Resources (DERs) in California. California Energy Commission.

<sup>50</sup> (Gimon, 2019)

<sup>51</sup> [Chris Nelder, James Newcomb, and Garret Fitzgerald, Electric Vehicles as Distributed Energy Resources, Rocky Mountain Institute, 2016, www.rmi.org/pdf\\_evs\\_asDERs](http://www.rmi.org/pdf_evs_asDERs)

<sup>52</sup> (Auto Alliance, 2019)

## **System Cost and Compensation**

For owners of DER, who traditionally interact only with the retail market, the issue of compensation must be addressed in order to incent participation in the wholesale market. The location and functionality of the Smart Inverter within the distribution grid greatly affects its value and compensation potential<sup>53</sup>. However, designing a locational value tariff presents significant technical, regulatory, and political challenges<sup>54</sup>. A harmonized retail and wholesale energy market will help address these challenges by creating a unified platform which can be used to establish this new value infrastructure.

For electricity providers, significant investment is required in order 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 (DERMS), recommends more investment into DERMS control infrastructure, including “improved data quality, modeling, forecasting, communications, cybersecurity, and a DER-aware [Advanced Distribution Management System] ADMS”<sup>55</sup>. While the results of this report demonstrate capabilities on the individual Smart Inverter level, these capabilities will only be realized with proper support from the grid infrastructure.

The advanced capabilities of Smart Inverters should be taken into consideration during the design process, both for individual DER systems and the future DER-enhanced grid. 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 to maintain stable grid operating conditions. From a regulatory standpoint, given the results provided in this report, grid modernization proposals need to adequately and accurately reflect benefits of DER. For example, restrictions on distribution circuits for DER penetration beyond 15% need to be re-evaluated in these proposals to accurately reflect the operational benefits and avoided costs of Smart Inverter DER.

## **Consumer Impacts and Protections**

Utilizing CA Rule 21 smart inverter functions can, dependent on the settings, reduce a DER system’s generation at certain locations. This can impact a consumer’s investment and project economics. Care must be taken to ensure customers are not unduly affected 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 of the customer’s control, such as utility voltage regulation practices, introducing these functions may complicate system performance, modeling and potentially reduce 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/or that recourse exists to the extent a single customer experiences a disproportionate amount of generation loss. Similarly, DER system

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<sup>53</sup> (Dave Gahl, 2018)

<sup>54</sup> (Spector, 2019)

<sup>55</sup> (Pacific Gas and Electric Company, 2019)

designers need to understand and model the effects of the new functions on DER output power to convey accurate information to customers regarding anticipated lifetime generation<sup>56</sup>.

## Future Capabilities of Smart Inverters

The results of this project will help shape the future of Smart Inverters and DER on the grid. By utilizing functional and communications standards, original equipment manufacturers avoid 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 eliminates “switching” costs associated with using one brand or another.

By providing standardized functional requirements and testing platform tools, development time can be dramatically compressed and product quality can be increased, allowing quicker implementation of DER on the grid. The SunSpec System Validation Platform reduces testing time by one to two orders of magnitude versus current practices<sup>57</sup>. This allows new Smart Inverters with 10X the functionality of non-Smart Inverters to be tested in less time.

Given a harmonized and unified retail and wholesale market for DER as described above, the IEEE 2030.5 infrastructure for the retail market can be extended to the wholesale market. This will allow Smart Inverter DER to be accessed for operation in both markets simultaneously.

Indeed, activity in other markets shows promise for DER wholesale market participation. In February 2019, Independent System Operator-New England (ISO-NE) became the first capacity market to accept an aggregated residential solar-plus-storage bid, awarding Sunrun for 20 MW of distributed grid capacity to be online in 2022<sup>58</sup>.

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 which could 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 DER could be dramatically reduced. 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 their wildfire mitigation plan, which accounts for planned mandatory grid shutdowns during unsafe fire conditions (e.g. high winds)<sup>59</sup>. Microgrids have been proposed as a solution to keep power to certain loads during these shutdown events. Smart Inverters, given their autonomous and controllable capabilities, would be a key component of these microgrids and could help reduce the costs associated with reducing wildfire risks.

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<sup>56</sup> Lydic, Brian and Sara Baldwin, January 2019. “Making the Grid Smarter”. Interstate Renewable Energy Council.

<sup>57</sup> Johnson, Jay, October 2015. Presentation at Energy Storage North America, San Diego.

<sup>58</sup> (Gheorghiu, 2019)

<sup>59</sup> (Pacific Gas and Electric Company's Wildfire Mitigation Plan, 2018)

Additional work is needed to incorporate Smart Inverters into such a microgrid. A local energy management system (EMS) would be required in order to coordinate Smart Inverter operation along with other system components. Smart Inverter settings would need to be reconfigured to accommodate microgrid operation modes, and existing communication protocols do not yet provide a 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 operation on the inverter. In short, just as aggregation and communications have been standardized for Smart Inverters in CSIP and Rule 21, microgrid operations also need to be standardized.

## **Conclusion**

This project successfully demonstrated that Smart Inverters compliant with CA Rule 21 Phase 1 and Phase 2 requirements can be installed safely at penetration levels of 100% 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% renewable energy goals.

This project includes a framework that enables Rule 21 compliant Smart Inverters to be easily deployed and integrated into the grid. SunSpec's combined results in lab and theoretical testing, technology dissemination, education, verification, and certification for Smart Inverters provides a pathway for DER to achieve critical mass, thus enabling DER to provide non-wires grid support solutions throughout California.

In summary, SunSpec has developed a streamlined Smart Inverter standardization platform for 100% 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 the state of California.

# CHAPTER 7:

## Benefits to Ratepayers

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This project represents a four-year intensive investment of EPIC 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 creation of the testing environment and tools, to inverter testing and reporting through field trials and market analysis, quantitative and qualitative benefits emerged impacting a broad range of California stakeholders. While the core results have been addressed in depth in this and other related reports, this California Energy Commission EPIC project has resulted in eleven benefits outlined here.

### Smart Inverter Value Proposition Analysis Shows \$640 Million to \$1.4 Billion Annually

By demonstrating that 100% DER grid penetration is possible, this project shatters the 15% DER ceiling currently enforced by utilities across the country within the IEEE 1547 standard guidelines. This report includes a Smart Inverter Value Proposition Analysis to quantify these benefits; the results of this analysis are presented below, showing value of \$640 million to \$1.4 billion due to Smart Inverters.

Table 5. Smart Inverter Value Proposition Analysis Summary



**SMART INVERTER VALUE PROPOSITION ANALYSIS SUMMARY**

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
<b>Total</b>	<b>\$ 640,000,000</b>	<b>\$ 1,430,000,000</b>

The values calculated accrue to the general customer population at large on an annual basis (Note: while some benefits may first accrue to the utility, such as avoided and deferred T&D upgrades, eventually the decreased costs would 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).<sup>60</sup> While the benefits are not intended to be discrete, and therefore may be related and overlap, the calculation purposely

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<sup>60</sup> Ron Nelson, Kevin Moy. January 2019. Networked DER Value Proposition Report. California Energy Commission. Available at <https://www.sunspec.org>

omits benefits that are almost entirely duplicative, such as the benefit of bill reduction that are reflected through avoided wholesale and infrastructure costs.

We note that there is considerable overlap between the Smart Inverter benefits and those resulting from DER in general. However, as Smart Inverters enable 100% DER penetration, and are indeed required of DER generation in current policy, these benefits cannot be decoupled from each other.

## **152X 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), and 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 by EPIC.

## **\$500 Per System Savings Due to Standardization**

With the availability of a standardized IEEE 2030.5/CSIP network approach validated, several areas of cost savings can be realized.

### **System Redesign Cost Reduction**

Every constructed DER system starts as a system design comprised of components specifically selected for that installation. Prior to the advent of smart inverters, inverter designs were considered unique, thus requiring special engineering consideration in each instance.

With smart inverters standardized, system designers are free to pick and choose amongst 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 adds further economy.

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 100's of thousands of units per year (California will install about 250,000 new smart inverter-based systems per year), residential gateway OEM's 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 compute 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 \$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 result in monitoring companies competing with one another for existing installations—something that was virtually impossible with bundled hardware/software solutions—and new software entrants coming into the market.

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

Table 6. Cost reduction opportunities from standardization.

### INTEROPERABILITY STANDARDIZATION LOWERS PV SYSTEM COST BY \$500 PER SYSTEM

Savings Description	Estimated Savings Per DER System from Interoperability Standardization	
System Redesign Cost Reduction	\$	200
Network Gateway Cost Reduction	\$	200
Monitoring/Management Cost Reduction	\$	100
<b>Total Estimated Savings</b>	<b>\$</b>	<b>500</b>

## DER With Smart Inverters Support California Clean Energy and Environmental Initiatives

The project supports the California Energy Commission’s commitment to help the State of California reach its ambitious targets for transitioning the electric grid to renewable energy as part of state level action on climate change.

When the project was initiated in 2015, SB X 1 was the underlying renewable energy legislation. DER enabled by interoperable, Smart Inverters support California’s clean energy and environmental initiatives. Over the last five years, the state has enacted increasingly proactive mandates to reach 100% clean energy. Smart Inverters, by empowering 100% penetration of DER on the grid, supports these mandates.

The following is a chronological list of CA clean energy legislation positively impacted and supported by DER systems enabled by Smart Inverters:

### **2011 SB X 1-2: California Renewable Energy Resources Act**

This bill, made official in 2011, obligates all California electricity providers to obtain at least 33% of their energy from renewable resources by the year 2020. It was considered the most aggressive renewable portfolio standard in the country<sup>61</sup>.

### **2016 CPUC DER Action Plan**

The California Public Utilities Commission (CPUC)'s 2016 DER Action Plan – updated in 2017<sup>62</sup> – created a roadmap for the Commission in distributed energy resource planning within the context of greenhouse gas emission reduction and the “reform of utility distribution planning, investment, and operations.”

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

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

The Commission sees value in DER and concludes its action plan with a commitment to develop market opportunities and remove barriers to DER.

### **2017 California Rule 21**

In 2017, the California Public Utilities Commission (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 connect to the California grid and are intended to maintain safety and reliability of the distribution and transmission systems<sup>63</sup>.

### **2018 SB 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 the commitments made in the Paris Agreement and take stronger action toward zero emissions by midcentury. To kick off the summit, Governor Brown signed SB 100, the 100 Percent Clean Energy Act of 2018<sup>64</sup>, which both accelerates the pace at which electricity providers in the state must achieve renewable energy goals and establishes a state policy to provide 100% clean energy by 2045. At the same time, Executive Order B-55-18 to Achieve Carbon Neutrality was signed, also with a 2045 target.

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<sup>61</sup> [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)

<sup>62</sup> <http://www.cpuc.ca.gov/General.aspx?id=6442458159>

<sup>63</sup> <http://www.cpuc.ca.gov/Rule21/>

<sup>64</sup> <https://focus.senate.ca.gov/sb100>

SB 100 outlines that:

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

These policy instruments are intended to generate benefits beyond achieving carbon neutrality, such as 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 use.
- Cleaner, healthier air and less pollution in vulnerable communities where power plants are often located.

The demonstration of the viability of 100% DER utilization on the grid supports California climate and clean energy legislation including SB 100. This project provided significant public benefit to California IOU electricity ratepayers by confirming that smart inverters can be deployed in support of PV penetration up to and exceeding 100% 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 Assessment<sup>65</sup> 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 California Energy Commission was one of the lead coordinating agencies.

The report succinctly states: “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 increasing electricity demand for air conditioning due to hotter temperatures (particularly peak hourly demand during the hottest months). Strategies for the subsequent challenge of electricity generating capacity matching this demand, and other climate adaptation needs, are being considered by the California Public Utilities Commission (CPUC). Climate related sea level rise and storm events increase flood and wildfire risk to energy infrastructure, particularly the NorCal grid and substations in low lying areas.

Possible response measures suggested for areas where capacity may be exceeded include additional substation capacity, distributed energy resources, or load shifting. The main adaptation suggestion for areas with damaged grid infrastructure is increased use of non-generating DER, such as such as energy storage or smart-charging electric vehicles.

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<sup>65</sup> <http://www.climateassessment.ca.gov/state/overview/>

## **CA Rule 21 Jumpstarts California's IEEE 1547-2018 Standard Compliance**

Concurrent with the activities of this project, the U.S. national standard (IEEE 1547) was further developed and refined, informed in large part by knowledge generated by SIWG 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 are SunSpec Modbus, IEEE 2030.5-2018, and IEEE 1815, thus aligning well with California Rule 21 requirements.

IEEE 1547-2018 is anticipated 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 serves to jumpstart the compliance of the DER marketplace to IEEE 1547, thus making the California grid smarter through networked and interoperable DER system components.

## **DER Systems with Smart Inverters Create Grid Benefits: Greater Reliability, Improved Capacity Optimization and Flexibility**

A pilot installation of 15 solar plus storage solutions, networked according to CA Rule 21 Phase 1 and 2 requirements, provided operational data that enabled important insights into the DER commissioning and data networking processes, facilitating higher levels of renewable penetration and providing greater flexibility to local capacity with increased reliability through improved capacity optimization.

**Improved power delivery reliability:** The tested smart inverters demonstrated that higher levels of renewable generation penetration can be achieved, obviating the need for conventional sources, while enhancing reliability by providing distributed services that were previously provided by conventional bulk generating sources. The result is an economic savings resulting from reducing the need to build new power system infrastructure, (i.e. voltage support, spinning reserves, etc.) 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.

## **DER Systems with Smart Inverters Provide Increased Ratepayer Safety**

Smart inverters plus storage networked within the CA Rule 21 tariff can be controlled by groups or nodes. Thus, DER systems supporting medical necessities and larger systems for critical loads can be programmed for active operation during fires or other natural disasters. Systems for which battery backup can keep critical functions going also service the greater good and can be powered when solar generation is available even if the grid is down.

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

## **High Penetration DER Enabled by Smart Inverters Drives Economic Development**

The high penetration potential of DER enabled by Smart Inverters has the additional potential of spurring economic development on several fronts.

While this project does not include a scope of work to outline quantitative benefits related to economic development, the report does point to qualitative results.

Job Development - By perpetuating solar, energy storage and related DER system proliferation in California through the clearing of challenges related to 15% DER grid penetration, the project points to job development in the following areas:

- Growth of construction jobs as a result of DER system growth.
- Software and services jobs.
- Export of CA grown DER expertise to other regions wherein CA based companies could leverage expertise in the CA market to accelerate networked grid to other parts of country.

Workforce Development - New industry entrants and existing workers in DER data communications, network IT and cybersecurity are being trained<sup>66</sup> now in relation to meeting CA Rule 21 mandates. These include educating existing power line engineers to understand IT parameters. This training to bridge the existing skilled worker gap in the renewables industry and ensure the workforce is prepared for the specialized nature of new jobs related to DER and the evolving grid. Community colleges can serve as the centers for this training.

Accelerate/Increase the Manufacturing Base in CA - Assimilating lessons learned into the California manufacturing base will increase penetration of smart inverters locally and support grid stability, benefiting all stakeholders. The rollout of smart inverters and storage is occurring globally, and the lessons learned through this project will aid the growth of the California smart inverter manufacturers, energy storage providers, and data communication industries significantly.

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<sup>66</sup> 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 <https://sunspec.org/sunspec-california-rule-21-educational-program/>

Cost Effective Replication of Project in Other California Locations - Given the complexity of testing CA Rule 21 related 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, DER asset owner/operators, and academic institutions (including other UC's, California State University campuses, and California Junior Colleges) can adopt the technology to develop their own DER research facilities and train the next generation of workers that will be required by the market.

Research into the effects of Distributed Energy Resources is in its infancy and this project delivered a new technology (smart inverter test automation) that can be leveraged by California for years to come. With the breakthroughs this project has yielded in the areas of capital equipment cost reduction for smart inverter testing, DER simulation, and test automation, it is conceivable smart energy laboratories may one day be affordable to the likes of California high schools and primary schools.

## **High Penetration Distributed Photovoltaics and Storage Reduce GHG Emissions by 112 million metric tons<sup>67</sup> annually for a cost savings of \$1.7 billion<sup>68</sup>**

The most recent figures for California's greenhouse gas emissions (GHG) are for 2016. That year, the state's total GHG emissions were 429.4 million metric tons of CO<sub>2</sub> equivalent (MMTCO<sub>2</sub>e). The electricity sector accounted for 16% of that, or 68.95 million metric tons<sup>69</sup>.

An earlier report for with 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 PV+storage systems by up to 200% 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 in 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 result, we can conclude that grid penetration levels of 100% or greater are technically feasible.

As a result, we can estimate that cost savings associated with supplying 100% of state-wide energy requirements with low cost solar energy could reduce GHG emissions by 112 million metric<sup>70</sup> tons.

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<sup>67</sup> California Greenhouse Gas Emission Inventory. California Air Resources Board.  
<https://www.arb.ca.gov/cc/inventory/data/data.htm>

<sup>68</sup> <https://rhg.com/research/the-footprint-of-us-carbon-pricing-plans/>

<sup>69</sup> <https://www.arb.ca.gov/cc/inventory/data/data.htm>

<sup>70</sup> California Greenhouse Gas Emission Inventory. California Air Resources Board.  
<https://www.arb.ca.gov/cc/inventory/data/data.htm>

## **High Penetration Distributed Photovoltaics and Storage Reduce Criteria Air**

The non-energy benefits, namely from GHG and criteria pollutant emission reductions, are equally important to California.

While not within the scope of the project's quantitative benefits study, the project team can qualitatively state that DER do reduce criteria air pollutants.

An August 2007 released analysis by the National Renewable Energy Laboratory (NREL), entitled "Energy, Economic, and Environmental Benefits of the Solar America Initiative<sup>71</sup>", found widespread DER/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<sup>72</sup>.

## **DER Systems Contribute to Energy Security**

Energy security in the context of this qualitative project benefit is defined in two dimensions. These dimensions are availability of energy and the security of DER 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<sup>73</sup>." In this context, the installation of ever higher levels of DER on the California grid and the resiliency and reliability benefits of those Smart Inverter enabled DER, as now proven feasible by this project, alleviates pressure on the state to generate and/or import energy from centralized and/or fossil fuel sources.

The second dimension of energy security to which this project contributed, and will continue to contribute indefinitely past the confines of its formal end, is to DER cybersecurity. The CA Rule 21 DER installation landscape, moving forward, will be informed by and encompassing of the SunSpec Certified™ Program<sup>74</sup> out of which the SunSpec Public Key Infrastructure (PKI) Program<sup>75</sup> flows. PKI is designated as the method of authentication used for Institute of Electrical and Electronics Engineers Standard (IEEE Std.) 2030.5 and is therefore the method to be used for authenticating and securing communications for SunSpec Certified products and services. Thus, the program's initial focus is to fulfill California Rule 21 compliance.

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71 <https://www.nrel.gov/docs/fy07osti/41998.pdf>

72 <https://news.energysage.com/health-environmental-benefits-of-solar-energy/>

73 [https://en.wikipedia.org/wiki/Energy\\_security](https://en.wikipedia.org/wiki/Energy_security)

74 <https://sunspec.org/sunspec-ieee-2030-5-csip-certification/>

75 <https://sunspec.org/sunspec-public-key-infrastructure-pki-program/>

SunSpec, working with such organizations as the Sandia National Laboratories, is also working on the harmonization and standardization of DER cybersecurity through its Cybersecurity Workgroup<sup>76</sup>.

The mission of the SunSpec DER Cybersecurity Working Group is to support the deployment of DER by defining best practices in cybersecurity for DER and driving the concepts that emerge from these best practices into relevant national and international standards. This work is bounded by requirements put forth by U.S. states that are rolling out advanced DER regulations including California (Rule 21) and Hawaii (Rule 14H).

Some of the international standards referenced or influenced include those published by the Institute of Electrical and Electronics Engineers (IEEE), International Electrotechnical Committee (IEC), Internet Engineering Task Force (IETF), American National Standards Institute (ANSI), the International Standards Organization (ISO), National Institute of Standards and Technology (NIST) Internal/Interagency Reports (NISTIR), North American Electric Reliability Corporation (NERC), CIGRE (International Council on Large Electric Systems) Reports, Federal Information Processing Standard (FIPS), Department of Homeland Security (DHS) Industrial Control Systems Cyber Emergency Response Team (ICS-CERT), and the Information Security Forum (ISF).

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<sup>76</sup> <https://sunspec.org/sunspec-cybersecurity-workgroup/>

## 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 which provides an interface between the smart grid and its users. It is the default communications interface in California for grid integration of DER as described in CSIP.
IOU	Investor-Owned Utilities
ISO	Independent System Operator
Modbus	Modbus is a 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 and 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.

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