Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

# CALIFORNIA UTILITY VISION AND ROADMAP FOR THE SMART GRID OF 2020

Prepared for: California Energy Commission

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# PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

*California Utility Vision and Roadmap for the Smart Grid of 2020* is the final report for the "Defining the Pathway to the California Smart Grid of 2020" project (Contract Number 500-09-014) conducted by the Electric Power Research Institute. The information from this project contributes to PIER's Energy Systems Integration Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

# ABSTRACT

California investor-owned utilities have a vision that the California Smart Grid of 2020 will be a more capable, robust, and efficient electricity infrastructure, which will help achieve multiple energy and environmental policy goals. This report describes that vision and presents a detailed roadmap for achieving that vision. The report provides clarity and direction to support California Smart Grid initiatives and the State's energy and environmental policy goals.

The report details findings in six domains of technical expertise: Communications Infrastructure and Architecture, Customer Systems, Grid Operations and Control, Renewable and Distributed Energy Resources Integration, Grid Planning and Asset Efficiency, and Workforce Effectiveness. These domains form a structure of technical areas under which the project provides further findings on vision, baseline, technology readiness roadmaps, gaps, and recommendations.

The envisioned California Smart Grid of 2020 will link electricity with communications and automated control systems to create a highly automated, responsive, and resilient power delivery system that will both perfect service and empower customers to make informed energy decisions. A smart grid with these characteristics would support California's energy policy goals, including increased penetration of renewable resources, reduced greenhouse gas emissions, increased energy efficiency, implementation of demand response, increased use of distributed energy resources, maintained and/or enhanced grid reliability, and transportation electrification. The smart grid would also provide greater protection from cyber security attacks and safeguard customer privacy and worker safety.

**Keywords:** California Smart Grid, 2010 baseline, 2020 vision, pathways, technology readiness roadmap, smart grid architecture

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# TABLE OF CONTENTS

## TABLE OF TABLES

## TABLE OF FIGURES

# EXECUTIVE SUMMARY

This report presents a vision for the California Smart Grid of 2020 and a policy-driven roadmap that defines pathways for achieving that vision. Reflecting the consensus of California's major investor-owned utilities, the vision and roadmap provide clarity and direction to support California energy policies by defining key capabilities and needs in six broad technical areas known as domains: (1) communications infrastructure and architecture, (2) customer systems, (3) grid operations and control, (4) renewables and distributed energy resources integration, (5) grid planning and asset efficiency, and (6) workforce effectiveness.

The project team synthesized utility perspectives on the progressive development of the California Smart Grid in light of key energy policy drivers. The drivers include greenhouse gas emission reductions, renewables portfolio standards, energy efficiency, distributed resource integration, system reliability, transportation electrification, and security and consumer privacy. The project also illuminated the challenges associated with smart grid development and deployment—such as maintaining and/or increasing reliability in the face of increased grid complexity and managing technologies at different levels of maturity.

California has many existing initiatives, projects, and demonstrations that put it in a leadership position for implementing the smart grid at all technical levels. This report identifies existing smart grid activities, as well as assumptions about factors that will continue to drive smart grid development. The report's findings are intended to help decision makers design and implement smart grid research, development, and demonstration programs and support California's energy and environmental policy targets.

## Project Objectives

The primary objectives of the project described in this report are:

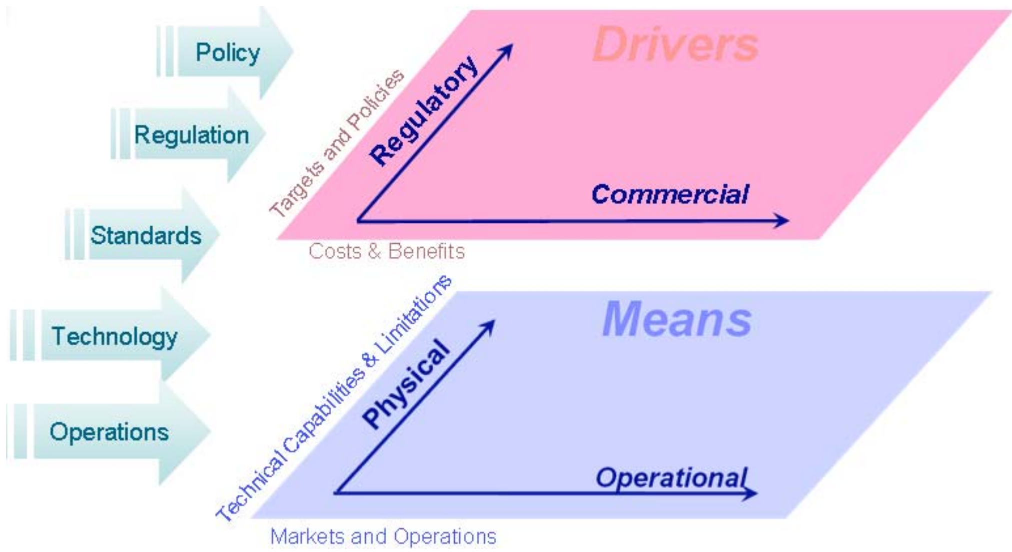
- In partnership with major California utilities, combine utility perspectives on development of the California Smart Grid in light of key state and federal policy drivers.
- Define the utility vision of the California Smart Grid of 2020 and define pathways to reach that vision, using 2010 as a baseline.
- Recommend critical activities to fill technology, policy, standards, process, and education gaps, which need to be closed to implement the vision.

## Project Approach

California's energy and environmental policies are driving the development of a smarter, stronger, and more efficient electricity infrastructure. The California Smart Grid will help achieve multiple energy and environmental policy goals, as described in Chapter 3 of this report. Besides policy and regulations, which evolve over time, an evolution of standards, technology, and operational capabilities also influences timing and commercial viability of smart grid capabilities.

The project team considered multiple factors, including regulatory, commercial, and technical considerations, as well as utility priorities for smart grid development and deployment. The drivers for the smart grid consist of both regulatory policy and commercial considerations. Technical factors determine physical capability and limitations of the smart grid, as well as operational readiness. These factors are depicted in the figure below.

**Figure ES 1: Dimensions of Factors Considered in California Utility Vision and Roadmap Development[1]**




Chapter 3 introduces the various California energy policies driving the development of the smart grid. Chapter 9 addresses commercial considerations including the cost and benefit impacts of smart grid initiatives. Technical capabilities and limitations are addressed in Chapter 7 and presented under six technical domain areas. Chapter 10 summarizes key needs or "gaps," as well as recommendations for overcoming these gaps. Further detailed findings are contained in the Appendices.

## 2010 Baseline

California investor-owned utilities report more than 80 ongoing and planned smart grid-related projects. The following figures show that these projects address all of the smart grid areas, but with different intensities. The focus of ongoing projects is oriented toward distribution applications, followed by transmission, substation, and end use. Most smart grid technology projects are focused on communication infrastructure development, followed by controls and data integration.

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[1] *Distributed Resource Integration Framework: A Reference Model for Characterizing Projects and Relating Programs that Integrate Demand Response and Distributed Energy Resources*. EPRI, Palo Alto, CA: 2009. Product ID: 1020313.

**Figure ES 3: Organizations Affected**

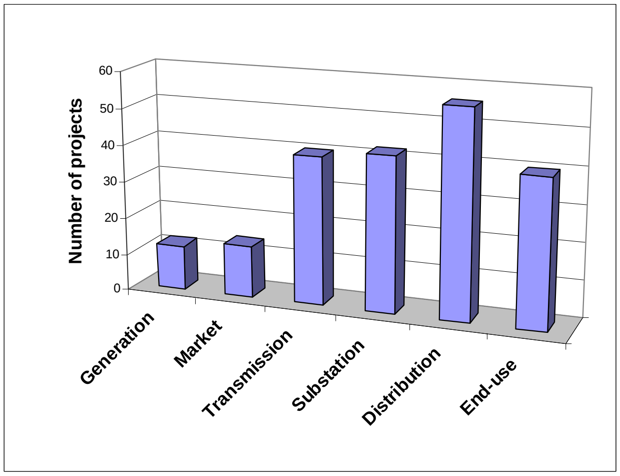
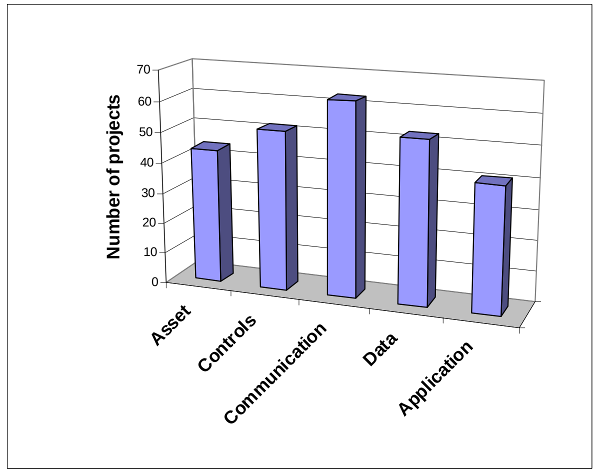



**Figure ES 2: Technology Level Coverage**




An analysis of baseline projects yielded the following findings:

**Projects are focused on tactical time frames.** About 84 percent of the projects are ongoing (started in 2009 or prior, or will start in 2010). Five smart grid projects have been completed, and eight will start later in 2012. Completion dates associated with existing projects (when reported) extend to 2014. More than half of the ongoing projects will be completed by the end of 2011. The schedule of projects is aligned with utility general rate case filings and reflects the short-term nature of the planning cycle for emergent technology evaluation projects. While concepts and roadmaps exist within each of the utilities for the 2011-2012 time frame and beyond, they have yet to be planned as projects.

**Focus on communications architecture for distribution.** Current efforts concentrate on developing the communication infrastructure and architecture for distribution. Such projects build the backbone for future smart grid deployments. The projects are being conducted over the next few years through initiatives that build upon current technologies. Examples of projects in this area include smart meter deployments, data collection from field equipment, distribution automation and control, mobile solutions developments, as well as integration of distributed energy resources (electric vehicles, renewables, storage).

**Reliability and system improvements are top drivers.** The highest overall drivers addressed by the projects are reliability and system improvements.

**Integration of distributed resources is a top priority objective.** Types of distributed resources include distributed renewables, storage, distributed generation, and flexible loads like plug-in electric vehicles. Their effective integration needs to be supported by research and technology development across organizations and technology levels.

## 2020 Vision for the Smart Grid

The California investor-owned utility vision for the smart grid will link electricity with communications and automated control systems to create a highly automated, responsive, and resilient power delivery system that will both improve service and empower customers to make informed energy decisions. Integrated communications will enable this smart power grid to continuously send, receive, and process data on system conditions, component health and power flows, as well as pass information among intelligent electronic devices, generators, independent system operators, marketers, and consumers. A smart grid with these characteristics will also allow for the integration of increased levels of renewable generation resources, accommodate increased loads associated with electric vehicle transportation, and provide increased protection from cyber security attacks and customer privacy concerns.

The vision for the smart grid consists of four categories that support key California and U.S. energy and environmental policies:

1. **Empower consumers and open markets.** The California Smart Grid will empower consumers and open markets by giving consumers information and tools to play an active role in the electricity marketplace. This capability offers a rich array of benefits, including improved energy efficiency, reduced emissions of greenhouse gases, and realized full potential of demand response in managing customer load (reducing peak demand  and using it as a dispatchable power resource, to be called on when needed.

2. **Widespread implementation of intermittent renewable generation.** By incorporating advanced technologies**,** the smart grid will continue to operate reliably with a high percentage of bulk and distributed renewable generation. These technologies will include active management of the grid, including the renewable generation sources themselves, energy storage on both the transmission and distribution systems with dynamic response and energy shifting capabilities, and integration of demand response and load control as a means of compensating for the variability of renewables.

3. **Maintained and/or enhanced grid reliability, resilience, security, and efficiency in the face of increasing complexity.** Advanced analytical tools, combined with widespread sensors to track performance and conditions, will help provide information to operators and planners to increase system security and performance. New distribution automation technologies will reduce system losses, manage bidirectional power flows associated with distributed energy resources, and minimize the extent of outages and increase the speed of restoration. Advanced transmission monitoring, control, and protection systems will decrease the probability of cascading failures that could lead to blackouts across a wide area. Similarly, robust security measures will reduce the odds of catastrophic bulk power system failures from human-caused and natural disasters such as cyber terrorism, vandalism, or earthquakes and extreme weather events.

4. **Increased worker safety and productivity.** The effective development and operation of a smart grid depend on a skilled workforce equipped with the training, tools, and technologies to support infrastructure deployment and grid operations and maintenance while enhancing safety and productivity. Utilities will be organizationally prepared through internal skills development, external education, recruiting, and information management. Worker safety will increase with the adoption of improved safety technologies, materials, and equipment, as well as new access to safety information and remote access to safety training materials.

The vision for the smart grid also includes coordination with the natural gas industry and supply system. Natural gas will be an important energy source used extensively along with the integration of wind generation. Natural gas infrastructure also has the potential to play an important role in supporting combined heat and power systems in the future and even electric transportation systems. Electric infrastructure planning and design may depend on natural gas infrastructure and its role in the overall generation mix and customer energy supply options. The role of natural gas in supporting the electric smart grid is described in Chapter 8.

## Pathways to Achieving the 2020 Vision

The California Smart Grid vision builds upon six critical domains, or areas of technical expertise. These areas are:

Domain 1: Communications Infrastructure and Architecture

Domain 2: Customer Systems

Domain 3: Grid Operations and Control

Domain 4: Renewable and Distributed Energy Resources (DER) Integration

Domain 5: Grid Planning and Asset Efficiency

Domain 6: Workforce Effectiveness

Across the six technical domains, 19 broad areas of smart grid use were identified as critical for smart grid advancement. Stages of advancement, applications available at each stage, and aids to reach each stage are described in technology readiness roadmaps. Time horizons in the roadmaps indicate the earliest period (short, mid, or long) that each stage of advancement can be reached, under identified assumptions. By advancing to each stage, distinct objectives for smart grid use and the associated benefits are supported. Important activities and demonstrations are already underway to support advancement of the smart grid uses identified in Chapter 7. Further research needs and recommendations for addressing them are summarized in Chapter 10 and detailed by domain in Appendix C.

Developments within the different domains are interdependent. For instance, progress depends on the definition of the overall architecture, which helps to understand the approach for the smart grid communications infrastructure. Moreover, some critical needs for future development require interactions and interdisciplinary advancements across multiple domains of technical expertise. For example, achieving the 2020 Vision will require advancements in integrated distributed resources management, unified grid operation and planning solutions, comprehensive resource portfolio management, and effective workforce education and training programs.

Figure ES 4 shows the general interdependence of the recommendations in the individual domains over the 10-year period of this study. Each of these domains has ongoing development requirements. The general interdependence between domains was considered in developing priorities for further advancement. Priorities for development along the pathway to the 2020 Vision include:

1. Agreement on the architecture for the smart grid is needed. This is consistent with the priorities in the National Institute of Standards and Technology Smart Grid Interoperability Panel and the work of the Smart Grid Architecture Committee.

2. The communications infrastructure and general approaches must be defined and understood so that new technologies can be developed that will connect with it.

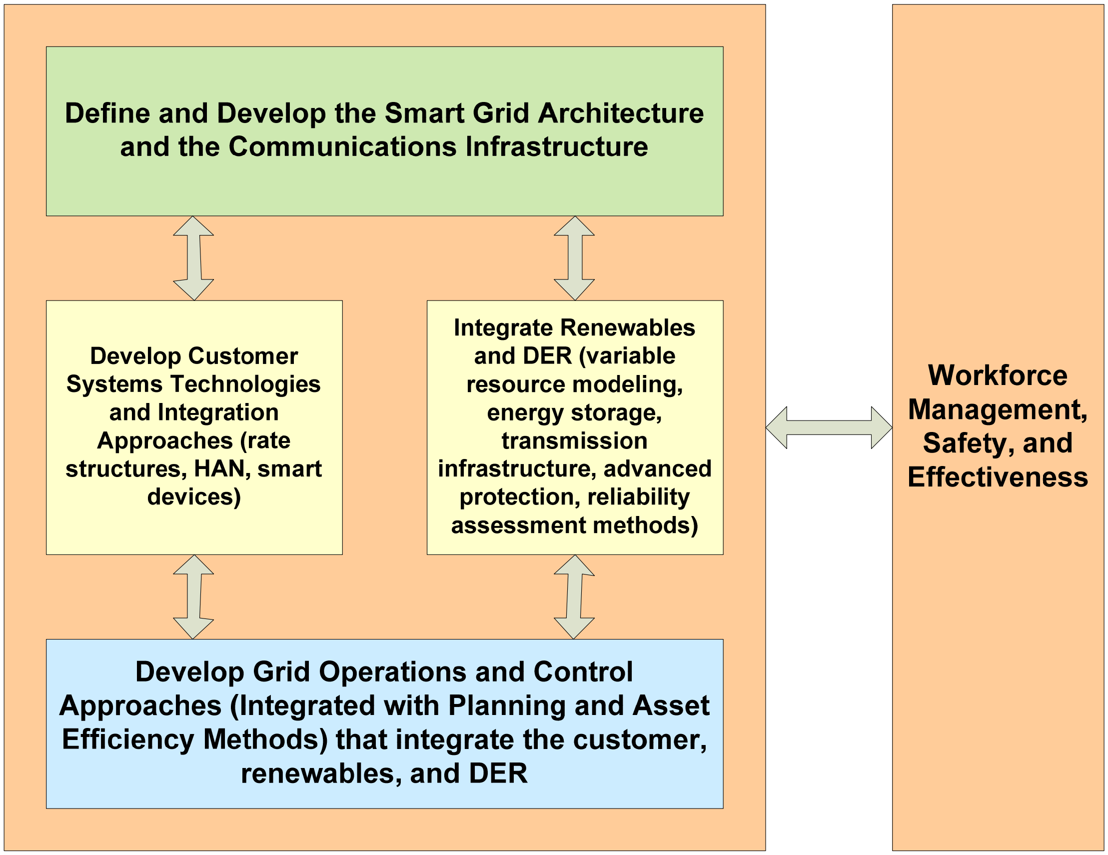
3. Technologies for customer integration with the grid will build on the definition of the communication infrastructure. Much will depend on rate structures and other incentives for customer involvement. This must include an overall approach for integrating electric vehicle charging (one example of an important controllable load).

4. Requirements for integrating more renewables are needed at both the transmission and distribution level. Analysis tools, forecasting, transmission infrastructure, compensation technologies, monitoring technologies, and distribution management approaches must all be developed.

5. The grid planning, operations, and control will change to support the developments described above. Real-time grid management at the transmission level will incorporate distributed energy resources, including demand response, that are part of the distribution infrastructure, requiring close coordination between advanced distribution management and the overall grid management. New models that support both planning and real-time grid management are needed and must be supported. These models will reach individual customers and associated distributed resources. Monitoring and control of the integrated grid will require management of widespread sensors integrated with the real-time system models. Technologies for reliability and security must take advantage of these real-time models and system awareness. However, system security cannot completely depend on this communication infrastructure. There is an ongoing requirement for distributed intelligence and the ability to operate local controls safely.

6. Worker and public safety must remain the top priority as new technologies and system management approaches are implemented. New training and skills must be developed as the technology base for managing and operating the system changes.

**Figure ES 4: Interdependence of Domain Recommendations**




## Benefit Impacts

The California Smart Grid offers an array of potential benefits to customers, society, and the environment.

**Advanced monitoring and control capabilities** will increase utility technical efficiency to improve overall performance of the power system by increasing asset use, limiting transmission and distribution losses, enabling integration of renewable resources, and reducing peak demand through reliability-based demand response and customer energy management. Results include kilowatt-hour (kWh) and kilowatt (kW) reductions and environmental improvements in the form of reduced emissions of greenhouse gases and pollutants including particulate matter, sulfur oxides, and nitrogen oxides.

**Improvements in grid operations, communications, and data integration** will contribute to improved service reliability, resulting in fewer and shorter outages.

**Advanced grid monitoring and condition assessment** will help improve power quality by predicting potential problems to reduce harmonic current distortions and improve voltage regulation.

**Widespread adoption of electric vehicles** will help reduce greenhouse gas and pollutant emissions and strengthen national security by reducing consumption of imported petroleum.

**Improved resistance to cyber threats and physical attack** will strengthen grid security and service reliability.

**Advanced tools and workforce training** will enhance the safety of the electric power industry workforce.

## Recommendations

The report identifies approaches for addressing technology, policy, standards, process, and education needs to support realization of the smart grid vision. The project team proposes 10 interrelated research and development streams that cut across domain areas to coordinate development of the smart grid with both national and international efforts.

The research and development streams emphasize architecture, information models, and interoperability requirements. The report also documents important technology development needs, including power electronics, energy storage, modeling and simulation, and sensor technologies. These technologies will continue to advance due to market pressures and manufacturer developments. However, demonstration projects should be combined with projects that focus on interoperability requirements.

## New Challenges

The proposed research and development activities also reflect common themes and challenges identified during the project. For utilities, a key driver for smart grid development is maintaining and/or enhancing reliability in the face of increased grid complexity. Efforts to meet ambitious energy and environmental policy targets could degrade power system reliability. For utilities, the smart grid represents the most appropriate technical and cost-effective approach for maintaining and/or enhancing power system reliability while integrating customer technology, such as photovoltaic and plug-in electric vehicles, and achieving policy targets.

Utilities also face challenges in dealing with technologies at different levels of maturity. Traditionally, utilities have introduced new, but proven and mature, technologies to increase power system reliability, operational efficiency, and safety. Now, however, energy policies are driving the adoption of new technologies, including some that are less mature or still in development. As a result, utilities will simultaneously deploy a new smart grid infrastructure while also engaging in research, development, and laboratory testing of new technologies.

Recognizing these challenges, the project team has taken a careful, detailed, and systematic approach to developing a vision and roadmap for the California Smart Grid.

Note: All tables, figures, and photos in this report were produced by the authors, unless otherwise noted.

# CHAPTER 1: Introduction

This report presents a policy-driven vision of the California Smart Grid of Year 2020 and a roadmap that defines pathways for achieving that vision.

California is leading the nation with ambitious energy and environmental policies that are driving the development of a smarter, more robust, and more efficient electricity infrastructure. The California Smart Grid will enable the achievement of multiple energy and environmental policy goals, including increased penetration of renewable resources, reduction in greenhouse gas emissions, increased energy efficiency, implementation of demand response, integration of distributed energy resources, maintained and/or enhanced grid reliability, and electrification of transportation.

Achieving these policy goals increases power system complexity and implementing even the most cost-effective solutions is likely to lead to increases in energy rates. Attempting to achieve these goals without smart grid capabilities would likely be costlier still—for example entailing extremely high expenditures for capital expansion of traditional transmission infrastructure to accommodate large blocks of new renewable generation.

In defining the utility perspective of the California Smart Grid of Year 2020, the project team's primary focus was on supporting the state's energy policy goals in a technically sound manner. Cost-benefit analyses are beyond the scope of the report, and to be conducted as appropriate as part of industry smart grid deployment activities.

## Drivers and Challenges

As noted above, energy policy is the primary driver for the California Smart Grid. For utilities, however, the key smart grid driver is maintaining and/or enhancing reliability in the face of increased grid complexity. Efforts to meet ambitious policy targets for renewable energy, greenhouse gas reduction, and energy efficiency could degrade power system reliability. For utilities, the smart grid represents the most appropriate technical and cost-effective approach for maintaining and/or enhancing power system reliability given the continued pursuit of current policy targets.

Utilities have traditionally introduced technologies to maintain and/or enhance power system reliability, increase operational efficiency and improve safety. The selected technologies were new, but proven and mature. Now, however, energy policies are driving the adoption of new technologies, including some that are less mature or still in development. As a result, utilities are presented with the considerable challenge of maintaining reliability while achieving ambitious policy targets and also dealing with technologies at different levels of maturity. Utilities will thus be simultaneously deploying new smart grid infrastructure while also engaged in research and development and laboratory testing of new technologies.

Recognizing these challenges, the project team has taken a careful, detailed, and systematic approach to developing a vision and roadmap for the California Smart Grid.

## Background

The State of California, through the development and adoption of progressive energy and environmental policy throughout the last decade—and most explicitly with the passage of Senate Bill 17 in 2009—has created a mandate for the deployment of a smart grid. However, in order to move forward with a successful smart grid deployment, a coordinated approach that includes a clear vision and a roadmap for achieving that vision must be developed. The report that follows was created jointly by major California utilities and the Electric Power Research Institute (EPRI) to define the utilities' perspective on a vision and approach to achieving smart grid deployment in California. The report provides a common vision of what the smart grid is and includes a high-level roadmap which outlines a pathway towards achieving the California Smart Grid and the policy goals it supports.

This project builds upon a 2008 California Smart Grid study conducted by EPRI for the California Energy Commission to gather initial stakeholder perspectives and identify key technical elements of a smart grid infrastructure. [2] A shared perspective identified through the study was that California's evolving smart grid infrastructure was regarded as a support for achieving the state's energy policies and targets for renewable integration, greenhouse gas emission reduction, energy efficiency, and grid reliability. The study also identified a critical need for a cohesive view of what a smart grid is for California, which in turn would provide clarity and direction towards achieving the common vision.

The 2008 study produced a framework for describing and relating a wide variety of smart grid technologies across the electric power industry. The study describes smart grid technologies at different levels, critical technology gaps, and initial recommendations for research, development, and technology demonstrations in support of smart grid deployment within California.

## Collaborative Process

Since 2001 EPRI has managed a collaborative research, development and demonstration (RD&D) process that has accelerated the industry's migration towards a smart grid. Because of EPRI's extensive prior work in developing smart grid roadmaps for utilities, the California Energy Commission, along with major investor-owned California utilities: Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), and Southern California Edison (SCE), are collaborating together with EPRI on this project to define a common utility perspective on a vision and roadmap to spur development of California's smart grid.

## Problem Statement

The 2008 California Smart Grid study revealed that California does not yet have a unifying vision for the state's smart grid. The vision needs to be defined by bringing stakeholders together to agree on objectives for smart grid use, key smart grid capabilities, and applications a smart grid would support. A collaborative process is critical for defining a common vision to help stakeholders develop a technology roadmap for achieving the vision.

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[2] *Integrating New and Emerging Technologies into the California Smart Grid Infrastructure.* EPRI, Palo Alto, CA and California EnergyCommission, Sacramento, CA: 2008. 1018191.

## Project Objectives

The primary objectives of the project described in this report are:

- In partnership with major California utilities, synthesize utility perspectives on development of the California Smart Grid in light of key state and federal policy drivers.
- Define the utility vision of the California Smart Grid of Year 2020 and define a pathway to reach that vision, using Year 2010 as a baseline.
- Recommend critical activities to fill gaps in technology, policy, standards, process, and education—gaps which need to be addressed in order to fully implement the vision.

## Project Funders

Major project funders include the Energy Commission, EPRI, and the state's investor-owned utilities (i.e., Pacific Gas & Electric, Southern California Edison, San Diego Gas & Electric, and Southern California Gas Company). Substantial cost-sharing from the utilities was provided through in-kind services from utility technical domain experts as well as executive and management advisers to the project. The Sacramento Municipal Utility District (SMUD) also contributed in-kind services to the project, primarily through participation of technical domain experts from the municipal utility.

## Report Structure

The report is structured as follows. Chapter 2 describes the approach taken for project execution. Chapter 3 describes energy policy drivers and details existing energy policies and targets in California. Chapter 4 provides a review of smart grid projects by investor-owned utilities. Chapter 5 presents a vision of the California Smart Grid capabilities of Year 2020. Chapter 6 presents architectural guiding principles. The following chapter presents further details on the 2010 baseline, 2020 vision, and stages of technology readiness by technical domain area: 1) Communications Infrastructure & Architecture; 2) Customer Systems; 3) Grid Operations & Control; 4) Renewable & Distributed Energy Resources (DER) Integration; 5) Grid Planning & Asset Efficiency; and 6) Workforce Effectiveness. Chapter 8 summarizes results of cross-domain analyses. Chapter 9 describes the road to benefits from smart grid investments, and Chapter 10 presents overall recommendations. The report concludes with Chapter 11, followed by a list of references and a glossary. A series of appendices present information on baseline utility projects, educational needs, gaps and recommendations, existing utility projects, and perspectives on the role of natural gas in supporting the electric smart grid.

# CHAPTER 2: Project Approach

## Secondary Research

To define the California Smart Grid vision and roadmap, the initial step in the overall approach was to collect and review existing works through literature review. The project team gathered and reviewed existing materials available from the participating utilities and other sources under a common framework for information collection. The elements of this framework for initial investigation included:

- existing smart grid vision documents
- drivers for the smart grid
- assumptions
- cost benefit assessment methodologies
- decision models for technology adoption
- metrics
- core smart grid policy drivers (state and federal) along with policy issues

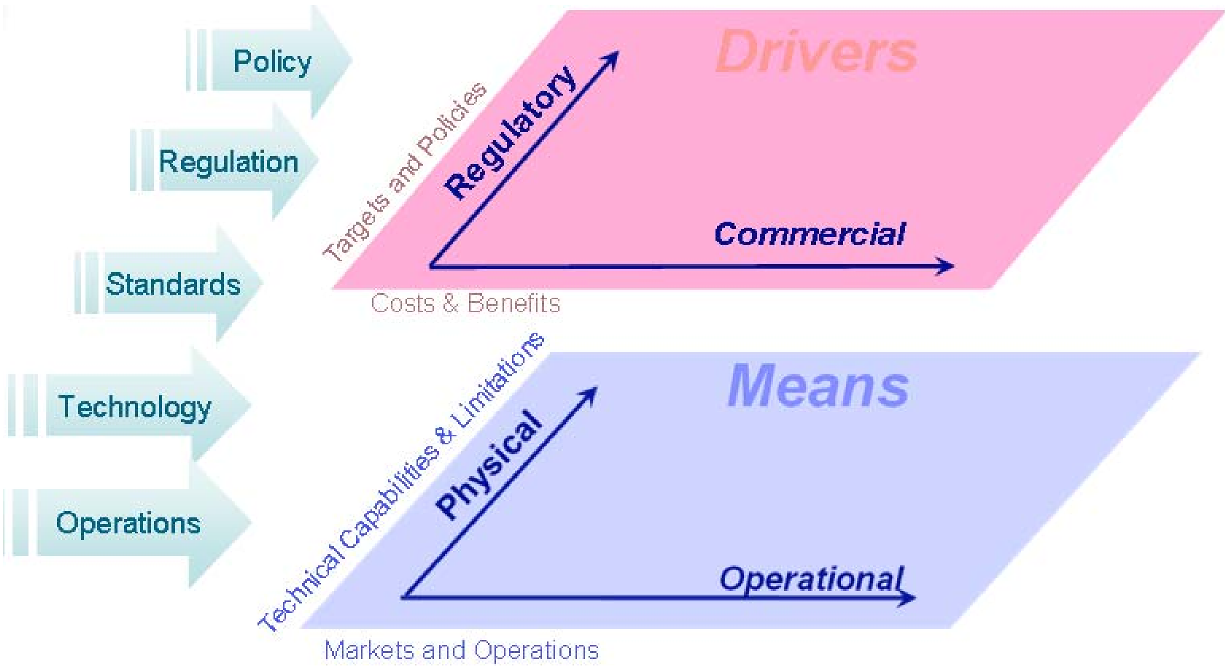
The majority of the effort was focused on the electric power grid rather than the natural gas delivery network, although the perspectives of gas industry representatives were also sought and incorporated into the vision and roadmap.

Initial findings were summarized and used to foster interactive discussions and direct focus to the highest priority areas for refining utility perspectives on the California Smart Grid vision and roadmap.

## Dimensions of Consideration

Another important element of the project approach was consideration of multiple dimensions of factors influencing smart grid vision and roadmap efforts, as depicted in Figure 1. These include regulatory policy and commercial considerations that together comprise the drivers for the smart grid. There are also technical factors that determine physical capability and limitations of the smart grid, as well as operational readiness factors which consider the extent to which utilities and markets are prepared to support smart grid functions. Together, these technical and operational considerations comprise the means, or enablers, for smart grid capabilities. The drivers heavily influence what is probable, while the means determine what is possible with smart grids.

**Figure 1: Dimensions of Consideration[3] (Source: [1])**




## Project Organization by Domains of Technical Expertise

The project team included technical domain experts from across the electricity value chain, including grid operators and other industry professionals well-grounded in the realities of power system and energy market operations. An organizational approach was to leverage the strength of experts in their respective areas of domain expertise, and to also organize the team to share perspectives across traditional boundaries of the electric power and natural gas industries.

The California Smart Grid vision builds upon six critical domains, or areas of technical expertise. These areas are:

Domain 1: Communications Infrastructure & Architecture

Domain 2: Customer Systems

Domain 3: Grid Operations & Control

Domain 4: Renewable & DER Integration

Domain 5: Grid Planning & Asset Efficiency

Domain 6: Workforce Effectiveness

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[3] *Distributed Resource Integration Framework: A Reference Model for Characterizing Projects and Relating Programs that Integrate Demand Response and Distributed Energy Resources*. EPRI, Palo Alto, CA: 2009. 1020313.

These domains define a structure of technical topics by which to further develop project findings on:

- Vision
- Baseline
- Technology Readiness Roadmaps (which identify applications and enablers at each stage of technical advancement)
- Gaps and Recommendations

The domains also served as the basis for organizing the project team, which included six technical domain teams dedicated to developing content for their respective domain areas. The six domains are described below. In particular, Domain 1 and Domain 6 involve issues that cut across the other four domains.

## Communications Infrastructure and Architecture

By 2020, the smart grid communications infrastructure and architecture is envisioned to support scalability, flexibility and interoperability for data and information exchange using standards across the entire grid supply chain from generation to customer. Field devices, distributed energy resources, consumer devices, and back-office technologies and systems will be able to be easily integrated—through increasingly unified communications networks—into a resilient and secure smart grid architecture that supports reliable and efficient electric system operations. The development and adoption of open standards will support the design and deployment of new smart grid technologies and products that are compatible and interoperable.

## Customer Systems

The California Smart Grid will enable customers to not only better manage their energy usage but to be active participants in energy markets through demand response and electric transportation. The smart grid enables customers to actively support the reliable, sustainable, economical delivery of power in three key ways:

- By providing feedback to help customers manage the timing and quantity of their energy usage.
- By enabling third-parties, including utilities, to manage energy usage on behalf of customers.
- By allowing customers to adopt environmentally friendly technologies (e.g., PEVs, Solar PV) without sacrificing grid reliability.

## Grid Operations and Control

The electrical power grid connects the customer to distribution, transmission, renewable resources and generation. The aging grid infrastructure is being replaced or upgraded, providing significant opportunities for smart grid applications to improve grid monitoring and control, while maintaining or enhancing reliability, efficiency and cost. Such opportunities exist for both the transmission and distribution systems.

### Renewable and DER Integration

Renewable and Distributed Energy Resource (DER) Integration involves critical technology for integrating and managing existing and new sources of renewable energy and distributed energy resources. Key areas of focus include 1) Bulk renewable integration in grid and market operations, 2) Bulk storage resources used to facilitate the integration and use of intermittent (variable) renewable resources, 3) Power electronic systems (inverters) used to interconnect and control many forms of renewable and distributed resources, 4) Interconnection and system protection, and 5) System models and studies development. Advances in renewable and DER integration is one of the primary requirements needed to support California's Renewables Portfolio Standards (RPS).

### Grid Planning and Asset Efficiency

This domain area focuses on improving capital efficiency using better intelligence and technology to optimize system planning and to improve asset performance. New technologies, better data and information integration along with an integrated planning process will enable future energy savings and greenhouse gas (GHG) reduction as well as renewable integration.

The smart grid will enable advanced planning tools to design facilities that can operate assets and resources more efficiently by dynamically controlling voltage and optimizing power flows. Monitoring and sensing capabilities will be expanded to enhance assets maintenance and investment decisions. Advanced planning tools will facilitate and leverage the integration of distributed resources (e.g., PV, PEV, demand response, renewables) and ensure system reliability and performance.

### Workforce Effectiveness

The Workforce Effectiveness domain aims to maximize workforce productivity, effectiveness, and safety through application of enabling tools, technologies, and training.

Smart grid workforce effectiveness involves preparing the workforce to support smart grid technologies and tools while enhancing safety and productivity. Utilities will be organizationally prepared through internal skills development, external education, recruiting, and knowledge management. The tasking, scheduling and routing of work will be more efficient and seamless. Ultimately, sensor technologies, advanced visualization tools and robotics applications extend to "office" and "field" personnel with a focus on training, safety and situational awareness.

## Top-Down Approach

The project team followed a logical top-down hierarchical approach to develop further technical details for the project. The logical top-down approach involved several broad technical tasks.

The first task focused on identifying guiding principles, methods, and priorities for the project, to guide the domain teams' efforts in subsequent project tasks. The priorities established early-on helped to direct the team to focus efforts on high priority areas, in order of priority. Establishing agreement with the project Steering Committee on priorities and assumptions for the project helped give the team critical focus and direction from the beginning, which is especially important considering project time and budget limitations.

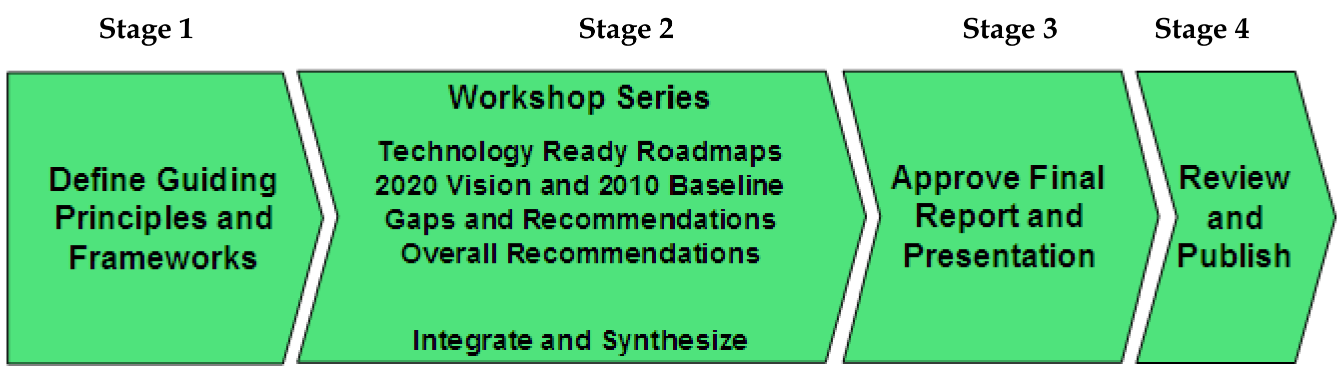
The next technical task was to develop domain-specific technical findings on vision, state of technologies, baseline, and a roadmap including multiple stages of technology readiness over time. After domain teams prepared technology readiness roadmaps, inclusive of smart grid applications, enablers, and value sources over a 10-year time horizon, they then compared them against policy and other technical findings from prior project tasks to identify gaps and recommendations for their domains.

Iterations on work products were conducted following integration exercises to ensure consistency with objectives, assumptions, and priorities identified for the project under the initial technical task. A critical review of domain findings was performed by looking across domain work products to identify overall gaps and recommendations. Findings were reviewed and submitted for final approval by the Steering Committee.

## Project Stages

The overall project was conducted through four stages, as summarized below.

**Figure 2: Stages of Project Execution**




Stage 1 involved reviewing existing publications, gathering and synthesizing utility inputs, establishing guiding principles and frameworks, and drafting a high-level 2010 baseline definition and a 2020 vision of a California Smart Grid.

Stage 2 encompassed a series of workshops by which the project team vetted and finalized the 2010 baseline definition and developed the 2020 California Smart Grid vision and technology readiness roadmaps. Through an iterative process the team approved the final work products of each domain team, integrated work products, and developed a draft report.

Stage 3 involved facilitation of review and comments for the final report and securing Steering Committee approval, while documenting any dissenting opinion.

In Stage 4, the report is reviewed by the Energy Commission, comments collected, and final edits incorporated for publication and distribution of the final document.

## Priorities and Assumptions

The project established a foundation of agreed-upon project assumptions and priorities, with priorities identified for both smart grid uses and objectives for those uses. The findings are summarized below. They were shared with domain teams to guide subsequent focused efforts in defining vision statements, roadmaps, and recommendations under a common framework of assumptions and priorities.

### Project Assumptions

The following assumptions were identified early on during the first stage of the project to guide domain team efforts. Domain teams were directed to develop project findings that did not conflict with any of the identified assumptions below.

1. Existing California Energy Policy Targets are met by Year 2020.
   A fundamental assumption of the project is that a critical driver for the smart grid is its ability to support achievement of California's energy policies and targets by Year 2020. Consequently, the project team was not to recommend existing energy policies be altered nor assume that existing energy policies become more aggressive by Year 2020.

2. Uncertainties affecting grid and market operations are handled logically.
   Given that customers will own distributed energy resources and other entities will also own resources, a key assumption is that market and grid uncertainties will be handled logically. For example, rules and controls will prevent market gaming and support wider market participation. Similarly, the intermittency of renewable resources will be managed.

3. Rates and programs encourage behavior that is in alignment with energy policy goals.
   Another assumption is that market and rate designs are in place to affect positive behavior with respect to energy policy goals. Rate structures and programs encourage customer behavior in support of energy policy goals. Market and rate designs support the development of a market for new smart grid enabling technologies. Rate structures embrace "cost causation" to reduce and eliminate cost shifts between various customer segments.[4]

4. The smart grid accommodates market enablement and customer-driven choices.
   The smart grid is expected to enable market innovations and enhanced customer choice. Although customers will expect grid reliability to improve or at least stay the same, customers will have expanded choices and their decisions will be driven by individual preferences. For example, those customers desiring premium service will be willing to pay a premium, either to their utility or for their own on-site equipment, while others will pay less. Customers will also desire increased access to their energy usage information and to energy markets, empowering them to take control over their energy consumption and production.

5. The smart grid accommodates the integration of alternative resources.
   The integration of electric transportation, solar DG, and bulk renewables will be accommodated. Energy storage will be integrated into the smart grid to support the transmission and distribution systems, communities and individual customers.

[4] Cost causation refers to consideration of the sources contributing to costs and allocation of costs accordingly.

## Priority Areas of Smart Grid Use

The following areas of smart grid use were initially identified as priorities for further focus:

1. Automation of demand response (DR) for all customer classes
2. Energy storage for grid management
3. Standards for residential AMI/HAN implementation
4. Grid integration of high penetration of plug-in electric vehicles (PEVs)
5. Implementation of synchrophasors for T&D Management
6. Energy Smart Communities (e.g., net zero customers and communities)
7. Grid integration of photovoltaics

A common utility perspective was that a substantial amount of demand response (3-5 GW) will be available by 2020. Grid integration of plug-in electric vehicles, photovoltaic systems, and bulk renewable resources were among the top priorities of the utilities.

Energy storage analysis and its integration into the grid to address renewable intermittency are high priorities for research and development, as are the completion of developing standards for residential AMI/HAN implementation (e.g., Smart Energy Profile). Other areas of smart grid use identified as priorities included implementation of synchrophasors for grid management and accommodating net zero customers and communities.

The list above identifies seven broad areas of smart grid uses. To further discern priorities the next subsection associates objectives with specific uses, so that the combination of objectives for which uses are also prioritized.

## Priority Objectives for Smart Grid Uses

The three investor-owned utilities (IOUs) on the project team ranked objectives (i.e., reasons) for various smart grid uses. These priority rankings provide a basis for discerning technical requirements associated with different smart grid uses. The ranking scheme uses a 1 to 5 scale, with 5 denoting a top priority objective, 4 a high priority objective, 3 an objective, 2 somewhat of an objective, and 1 not an objective. Consensus findings are listed below on which objective for which smart grid use ranked highest in priority among the three IOUs.

**Top Priority (3 IOUs scored 5, meaning these are consensus top priorities):**

- Bulk wind and solar integration to meet renewables portfolio standards (RPS)
- Wide area situational awareness and distribution grid management for system protection and restoration

**Near-Top Priority (2 IOUs scored 5, 1 IOU scored 4):**

- PEV integration to reduce greenhouse gas (GHG) emissions and meet customer needs
- Demand response to reduce peak demand and enhance service innovation
- PV for meeting RPS

- Customer systems to enhance service innovation
- Distribution grid management to improve voltage regulation
- Grid efficiency and voltage reduction to reduce losses
- Bulk wind and solar integration to reduce GHG emissions
- Data integration for system protection and restoration

**Above High Priority (1 IOU scored 5, and 2 IOUs scored 4):**

- Energy efficiency via customer systems for meeting customer need and reducing peak demand
- Bulk electric storage for meeting RPS
- Distributed electric storage for providing for micro grid operation
- Data integration for enhancing service innovation and improving voltage regulation
- Customer relationship management to enhance customer choice (via meeting customer needs or enhancing service innovation)
- Asset management for deferral of capital expansion

**High Priority (4 IOUs scored a 4, meaning these are consensus high priorities):**

- Electric rail system to reduce GHG emissions
- Demand response for deferral of capital expansion
- Customer systems to reduce losses and for deferral of capital expansion
- Grid efficiency and voltage reduction for reducing peak demand
- Integration of PV for reducing GHG emissions and provide for microgrid operations
- Distribution grid management for reducing peak demand or deferral of capital expansion and providing emergency support/ancillary service
- Data integration for meeting customer need

# CHAPTER 3: Policy Drivers

The project leadership team investigated core driving forces and policy statements promoting the smart grid in California and the specific targets and goals that these policies require or imply. Based on this review, the leadership team then developed:

- A set of policy issues (presented here in Chapter 3)
- A first draft of a 2010 baseline of smart grid initiatives completed or in progress at the California utilities (Chapter 4)
- An overall smart grid vision statement (Chapter 5)

Each of these items were then presented to the domain teams to guide their efforts as they created specific vision statements, refined baselines, and developed technology roadmaps, gaps, and recommendations for each smart grid domain.

## Driving Forces for a California Smart Grid

Based on a review of numerous sources, the project leadership team believes the key drivers of the smart grid to be:

1. Empowering customers to take control over their energy use and production
2. Reducing GHG emissions
3. Resisting attacks and mitigating natural disasters
4. Enabling energy independence through increased electrification of the economy
5. Opportunity to strengthen the state and national economy by fostering clean technology innovation and related job growth
6. Maintaining or increasing the reliability, efficiency and safety of the power grid

This remainder of this chapter describes how State energy policy goals and targets have led to or are in response to some of these major drivers for the California Smart Grid.

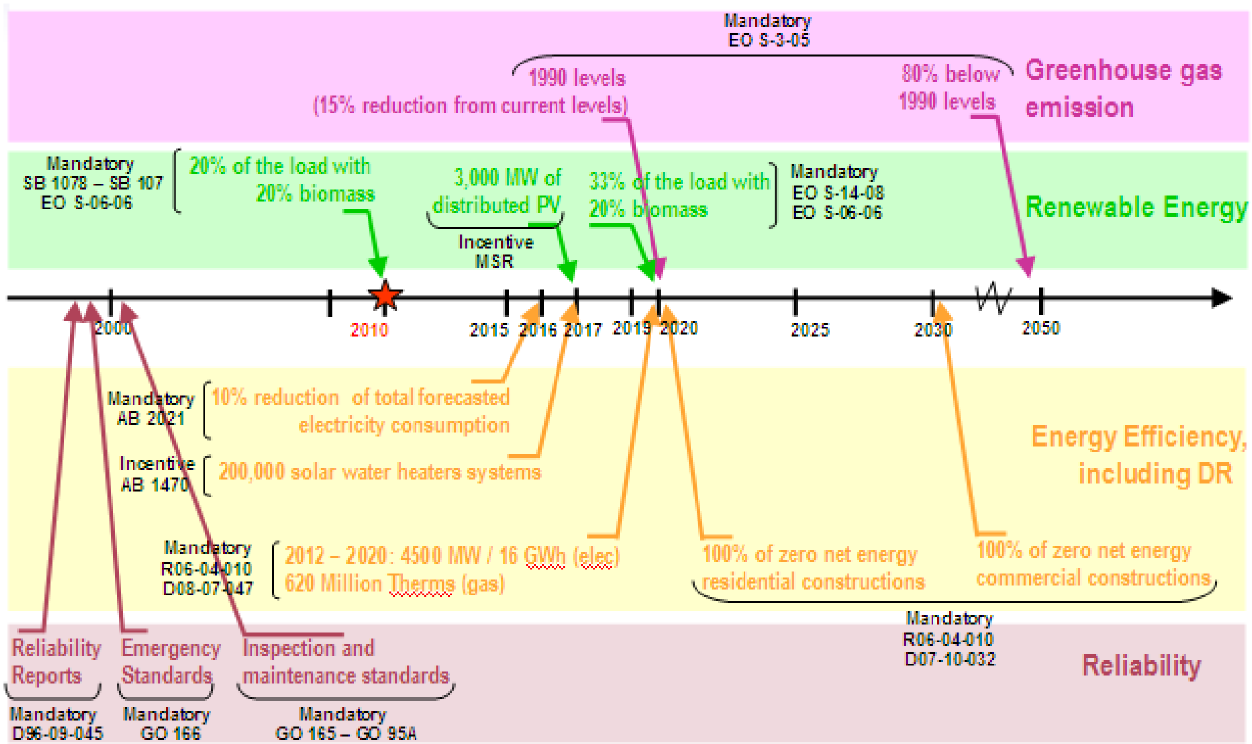
## Existing Policy and Incentives

This section provides an overview of the principal regulations and incentive mechanisms in place with an identified impact on smart grid development and deployment activities.

### California Energy Policy Elements

Figure 3 provides a summary of the different energy policy elements in California, along with their timeline for implementation. The elements are described in the following text.

**Figure 3: California Energy Policy Elements**




## Greenhouse Gases Emissions Reduction

*Assembly Bill 32* (AB 32, the California Global Warming Solutions Act) establishes a comprehensive program of regulatory and market mechanisms to achieve real, quantifiable, cost-effective reductions of greenhouse gases (GHG). AB 32 makes the Air Resources Board (ARB) responsible for monitoring and reducing GHG emissions.

*Executive order S-3-05* calls for a greenhouse gas reduction goal of 1990 levels by 2020 (30 percent reduction from projected levels by 2020, 15 percent reduction from current levels), with a target of 80 percent below 1990 emissions levels by 2050.

## Renewables Portfolio Standard

*Executive Order S-14-08* requires California's retail sellers of electricity to serve 20 percent of their load with renewable energy by 2010, and 33 percent of their load with renewable energy by 2020.

*Executive Order S-06-06* promotes the use of bioenergy, and calls for the state to meet a 20 percent target for the use of biomass for electricity generation within the established state goals for renewable generation for 2010 and 2020.

A rulemaking for the implementation and use of *tradable renewable energy credits* was conducted and finally withdrawn.[5] The objective was to provide more options and flexibility to RPS-

[5] CPUC Rulemaking 06-02-012 Decision 10-03-021.

obligated load serving entities (LSE) to comply with RPS mandates and additional flexibility and incentives for the development of RPS-eligible generation by supplying useful revenue options for generation developers.

### Distributed Energy Resources

*Million Solar Roofs Program*: the goal of this program is to install 3,000 MW of distributed solar photovoltaic (PV) electricity generation in California by the end of 2016.

*Combined heat and power (CHP)*: the California Air Resource Board in its Scoping Plan sets a target of an additional 4,000 MW of installed CHP capacity by 2020, enough to displace approximately 30,000 GWh of demand from other power generation sources.[6]

*(Pending) AB 2514 Skinner* would require the CPUC, by April 1, 2011, to open a proceeding to establish procurement targets for each electrical corporation for viable and cost-effective energy storage systems and, by January 1, 2013, to adopt an appropriate energy storage system procurement target to be achieved by each electrical corporation by January 1, 2015, and a 2nd target to be achieved by January 1, 2020.

### Energy Efficiency

*AB 1470 –Solar Water Heating and Efficiency Act:* Authorized a ten year, $250-million incentive program for solar water heaters with a goal of promoting the installation of 200,000 systems in California by 2017.

*AB 2021 – Public utilities: energy efficiency:* Sets a statewide goal of reducing total forecasted electricity consumption by 10 percent over the next 10 years (starting 2006).

*Rulemaking 06-04-010 Decision 08-07-047*: First, this decision sets interim energy efficiency savings goals for 2012 through 2020 for electricity and natural gas on a total market gross basis. For 2012 through 2020, total energy savings are expected to reach over 4,500 megawatts, the equivalent of nine major power plants. Further, the decision expects savings of over 16,000 gigawatt-hours of electricity and 620 million therms over that period. The decision also confirms existing energy savings goals for 2009 through 2011 that shall be gross goals, not net of free riders (D.04-09-060 goals over the 2009-2011 period: 7516 GWh, 1584 MW and 162 million therms).

*Rulemaking 06-04-010 Decision 07-10-032*: All new residential construction in California will be zero net energy by 2020. All new commercial construction in California will be zero net energy by 2030.

*CARB Scoping plan*: the plan would set new targets for statewide annual energy demand reductions of 32,000 gigawatt hours and 800 million therms from business as usual – enough to

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[6] The Air Resource Board was mandated to develop a Scoping Plan outlining the State's strategy to achieve the 2020 greenhouse gas emissions limit. The Scoping Plan, developed by ARB in coordination with the Climate Action Team (CAT), proposes a comprehensive set of actions designed to reduce overall greenhouse gas emissions in California, improve the environment, reduce dependence on oil, diversify energy sources, save energy, create new jobs, and enhance public health. The "Approved Scoping Plan" was adopted by the Board at its December 11, 2008 meeting. The measures in the Scoping Plan will be developed over the next two years and be in place by 2012.

power more than 5 million homes, or replace the need to build about ten new large power plants (500 megawatts each). These targets represent a higher goal than existing efficiency targets established by CPUC for the investor-owned utilities due to the inclusion of innovative strategies above traditional utility programs.

## Reliability

*Annual Reliability Reports* (D.96-09-045): the major California electric utilities must comply with a number of reliability guidelines for the duration and frequency of sustained and momentary outages using SAIDI, SAIFI, and MAIFI, with and without excludable major events for the past 10 years; the top ten power outage events based on customer-minutes, excluding events such as weather, declared emergencies, or disasters affecting over 10 percent of the utility's customers; the number of circuits in which customers have experienced greater than twelve sustained outages in a reporting year.

*Emergency standards*: in 1998, the Commission signed D.98-07-097, adopting General Order 166, which comprises standards for operation, reliability, and safety during emergencies and disasters. Subsequently, in the year 2000, the Commission adopted D.00-05-022 adding Standards 12 and 13 to GO 166, pertaining to the Restoration Performance Benchmark for a Measured Event.

*Electric Emergency Action Plan*: During the power crisis (2000-01) the Commission revisited programs of distribution utilities to preserve electric service to the greatest number of customers by opening Rulemaking R.00-10-002.

*Inspection and maintenance standards*: Decisions 96-11-021 and 97-03-070 establish inspection cycles and record-keeping requirements for utility distribution equipment, which are contained in General Order 165. Decision 97-01-044 of Investigation 94-06-012 establishes standards for trimming trees near power lines, issued as a revision to Rule 35 of General Order 95-A.

## Electric Transportation

*AB 1007, Pavley Air quality: alternative fuels*: the bill requires the State Energy Resources Conservation and Development Commission, in partnership with the state board, and in consultation with specified state agencies, to develop and adopt a state plan to increase the use of alternative fuels to achieve a goal of 20 percent non petroleum fuel use in the year 2020 and 30 percent in the year 2030. As required, the California Energy Commission released in December 2007 its State Alternative Fuel Plan, providing strategies, actions and recommendations to meet the state goals to reduce petroleum consumption in the transportation sector.

More recently, a TIAX LLC investigation studied scenarios designed to differentiate between the benefits and impacts of business-as-usual or aggressive incentives, regulations, or both for the transportation sector.[7] The penetration levels assessed under this analysis for light duty electric transportation are presented in the Table 1.

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[7] *Electric Transportation and Goods Movement Technologies in California: Technical Brief*. TIAX LLC: 2008. D0289. Available at http://www.arb.ca.gov/regact/2009/lcfs09/tiax.pdf.

**Table 1: Assessment of California Electric Vehicle Market Population**[8]

| | 2010 | | 2015 | | 2020 | |
|---|---|---|---|---|---|---|
| | **Expected** | **Achievable** | **Expected** | **Achievable** | **Expected** | **Achievable** |
| Light duty EVs | 17k – 23k | 36.4k | 22k – 33k | 209k | 28k – 44k | 455k |
| Light-duty plug-in hybrid EVs | 10k | 10k | 138k | 480k | 548k | 2,112k |

### Water Use: Once-Through Cooling

The State Water Resources Board's *Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling* calls for coastal power plants to phase out once-through cooling systems. The policy aims to provide standards and consistency in implementing the Federal Clean Water Act, which requires the use of best technology available for protecting marine life. Most power plants would have until 2015 to phase out their once-through cooling systems. Plants in the Los Angeles area would have until 2020 owing to the city's more complex power needs. The San Onofre and Diablo Canyon nuclear plants would have until 2022 and 2024, respectively.

## IOU-Specific Forecasts

Figure 4 illustrates investor owned utility-specific forecasts associated with the energy policy elements identified in the previous subsection. The figure includes forecasts for:

- Renewables Portfolio Standard Bulk Power Integration
- Renewables Portfolio Standard Distributed Generation Integration
- Energy Efficiency and Demand Response

The figure also includes forecasts for penetration of light duty electric vehicles from the electric transportation study cited in the previous subsection.

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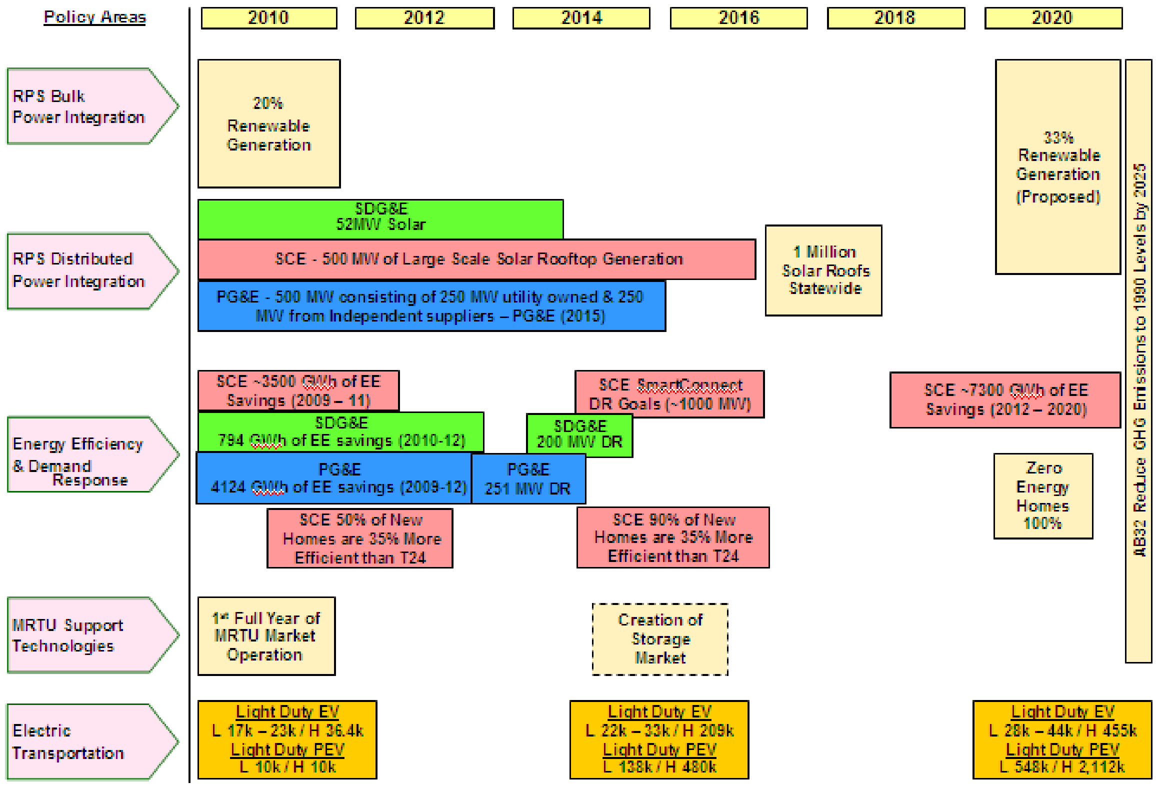
[8] *Electric Transportation and Goods Movement Technologies in California: Technical Brief*. TIAX LLC: 2008. D0289. Available at http://www.arb.ca.gov/regact/2009/lcfs09/tiax.pdf.

**Figure 4: IOU-Specific Forecasts**




## Key Smart Grid Policy Issues

This section describes key smart grid policy issues that have been identified from a utility perspective after review of the key policy areas discussed above. Such policy issues will need to be addressed in order to ensure that the California Smart Grid vision and roadmap can ultimately be realized.

### Deployment Pace

*Are policy mandates driving smart grid deployment at an appropriate pace?*

- **Engineering economics and timing of tech deployments –** The costs of emerging technologies decrease over time as they mature. The point in time at which investments become cost effective—and are therefore suitable for deployment—is typically a matter of debate among different stakeholders.

- **Technology complexity and reliability –** Consideration must be given to a potential trade-off between system complexity and grid reliability. The deployment of complex smart grid systems must help optimize the grid while maintaining and/or improving, not sacrificing, reliability.

- **Technology maturity and contingency costs –** As new smart grid technology suppliers enter the industry landscape, stakeholders must understand the contingency costs related to working with emerging smart grid technologies.

- **Unknown cost effectiveness of emerging technologies –** Value streams, lifecycle costs, optimal locations and quantities needed (e.g. partial or full system deployment) may all be unclear for emerging smart grid technologies.

- **Federal stimulus projects –** Smart grid demonstrations won't be complete until 2015. Will the pace of smart grid deployment, when mandated by policy targets, allow for lessons learned from these stimulus projects to be incorporated? Is the pace of deployment that's required to meet policy objectives a prudent one?

### Regulatory Role

*How can regulatory bodies best support the smart grid? (state and federal)*

- **Regulatory role in standards development –** What standards are needed and what is the appropriate time to adopt a standard? Will the pace of deployment that is required to meet policy mandates allow for achieving "consensus" standards? Can regulatory bodies play a role in supporting the standards development process, yet stop short of mandating state-specific standards?

- **Regulatory role in cyber-security and interoperability standards enforcement –** What is the "right level" of security requirements for different smart grid applications? Are there jurisdictional conflicts between state and federal entities with regards to the regulation of cyber-security?

- **Regulatory oversight, investment approval and progress measurement –** How to ensure that smart grid investments proposals are evaluated fairly as compared to other utility capital investment? How is smart grid deployment progress measured? Can metrics really convey a successful deployment?

- **Regulatory jurisdiction –** Many smart grid applications bring with them new levels of complexity which cross traditional jurisdictional boundaries (e.g., state vs. federal, multiple agencies within a state, state A vs. state B, etc.).

### Customer Readiness

*How to best engage customers and their resources?*

- **Customer adoption and participation –** To what extent and at what pace will customers embrace smart grid technologies ranging from demand response to electric vehicles? To what extent can this adoption be influenced through education and incentives?

- **Customer data and privacy –** What data (content/frequency) needs to be made available to customers? How can customer data be made available to 3rd parties while maintaining privacy?

- **Customer resources –** Clearer definitions of rules and policy are needed for customer-owned/sited energy resources including demand response, distributed generation, storage, and electric vehicles. What are the minimum requirements for participation in market-oriented programs?

# CHAPTER 4: Analyzing the 2010 Baseline of Existing Utility Projects

## Analyzing the Baseline of Existing Projects

This chapter provides a comprehensive and consolidated analysis of California Investor-Owned Utility (IOU) smart grid related projects, both ongoing and planned. Each project falling under the scope of the analysis, 82 in total, was identified and characterized by IOU representatives using common criteria in order to enable consolidation and identification of trends, with each project being able to contribute to more than one category of criterion. The categories are mainly derived from parameters used in the 2008 report and include:

- **Organization impacted:** the electric system business areas covered by the project (generation, market, transmission, substation, distribution, end-use).
- **Smart grid technology level:** the technology level the project covered (power system assets and resources, controls and sensors, communication infrastructure, data integration, application).
- **Time frame of execution:** starting date and duration of the project
- **Technical domain:** this parameter characterizes the projects using the critical technologies areas (domains) identified in the 2008 report: Communications Infrastructure & Architecture, Customer Systems, Grid Operation & Control, Renewable and Distributed Energy Resource Integration, Grid Planning & Asset Efficiency, and Workforce Effectiveness.
- **Energy policy and other drivers:** this parameter identifies the category of energy policy target a given project will contribute to achieve: system improvements, reliability, energy efficiency, demand response, renewable, and greenhouse gas reduction.

The smart grid projects identified and considered in the analyses vary by nature (e.g., deployment, demonstration or pilot for technology evaluation), scale, and budget. The objective of the consolidated analyses is to identify the concentration of efforts and how they (1) contribute to the development of the smart grid and (2) support achieving energy policy objectives in California.

## Consolidated Analyses

This section summarizes trends that can be identified based on consolidated analyses of data collected on smart grid-related projects reported by the California IOUs.

### Finding 1: Cross-Organizational Impact and Technology Coverage at All Levels

An analysis of smart grid projects by organizations impacted and level of technology involved was conducted. Organizations and technology areas covered by the projects are illustrated in Figure 5 and Figure 6, respectively.

**Figure 6: Organizations Impacted**

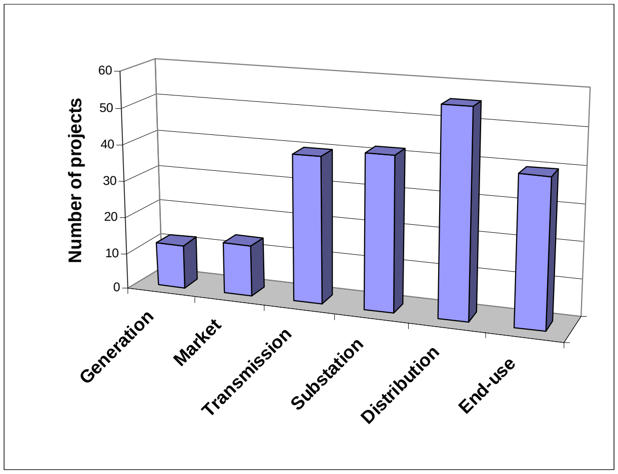
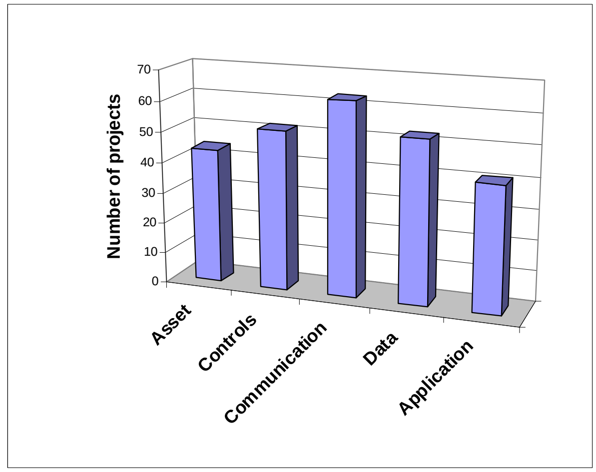



**Figure 5: Technology Level Coverage**



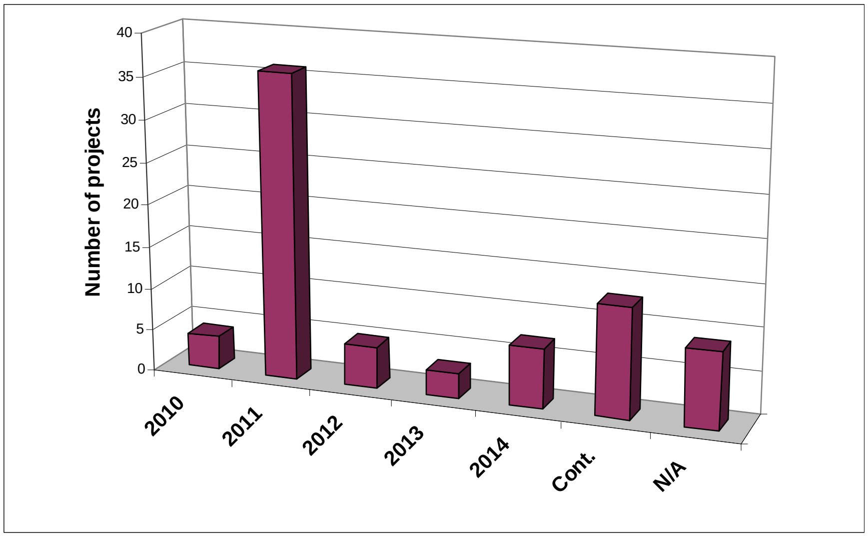

These graphs show no gaps in the current project scopes either in terms of organization impacted or technology level. All of the smart grid areas are addressed but with different intensities. The focus of ongoing projects is clearly oriented towards distribution applications, followed by transmission, substation, and end-use to a lesser extent. The greatest number of smart grid technology projects reported by the IOUs are focused on communication infrastructure development, followed by controls and data integration to a lesser extent. Advanced metering infrastructure and systems current deployments in California are examples of the emphasis.

## Finding 2: Project Timelines are Concentrated in Tactical Time frames

Analysis of project timelines shows that about 84 percent of the projects are ongoing (started in 2009 or prior, or will start in 2010). Five of the reported smart grid projects have been completed and eight will start later in 2012. Completion dates associated with existing projects (when reported) extend up to 2014.

Figure 7 illustrates the distribution of projects by year-ending date. Results highlight the fact that 58 percent of ongoing projects reported will be completed by the end of 2011.The schedule of projects is well aligned with utility general rate case filings and also reflects the short term nature of the planning cycle for emergent technology evaluation projects. While concepts and roadmaps exist within each of the utilities for the 2011-2012 time frame and beyond, they have yet to be fully planned as projects. The Smart Grid Order Instituting Rulemaking (OIR) process initiated by the California Public Utility Commission to address Senate Bill 17 on smart grid deployment planning, is proposing a framework to enhance the visibility and consistency of long-term plans for utility smart grid technology deployments.

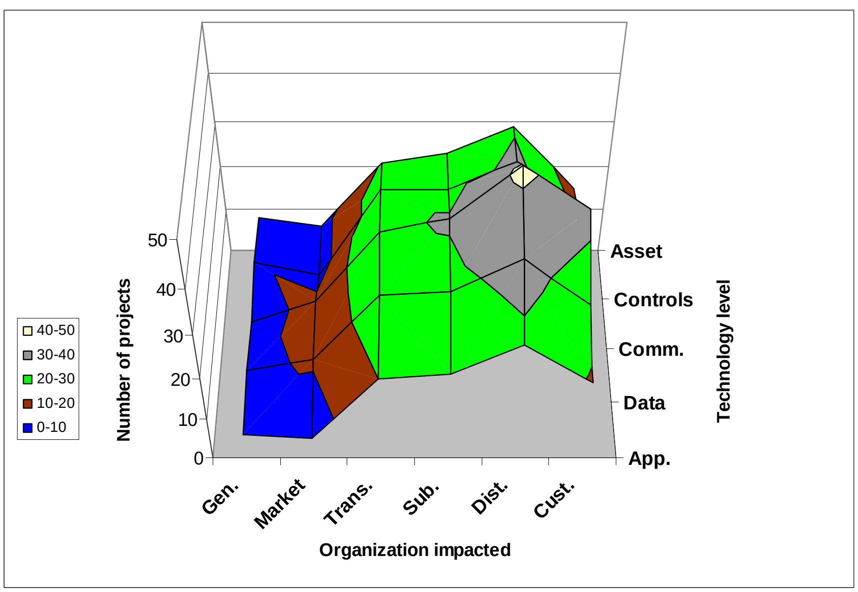
**Figure 7: Project Completion Time Horizons**




## Finding 3: Focus of Activities on Communication Infrastructure for Distribution

Figure 8 provides a three-dimensional perspective on the number of smart grid projects reported, by technology level and organizations impacted. From the figure, the peak of current efforts and activities is concentrated on the development of the communication infrastructure and architecture for distribution. Such projects build the backbone for future smart grid deployments. The projects are being conducted over the next few years through initiatives that enable building upon technologies currently implemented. Examples of projects in this area include smart meters deployments, data collection from field equipment, distribution automation and control, mobile solutions developments, as well as integration of distributed energy resources (electric vehicles, renewables, storage).

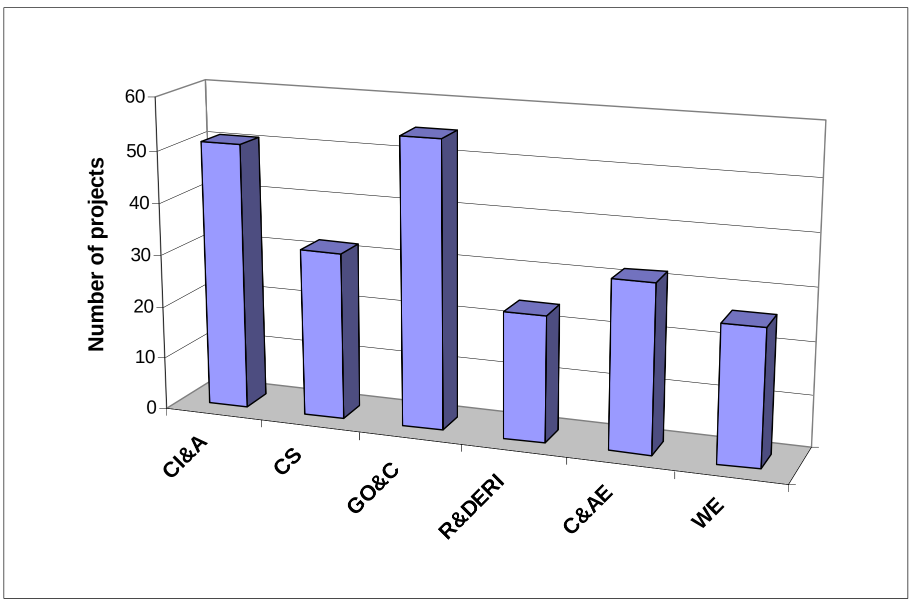
**Figure 8: Coverage Map of Projects by Technology Level and Organizations Affected**



Other areas shown in Figure 8 that are receiving strong emphasis are distribution controls and data integration as well as customer systems' communication infrastructure and substation communication infrastructure. Examples of distribution controls and data integration projects include energy management or geographical information system upgrades, enhancements to outage management systems, and protection and control systems. In the area of customer systems communication infrastructure, typical projects include Home Area Network integration, dynamic pricing integration, standards developments (e.g., Zigbee, Smart Energy Profile 2.0, and other protocols for Automated Demand Response), and customer enhancements including microgrids. In the area of substation communications infrastructure, supporting projects include synchrophasor deployment, remedial action scheme development, and condition-based maintenance.

Figure 9 provides a perspective of projects by technical domain area. The analysis reveals specific emphasis in the domain areas of Communications Infrastructure & Architecture as well as Grid Operation & Control, which are represented by the two highest peaks in the bar chart of Figure 9. This result supports the finding that current utility efforts are highly focused on communications infrastructure and architecture for distribution.

**Figure 9: Technical Domain Coverage**




CI&A = Communications Infrastructure & Architecture; CS = Customer Systems; GO&C = Grid Operations & Control; R&DER = Renewables & DER Integration; C&AE = Grid Planning & Asset Efficiency; WE = Workforce Effectiveness

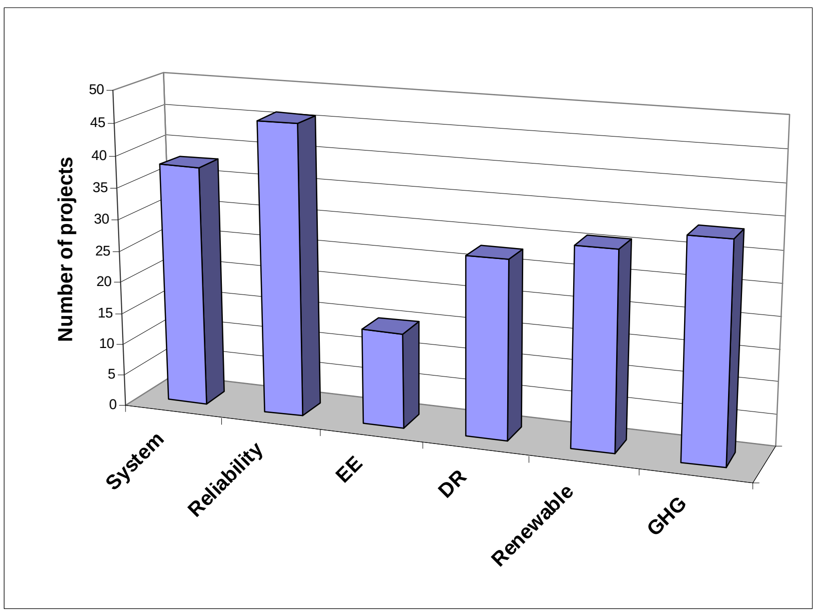
Figure 9 also indicates significant attention in the domain area of Customer Systems, which includes demand-side activities focused on demand response and energy efficiency objectives, as well as customer energy management systems and electric transportation. Stemming from current advanced metering deployment projects, much attention is focused on enabling linkages with customers and their metering or demand response systems and capturing benefits with demand response and energy efficiency applications.

## Finding 4: Reliability and System Improvements Are Top Drivers

Energy policy and other categories of smart grid drivers were considered. Utilities were asked to indicate the top drivers behind each of the smart grid activities reported. The categories of drivers included energy policies (e.g., reliability, energy efficiency, demand response, renewables portfolio standards, and greenhouse gas emission reductions) as well as system improvements (i.e., upgrades economically justified to achieve utility operational efficiencies). The analysis helps to qualitatively link the baseline of smart grid projects to support for the framework of energy policies in California. Analysis of the consolidated data reveals reliability and system improvements are the highest overall drivers addressed by the projects, as illustrated in Figure 10.

California IOUs are mandated to annually report their reliability levels through indicators such as SAIDI (System Average Interruption Duration Indicator) and SAIFI (System Average Interruption Frequency Indicator). Utilities as well as other grid operators in general take reliability very seriously. Reliability and system improvements are common drivers in their projects, including smart grid related projects.

**Figure 10: Linkage to Energy Policy and Other Drivers**




## Finding 5: Advancements to Accommodate Distributed Resource Integration Is a Top Priority

The integration of distributed resources is a top priority objective associated with the deployment of the California Smart Grid. Types of distributed resources include storage, distributed generation (including renewable), demand response resources, and flexible loads like plug-in electric vehicles, which could potentially be leveraged as storage and/or demand response. Their effective integration needs to be supported by research and technology development across organizations and technology levels.

As indicated in Figure 10, renewable and demand-side integration are drivers for many existing smart grid projects. However, coverage of projects supporting Renewable & DER Integration is among the lowest of all technical domains, as indicated in Figure 9. However, this apparent discrepancy between drivers and activities doesn't account for projects included in other domains, notably Customer Systems and Grid Operations & Control, that may be primarily customer or control focused, but also have significant secondary objectives in enabling the integration of distributed and renewable resources. In addition, technology evaluation activities related to the performance and use of the actual renewable and/or distributed energy generation equipment (as opposed to how it is integrated into the grid) may be occurring outside of the scope of the smart grid footprint; that is, they may be occurring in the utilities' generation planning area. Certainly the maturity of methods, technologies, and standards to enable the planning and coordinated integration of renewables and distributed energy resources require continued advancement. Projects exist that focus on demonstrations and pilots for distributed resources. These and other smart grid activities are needed to support development of generalized methods to effectively integrate distributed and renewable resources in support of RPS and demand-side integration drivers.

Figure 10 indicates that energy efficiency received the least attribution as a primary driver behind utility smart grid projects. Energy efficiency is not a new concern in California. The state has had a history of proven standards and programs for energy efficiency that has contributed to maintaining a flat level of consumption per capita over the years, despite steady population growth. An abundance of programs and activities at the California utilities continue to address energy efficiency goals in the state. However, the low attribution of smart grid efforts driven by energy efficiency is likely due to the fact that energy efficiency projects are not always considered within the smart grid footprint by the utilities.

# CHAPTER 5: California Smart Grid 2020 Vision

## Introduction

California is leading the nation with ambitious energy and environmental policies that are driving the development of a smarter, more robust, and more efficient electricity infrastructure. The California Smart Grid will enable the achievement of multiple energy and environmental policy goals, as described in detail in Chapter 3, including:

- Renewables portfolio standards (RPS)
- Greenhouse gas reduction
- Energy efficiency standards
- Demand response (DR)
- Distributed energy resources (DER)
- Consumer Empowerment
- System reliability
- Transportation electrification through adoption of plug-in electric vehicles

The California utility vision for the smart grid will link electricity with communications and computer control to create a highly automated, responsive, and resilient power delivery system that will both optimize service and empower customers to make informed energy decisions. Integrated communications will enable this smart power grid to continuously send, receive, and process data on system conditions, component health and power flows, as well as pass information among intelligent electronic devices, generators, independent system operators, marketers, and consumers. A smart grid with these characteristics will also allow for the integration of increased levels of renewable generation resources, accommodate increased loads associated with electric vehicle transportation, and provide increased protection from cyber security and customer privacy concerns.

This chapter presents a high-level vision of the capabilities of the California Smart Grid in 2020. The capabilities explicitly support the key California and U.S. energy and environmental policies, and fall into four categories:

1 Empower consumers and open markets.

2 Widespread implementation of intermittent renewable generation.

3 Optimized grid reliability, resilience, security and efficiency in the face of increasing complexity to mitigate issues such as plug-in electric vehicles, intermittent renewable generation, and human-caused and natural disasters.

4 Increased worker safety and productivity.

The smart grid vision within each of these categories is described in the following pages. For each of the first three categories above, the vision description is segmented into three perspective based sub-categories (Utilities, Consumers, and Third Parties), with each providing a point of view on the vision from that perspective.

## Empower Consumers and Open Markets

California policy over the past decade has clearly recognized the benefits of enabling customer participation in the energy supply chain. This is readily apparent through the adopted loading priority order that favors energy efficiency and demand response over alternative types of resources, and through several regulatory policies that have led to smart metering, dynamic rate options and demand response programs for all customers.

The California Smart Grid will empower consumers and open markets by giving consumers information and tools to play an active role in the electricity marketplace. This capability offers a rich array of benefits, including improved energy efficiency, reduced emissions of greenhouse gases, and realizing the full potential of demand response in managing customer load—not only to reduce peak demand but also by unlocking its value to customers as a dispatchable resource as though it were the output from a power plant.

**Consumers** will have access to pricing and usage information to help them better manage their consumption and production of electricity and will be able to select from a variety of tariffs and programs to best meet their lifestyles and budgets. Their energy-related decisions will become integrated with other parts of their lifestyle. For example, an increasing number of customers will have the ability to receive electric and natural gas usage data or adjust their thermostat from a smart phone, and to charge their Plug-in Electric Vehicle (PEV) at home, at work, or in public locations such as shopping malls. "Smart" devices and appliances will be commercially available that will help consumers reduce their electricity bills and become more efficient users of electricity. Consumers will view utilities in new ways—as interfaces to energy markets through demand response, and as the fuel provider for third-party vehicle fuel distribution systems to support electric transportation. Rooftop solar, on-site energy storage, and other distributed energy resources (DER) will further change consumer behavior with respect to participation in electricity markets and their relationships with utilities.

**Utilities** will face numerous changes and challenges due to an evolving market and new customer behaviors. Rate structures will change, for example, and the complexity of planning, designing, and operating the grid will increase significantly. Utilities will need to develop new programs, rates and services, and learn how to support the technologies and connections customers adopt in homes and businesses. Utilities will also need to manage new channels of customer information, and new issues related to customer data privacy and security. Moreover, utilities will have to mitigate the emerging adverse grid impacts and leverage the advantages of customer-sited DER, electric vehicles, and energy storage.

**Third Parties** will become part of the consumers' energy ecosystem as new market roles emerge. Players such as solar aggregators and internet-based information providers will offer value-added services to consumers such as energy management, demand response, and PEV aggregation.

## Widespread Implementation of Intermittent Renewable Generation

In 2009, California's Governor signed an executive order to increase the state's renewables portfolio standard from 20 percent to 33 percent by 2020. The intermittent nature of wind and solar generation makes their integration into the electric system challenging. Sudden gusts and drop-offs in wind energy can affect power system stability, and cloud effects on photovoltaic systems can cause voltage spikes/sags and demand shifts that may be even more severe than wind ramps. Adding to the complexity of high penetrations of intermittent resources is the move to eliminate once through cooling in coastal generating plants. These plants provide system inertia needed for stability and the safe and reliable operation of the power grid.

From the utility and grid operator's perspective, the California Smart Grid of 2020 must continue to operate reliably with a high percentage of bulk and distributed renewable generation by incorporating advanced technologies. For example, energy storage on both the transmission and distribution systems will provide dynamic response and energy shifting capabilities to mitigate the intermittency, ramping, and dump power issues associated with renewable generation. Enhanced situational awareness and control of the transmission and distribution systems will enable the operator to respond to quickly changing conditions. The ability to dispatch distributed generation and storage will help balance the intermittency of renewable resources and provide support to the grid, as will price-responsive demand response and direct load control. Advanced system protection capabilities will be required to manage increasing levels of renewable intermittency and bidirectional power flows.

Increasing numbers of customers will be "prosumers" who both consume and supply energy from and to the grid. Consumers can participate in demand response programs with minimal inconvenience. The infrastructure for PEV charging will continue to expand and provide consumers with more options and locations. More generally, customers will begin to enjoy and appreciate the benefits of an increasingly renewable generation portfolio (environmental/carbon improvements, energy independence, reduced fuel price volatility, etc.) without a noticeable negative impact to service quality or reliability.

Third parties will have expanded roles in customer services and as providers of bulk renewable generation and energy storage. Customer services will include support in making supply and storage decisions or help in managing and maintaining their supply and storage resources. Third-party aggregators will also participate in ancillary services market.

## Optimized Grid Reliability, Resiliency, Security and Efficiency in the Face of Increasing Complexity to Mitigate Issues Such as Plug-In Electric Vehicles, Intermittent Renewable Generation, and Human-Caused and Natural Disasters

The 2020 smart grid will integrate numerous **utility** capabilities to maintain or increase grid reliability, resilience, security and efficiency. A key characteristic is that the smart grid's monitoring, analysis and control systems will be information-directed rather than data-intensive. Although a myriad of distributed sensors will generate volumes of new smart grid data on power system and component condition, advanced analytical tools will convert this data into usable information, providing wide-area situational awareness and control capabilities that will make operators more effective and enhance system protection and restoration. The same or similar data can be converted into different usable information for the engineering workforce that will allow for improved grid design practices which can account for specific localized load and supply characteristics, and proactively address new grid resources/loads such as distributed generation and/or electric transportation load.

New generations of flexible and intelligent switches, interrupters and other electronic devices will reduce system losses, manage bi-directional power flows associated with distributed energy resources, and minimize the extent of outages and increase the speed of restoration. These distribution automation technologies will be widely included in distribution system design to extend intelligent control throughout the entire distribution grid and beyond, inclusive of distributed energy resources, buildings and homes.

Advanced transmission monitoring, control and protection systems will decrease the probability of cascading failures that could lead to wide-area blackouts. Similarly, robust security measures will reduce the odds of catastrophic bulk power system failures from human-caused and natural disasters such as cyber terrorism, vandalism, or earthquakes and extreme weather events.

Power quality issues such as voltage perturbations and harmonics will be minimized, and different levels of power quality will be provided at differing rates. From an asset management perspective, the smart grid's advanced distributed sensor, communications, and data networks will enhance condition-based maintenance and enable intelligent vegetation management. Application of dynamic ratings enable less constrained operation and timely mitigation action that avoids dangerous system security conditions by tracking the thermal state of equipment.

Consumers will be able to choose the level of power quality and reliability that best meets their needs and budget. Customers also will appreciate the benefits of a greener, more efficient, and participatory power grid, that promotes energy independence by accommodating electric transportation and reduces exposure to fuel price volatility with increased integration of renewables—all with improved service quality and reliability.

Third parties will provide wholesale market services as well as renewable generation and ancillary services. The smart grid will enable increased cooperation among regional utilities and generation providers, increased cooperation and information transparency with WECC regarding synchrophasor data, as well as an enhanced partnership between California utilities and the Independent System Operator. It will also increase communication and coordination between the operators of interdependent infrastructures such as natural gas, water and telecommunications.

## Increased Worker Safety and Productivity

The effective development and operation of a smart grid depends on a skilled workforce equipped with the training, tools and technologies to support infrastructure deployment and grid operations and maintenance while enhancing safety and productivity. Utilities will be organizationally prepared through internal skills development, external education, recruiting, and knowledge management.

Worker safety will increase with the adoption of improved safety technologies, materials, and equipment; as well as new access to safety information and remote access to safety training material.

The field workforce will adopt mobile workforce computing applications that utilize real-time component and system information. They will also make greater use of robotics and remote controlled devices, and will be able to access experts/specialists back at the office through on-demand video conferencing. Operators will have access to improved situational awareness and decision support tools. Planners and engineers will make use of smart grid information to assist in scheduling maintenance, planning of system enhancements and grid design and construction standards.

## From Vision to Roadmap

The high-level vision of the California Smart Grid of 2020 provides a conceptual goal to support and inspire the development of a technology roadmap that defines a pathway to the 2020 vision destination.

The following chapter provides a summary of the principles guiding the development of the smart grid architecture. Subsequent chapters present the 2010 baseline, 2020 vision, technology-ready roadmaps, gaps and recommendations developed by each of the six domain teams.

# CHAPTER 6: Architectural Guiding Principles

## Guiding Principles

Smart grid architecture needs to be designed based on specific requirements supporting each of the smart grid uses. Guiding principles for architecture design, as identified in the table below, have been created to help provide direction for the development of the technology roadmap for systems architecture, and ultimately to influence the execution of that roadmap going forward.

| | Principle | Rationale |
|---|---|---|
| 1 | **Interoperable Common Use Services** | Some critical areas of smart grid technology require agreement for interoperable systems integration and service offerings (e.g., plug and play systems). For example, interaction with common customer-side devices/systems will require such agreement to enable key service offerings. |
| 2 | **Common Smart Grid Business Vocabulary** | A common vocabulary (based on IEEE or NIST documentation, where possible) serves to reduce ambiguities and can help to ensure effective communications across stakeholder communities. |
| 3 | **Open Systems** | The smart grid will need to evolve over time and will need to be robust and flexible enough to seamlessly support not only today's services but adequately support future innovation. |
| 4 | **Consistent Data and System Security** | Consistent security protocols and services for common types of smart grid communications and information will help to ensure effective management of security across different systems. |
| 5 | **Rigorous Technology Evaluation** | The smart grid represents a significant investment and the technologies used – including the underlying architecture – should stand up to the rigors of long term deployment and use. |
| 6 | **Systems Engineering Approach** | Systems engineering provides a rigorous systematic and scenario based approach to defining and documenting systems, notably including use cases which provide clear functional and non-functional business requirements. |
| 7 | **Proactive Standards Development and Adoption** | Standards are necessary to enable components to integrate and interoperate. Standards require work to develop, codify and effectively use. |
| 8 | **Scalability** | Technology for the smart grid will involve large numbers of components and functions. Management of this technology will need to effectively scale to the number and scope of proposed systems. |
| 9 | **Develop Infrastructure Management and Security in Parallel with Desired Functions** | The smart grid infrastructure must not only support desired primary end-user functions but must also support system administration and security management. |
| 10 | **Architecture Development** | The smart grid will be comprised of wide variety of technologies integrated through several open standards. The integration of this system requires the application of architecture development concepts and principles. |
| 11 | **Open Innovation** | Across broad groups of stakeholders including utilities, technology vendors, regulatory bodies, and standards development organizations, support idea sharing and consensus building, in order to develop critical mass supporting smart grid communications and architecture requirements and standards. |

## Nonfunctional Attributes for a Smart Grid Systems Architecture

In addition to the prior list of guiding principles, each of the following attributes of smart grid architecture is important for consideration in determining non-functional requirements for the different uses (and associated functional requirements) of a smart grid. As the smart grid systems architecture roadmap is executed, each of the non-functional attributes must be addressed and considered in smart grid design as the underlying architecture evolves over time to support additional and increasingly integrated smart grid functions. Each of the architecturally important non-functional attributes is described below.

| Non-Functional Attribute | | Meaning |
|---|---|---|
| **Interoperability** | | The ability of multiple systems to exchange information and effectively work together to support a business capability. |
| **Scalability** | | The ability to accommodate, over time, an increasing number of units (e.g. of information, devices, users, systems, etc.) and the other non-functional requirements that are associated to them. |
| **Expandability** | | The ability to accommodate, over time, additional business functionality (i.e. functional requirements) or scope. |
| **Adequacy** | | Having sufficient processing capacity to meet peak demands, taking into account both expected and reasonably unexpected cases of system use. |
| **Physical Security** | | The measures used to provide physical protection of resources against deliberate and accidental threats. |
| **Cyber Security** | **Confidentiality** | Ensuring that data is available on a need to know basis (e.g., securing information and providing it only to those authorized to have access); includes authenticity. |
| | **Integrity** | Ensuring that data generated, stored, or transmitted is exactly accurate in format and value. |
| | **Availability** | The proportion of time that a system and its data are in a functioning and accessible condition. |
| **Traceability** | | The ability to chronologically interrelate uniquely identifiable transactions in a way that is verifiable. |
| **Flexibility/Adaptability** | | The ability to adapt or be changed to fit changed circumstances. |
| **Usability** | | The ability of a system to be easily employed to achieve its intended goals. |
| **Resilience/Disaster recovery** | | The robustness or ability of a system to withstand stress and yet maintain stable operation; and ability to recover from a major stress event. |
| **Performance/Latency** | | The speed at which data needs to be received in order to support a business function. |
| **Maintainability/Serviceability** | | The ability of a device or system, once deployed, to be repaired, diagnosed, or administered remotely. |
| **Self-awareness/Self-discovery** | | The ability to understand location and status relative to surrounding environment. |

# CHAPTER 7: Findings by Technical Domain Area

## Domain 1: Communications Infrastructure and Architecture

### 2010 Baseline Summary

The 2010 baseline of smart grid communications infrastructure and architecture consists primarily of multiple, single-purpose communication networks built for individual smart grid applications such as advanced metering, distribution automation and substation automation. Convergence technologies are envisioned, but not yet deployable and primarily reside in the early stages of development and maturity. Different communication media are deployed to fill specific purposes, such as fiber optic and microwave systems for high-volume traffic, radio-based networks for lower volume interactions, and now AMI systems to communicate with smart meters.

It is expected that communications networks will be increasingly deployed throughout the distribution system to remotely monitor and control field devices for improved distribution grid management. Traditional communication protocols such as DNP3 are used as common practice in transmission grid management. It is expected that information exchanges will eventually be based on object modeling technologies, such as the Common Information Model (CIM) and IEC 61850, but these have not yet been deployed extensively. Standards for communications and information exchange extending to and within customer premises are in active development (e.g., Smart Energy Profile (SEPv2) for AMI/HAN). Focused industry efforts by different organizations and standards groups (e.g., the NIST Priority Action Plans, NIST Cyber Security Working Group, IEC object modeling standards, IEEE substation and wide area phasor measurements, and DER electric connectivity standards) involving many different, often interrelated segments of the electric power industry are expected to produce smart grid interoperability standards and security guidelines in the near term. These efforts will ultimately drive the realization of the smart grid vision.

### 2020 Vision

The 2020 Vision for smart grid communications infrastructure and architecture is envisioned to integrate diverse, single-purpose communications networks into an efficient and flexible unified information infrastructure. This information infrastructure will support the timely and secure exchange of information using interoperable, model-driven standards across the entire grid supply chain covering bulk generation, transmission and distribution grids, market operations, power system operations, distributed energy resources, energy service providers, and the customer. Field devices, consumer devices, authorized third-party systems, and back-office technologies and systems will be able to be easily secured and integrated—through increasingly unified communications networks—into a resilient and secure smart grid architecture which supports reliable and efficient electric system operations.

### Benefits

Significant benefits can be realized from the unified, interoperable communications infrastructure. The key benefits include:

- **Utility technical efficiency:** More efficient utility operations through expanded reach of communication capabilities, economies of scale, multi-use of communication networks, and efficiencies from using standards.

- **Utility and national security:** Enhanced utility security and safety, as well as national security, through improved defenses against cyber-threats and more resilient energy delivery.

- **Enabling smart grid applications:** Enabling of the many benefits that can be realized by the applications in other domains, which rely on the smart grid communications infrastructure to achieve their goals.

## Smart Grid Subdomains under Communications Infrastructure and Architecture

- Smart Grid System Architecture Design
- Communications Network, System, and Data Integration
- Interoperable Communication Protocols and Information Models
- Cyber Security

### *Smart Grid System Architecture Design*

The Smart Grid System Architecture will be used to guide and manage the design of the communication networks, systems, information models, and security. In particular, the 2020 vision must be based on a scalable event-driven smart grid architecture that covers all aspects of the power system infrastructure (including bulk generation, transmission and distribution grids, market operations, power system operations, distributed energy resources, energy service providers, and the customer) while interconnecting field devices, consumer devices, authorized third-party systems, and back-office technologies and systems.

The Smart Grid System Architecture will be based on the following concepts:

- **Formal methods** for developing specifications to ensure robust, reliable, and scalable designs that cover both functional and non-functional requirements.

- **Interoperability standards** that permit all smart grid systems to be integrated into a "system of systems."

- **Inclusion of cyber security technologies and methodologies** from the beginning to ensure appropriate levels and layers of security.

- **Flexible and expandable data management technologies** to ensure that the extensive increases in data generated by the smart grid can be readily stored, accessed, utilized, and archived, while still mitigating privacy concerns.

The Smart Grid System Architecture will be developed in the short term stage in order to guide the other sub-domains, although it will likely be updated to reflect new technologies and capabilities over time. These stages are shown in Table 2.

**Table 2: Technology-Ready Roadmap for Smart Grid System Architecture**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(2010-2015) | Develop Smart Grid System Architecture document, covering:<br>• Formal methods for developing specifications to ensure robust, reliable, and scalable designs that cover both functional and non-functional requirements.<br>• Interoperability standards that permit all smart grid systems to be integrated into a "system of systems".<br>• Inclusion of cyber security technologies and methodologies from the beginning to ensure appropriate levels and layers of security.<br>• Flexible and expandable data management technologies to ensure that the extensive increases in data generated by the smart grid can be readily stored, accessed, utilized, and archived, while still mitigating privacy concerns. | The Smart Grid System Architecture will be used to guide and manage the design of the communication networks, systems, information models, and security. | • Utility Technical Efficiency | System Architecture concepts being developed by various groups, such as:<br>• EPRI IntelliGrid<br>• The Open Group Architecture Framework (TOGAF) is a framework for enterprise architecture that provides a comprehensive approach to the design, planning, implementation, and governance of an enterprise information architecture.<br>• IEC Publicly Available Specification (PAS) 62559<br>• NISTIR 7628 v1 |
| **Medium**(2015-2020) | Update Smart Grid System Architecture to reflect any new concepts, technologies, and issues. | The Smart Grid System Architecture will be used to guide and manage the design of the communication networks, systems, information models, and security. | • Utility Technical Efficiency | • Experience with initial Smart Grid System Architecture |
| **Long**(2020+) | Update Smart Grid System Architecture to reflect any new concepts, technologies, and issues. | The Smart Grid System Architecture will be used to guide and manage the design of the communication networks, systems, information models, and security. | • Utility Technical Efficiency | • Experience with initial Smart Grid System Architecture |

### *Communications Networks, Systems, and Data Integration*

The sub-domain of Communications Networks, Systems, and Data Integration will progress through three stages as it moves from 2010 Baseline to 2020 Vision. In the near-term stage, the communication networks would be characterized as being "single purpose", while the interfacing of data and systems would be handled on a one-by-one basis. In the medium term, looking out five years, communication networks will begin to converge on a larger scale, while the integration of systems and data will more consistently use standards. Finally, in the long term stage, the communication networks will be unified, while systems and data will always use interoperable standards.

More details of this staged progress of the Communications Integration are shown in Table 3**.**

**Table 3: Technology-Ready Roadmap for Communications Networks, Systems, and Data Integration**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(2010-2015) | Single Purpose Communications Networks<br>• Basic AMI, Distribution and Substation Automation, Phasor Measurement, Market operations (independent systems/initiatives)<br>• Classic, Information Technology-Centric Service Oriented Architecture (SOA)<br>• Supports HAN applications/Device Management<br>• Limited integration between distribution automation & customer applications (AMI/DMS)<br>Single purpose interfacing of systems and data<br>• Mapping of older protocols to SG standard protocols<br>• Occasional use of information models for exchanging data | Convergence of multiple siloed communications networks and information technology can result in improved operating and maintenance efficiency, more coordinated security technologies and methodologies, and thereby, lower costs.<br>Co-existence of multiple protocols and users of communication networks can permit more effective and timely (authorized) use of information. | • Utility Technical Efficiency<br>• National Security – Through improved defenses against cyber-threats<br>• (other benefit categories are realized by applications – in other domains – supported by communications infrastructure and smart grid systems architecture) | • From standards development and “mapping” to “harmonization”<br>• Network segmentation to connected (virtualized) networks<br>• Vendor readiness<br>• 3rd Party and carrier relationship development/3rd party networks and secure interconnection<br>• Availability of Smart Grid protocol and information modeling standards – some are well-tested, others are untested, some are still under development<br>• Cyber security technologies and methodologies can permit co-existence of information exchanges without compromising security requirements |
| **Medium**(2015-2020) | Converging Technologies Communications Networks<br>• T&D Integration – Centralized and integrated control systems (enabling limited advanced distribution and substation automation)<br>• Wide Area Situation Awareness and advanced protection applications (using synchrophasor data)<br>• Increased integration of “Behind the Meter” applications (DR, DER, PEV, etc.) with utility operations allowing for dynamic customer participation and response<br>• Event driven architecture, SOA concepts extended to field devices<br>Increased use of interoperable standards for interfacing systems and integrating data<br>• Replacing of older protocols with SG standard protocols<br>• Increased use of information models for defining data exchanges | Convergence of multiple siloed communications networks and information technology can result in improved operating and maintenance efficiency, more coordinated security technologies and methodologies, and thereby, lower costs.<br>Co-existence of multiple protocols and users of communication networks can permit more effective and timely (authorized) use of information. | • Utility Technical Efficiency<br>• National Security – Through improved defenses against cyber-threats<br>• (other benefit categories are realized by applications – in other domains – supported by communications infrastructure and smart grid systems architecture) | • Parallel and coordinated development of national/international standards<br>• Enforcement rules and agencies<br>• Improved networks<br>• Workforce/organizational readiness<br>• Availability of SG protocol and information modeling standards – more will be well-tested<br>• Cyber security technologies and methodologies can permit co-existence of information exchanges without compromising security requirements |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Long**(2020+) | Unified Communications Networks<br>• Fully integrated and dynamic Generation –> Transmission –> Distribution –> Customer Systems (accessing common services through interoperable standards)<br>• Distributed and (semi-)autonomous automation and control systems, centrally monitored and configured with integrated systems and information<br>• Advanced WAMACS and widespread advanced protection<br>• Full event driven architecture coupled with simulation and predictive analytics to improve grid resiliency<br>• Smart cities/communities resulting from integration of customer-side applications from multiple customers<br>• Complete use of interoperable standards for interfacing systems and integrating data<br>• Replacing of older protocols with SG standard protocols<br>• Complete use of information models for defining data exchanges | Convergence of multiple siloed communications networks and information technology can result in improved operating and maintenance efficiency, more coordinated security technologies and methodologies, and thereby, lower costs.<br>Co-existence of multiple protocols and users of communication networks can permit more effective and timely (authorized) use of information. | • Utility Technical Efficiency<br>• National Security – Through improved defenses against cyber-threats<br>• (other benefit categories are realized by applications – in other domains – supported by communications infrastructure and smart grid systems architecture) | Standards<br>• Unified Standards<br>Other<br>• "Smart" and Collaborative Networks<br>• Availability of SG protocol and information modeling standards – more will be well-tested<br>• Cyber security technologies and methodologies can permit co-existence of information exchanges without compromising security requirements |

### *Interoperable Communication Protocols and Information Models*

In 2010, many different types and capabilities of communication protocols are deployed, most of which are not interoperable or even mappable to each other. For 2020, the communications architecture will specify a limited set of standardized, state-of-the-art communication protocols and information models that will provide widespread interoperability and will minimize the customization needed for any implementation.

The NIST Framework document, NIST SP 1108, *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0,* identifies many missing or incomplete standards that would be needed to provide interoperable communications. The NIST Priority Action Plans (PAPs) were established to speed up the development and/or enhancement of standards to fill these gaps. Of particular interest are the NIST PAP activities for the:

- Development of demand response (DR) pricing models, scheduling models, and DR interactions.
- Development of requirements and models for providing energy usage information to third parties (including customers).
- Development of Distributed Energy Resources (DER) standards for electrical connectivity for the smart grid (IEEE 1547.8).
- Enhancement of IEC 61850 object models for Energy Storage and DER (ES-DER) to support the management of energy levels, peak shifting, reactive power, frequency deviation mitigation, mitigation of the impact of intermittent renewables, and other ancillary services to maintain or improve the reliability and efficiency of the distribution grid.
- Enhancement of IEC Common Information Models and IEC 61850 models for distribution grid management, such as distribution operational models using power flow-based analysis to manage distribution automation (DA), including fault location, isolation, and service restoration, as well as volt/var/watt optimization for feeders.
- Development of use cases and charging requirements for electric vehicles to further the understanding of the impacts and challenges of EVs on the power system, and what benefits and opportunities for supporting distribution grid management they could provide.
- Completion of IEC standards for phasor measurement units (PMUs).
- Assessment of IEC 61400-25 (61850-based standard) for wind plant management within the United States.
- Mapping of DNP3 and IEC 61850 object models.

The following progression of actions will lead from the current variety of communication protocols and information models to the coherent, interoperable protocols and models of 2020:

- Plan 2020 communications protocol and information modeling architecture by identifying which available protocols and information models should be utilized for which environments.
- Develop high level requirements for 2020 information analysis functions.
- Gradually map information models on to protocols and eventually utilize only standardized protocols and information models.

**Table 4: Technology-Ready Roadmap for Communication Protocols and Information Models**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(2010-2015) | Plan 2020 communications protocol architecture by identifying which available protocols should be utilized for which environments, such as IPv6, TCP/IP suite, MMS for 61850, Web Services, ICCP, OPC/UA, SEPv2, DNP3, etc.:<br>• SCADA monitoring and control of substations<br>• Intercontrol center communications<br>• Substation automation<br>• Distribution automation<br>• Utility-owned Distributed Energy Resources (DER)<br>• Customer-owned DER<br>• Access to customer sites for metering (AMI), direct load control, and demand response | • A communications architecture with a limited set of standardized, state-of-the-art protocols provides interoperability and minimizes the customization needed for any implementation<br>• Standardized protocols take less time to implement, and are supported by vendors over longer time-frames<br>• Standardized protocols can take advantage of existing cyber security technologies<br>• Standardized protocols can be updated more easily as needs and technologies change | • Utility Technical Efficiency | • Existing standard protocols may need to be updated<br>• Standards under development may need to be fast-tracked<br>• Older, non-standard protocols will need to be (gradually) replaced with standards |
| | Plan 2020 information modeling architecture by identifying which information models should be utilized for which environments, such as CIM, IEC 61850, and MultiSpeak:<br>• For exchanging power system models<br>• For exchanging information between other control center applications, such as EMS, DMS, GIS, CIS, WMS, OMS, and AMI headend<br>• For interactions within/between substations<br>• For interactions with field equipment,<br>• For direct load control<br>• For interactions with DER devices<br>• For demand response interactions | • Information models provide many capabilities, such as interoperability across different vendors, self-description, minimal implementation errors, and ease of update<br>• Standardized information model take less time to implement, and are supported by vendors over longer time-frames<br>• Information models can be updated more easily as needs and technologies change | • Utility Technical Efficiency | • Existing information models need to be implemented by more vendors<br>• Additional information models need to be developed to support new devices, systems, and interactions |
| | Develop high level requirements for 2020 information analysis functions:<br>• Distribution planning for high penetration of electric transportation and demand side resources (Demand Response, DER, etc.)<br>• Distribution automation management functions<br>• Energy usage and pricing functions<br>• Demand response functions<br>• Renewable intermittency mitigation functions<br>• Load/DER forecasting | • Information analysis will become increasingly vital to managing the power system as increased penetration of DER and increased use of demand response add significant uncertainty to reliability of operations, power system stability, and efficiency<br>• Analysis of information will permit improved power system reliability and efficiency | • Utility Technical Efficiency | • Utility requirements need to be developed for the various information analysis functions<br>• Vendors need to implement these more sophisticated information analysis functions<br>• Regulators need to establish the overall strategy toward pricing tariffs for demand response |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Medium**(2015-2020) | Start implementing the 2020 plan for the communications protocol architecture<br>• For all new implementations, use the protocols selected for the environment<br>• For upgrades, gradually replace any existing, non-standard protocol with the appropriate protocol | • A communications architecture with a limited set of standardized, state-of-the-art protocols provides interoperability and minimizes the customization needed for any implementation<br>• Standardized protocols are lower cost, take less time to implement, and are supported by vendors over longer time-frames<br>• Standardized protocols can take advantage of existing cyber security technologies<br>• Standardized protocols can be updated more easily as needs and technologies change | • Utility Technical Efficiency | • New protocols need to be specified, with appropriate training for utility staff<br>• Gateways, conversions, and other mechanisms will have tobe developed to handle the transition from older protocols to the new, standard protocols |
| | Start implementing the 2020 plan for the information model architecture<br>• For all new implementations, use the information models appropriate for the environment | • Information models provide many capabilities, such as interoperability across different vendors, self-description, minimal implementation errors, and ease of update<br>• Standardized information models take less time to implement, and are supported by vendors over longer time-frames<br>• Information models can be updated more easily as needs and technologies change | • Utility Technical Efficiency | • Existing information models need to be implemented by more vendors<br>• Additional information models need to be developed to support new devices, systems, and interactions<br>• The information models need to be tested and validated under real-world conditions |
| | Start implementing the 2020 plan for the information analysis functions | • Information analysis will become increasingly vital to managing the power system as increased penetration of DER and increased use of demand response add significant uncertainty to reliability of operations, power system stability, and efficiency<br>• Analysis of information will permit improved power system reliability and efficiency | • Utility Technical Efficiency | • Utility requirements need to be developed for the various information analysis functions<br>• Vendors need to implement these more sophisticated information analysis functions<br>• Regulators need to establish the overall strategy toward pricing tariffs for demand response |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Long**(2020+) | Substantially all operational interactions use standardized protocols, according to the 2020 communications architecture plan | • A communications architecture with a limited set of standardized, state-of-the-art protocols provides interoperability and minimizes the customization needed for any implementation<br>• Standardized protocols are lower cost, take less time to implement, and are supported by vendors over longer time-frames<br>• Standardized protocols can take advantage of existing cyber security technologies<br>• Standardized protocols can be updated more easily as needs and technologies change | • Utility Technical Efficiency | • Standardized protocols will be accepted by the smart grid stakeholders for each of the environments |
| | Substantially all operational interactions use standardized information models, according to the 2020 information model architecture plan | • Information models provide many capabilities, such as interoperability across different vendors, self-description, minimal implementation errors, and ease of update<br>• Standardized information model are lower cost, take less time to implement, and are supported by vendors over longer time-frames<br>• Information models can be updated more easily as needs and technologies change | • Utility Technical Efficiency | • Standardized information models will be accepted by the smart grid stakeholders for each of the environments |
| | Substantially all operational interactions use information analysis functions, according to the 2020 information analysis plan | • Information analysis will become increasingly vital to managing the power system as increased penetration of DER and increased use of demand response add significant uncertainty to reliability of operations, power system stability, and efficiency<br>• Analysis of information will permit improved power system reliability and efficiency | • Utility Technical Efficiency | • Information analysis functions will be accepted by the smart grid stakeholders, including regulators, as the mechanism for managing the complex power system |

### *Cyber Security*

The smart grid can be thought of as a large, complex "logical plane" with numerous sensing, monitoring, diagnostic, and control interfaces to the "power plane." (The "power plane" is represented by the level of technologies labeled "Power System Resources" in Figure 12 in the Appendix. The other levels of technologies in Figure 12 represent the logical plane). Automation through smart grid technology is essential for reliability, and future grids will require unprecedented levels of monitoring and self-awareness. Autonomous agents will act to maintain grid availability and stability in the presence of changing environmental conditions (in the case of renewables), variable demand, and system conditions.

This rapidly evolving smart grid logical plane needs to be protected using a holistic approach: secure not only from deliberate attacks, but also from the more frequent inadvertent events, such as mistakes, equipment failures, inadequate procedures, and natural disasters.

The logical plane presents a cyber adversary with a greatly expanded attack surface that is not adequately understood. Security awareness is essential to overall grid self-awareness. However, security procedures and technologies must be implemented so as to not interfere with power system availability, reliability, and stability, and must be robust against the inadvertent acts that can make the overall system less secure.

Cyber security cuts across all domains noted in this document, and securing the logical plane is essential to safe, efficient, and stable operation of the grid. Security, broadly defined, is a major enabler for all smart grid objectives.

### *2010 Cyber Security Baseline Summary*

2010 is a time of transition between the traditional power system and the smart grid. As such, there is currently an odd mix of difficult-to-secure legacy equipment along with more modern devices with embedded systems that support highly sophisticated cyber security mechanisms. Smart grid communications are moving away from obscure protocols that are unique to the power industry and are adopting the mainstream internet protocols. For grid operations, best practices recommend against using the public Internet, but emerging models for home energy management services now assume the use of the public Internet. The profusion of addresses and security issues may motivate adoption of Internet Protocol Version 6 (IPV6). Smart meter installation is proceeding rapidly, although security for AMI systems and meters is still under development. Public confidence in and acceptance of the smart meter program has encountered some hurdles, though these are not due to cyber security flaws.

New protocols such as SEPv2 are being developed primarily to support systems, equipment and appliances in the HAN. Information standards for PEV interactions are still being defined. Security in the HAN domain is only beginning to be addressed. Security best practices for asset owners are being promulgated by, for example, the national labs. However, there is almost none of this for the consumer side of the equation, and security awareness is not adequate among DER providers.

### *Cyber Security and the Smart Grid Vision*

By 2020, all systems that connect to the grid will use secure interfaces with standard security technologies that provide high availability, high integrity of information, strong authentication procedures for access control, and where needed, confidentiality. By 2020, the vision includes:

- Security is embedded in systems and devices, such that security configuration is intuitive, simple, and easy to get right the first time, particularly for customer premise devices.
- The grid is resilient against attack, with the ability to island itself logically as well as physically in case of inadvertent events, equipment failures, misconfigurations, attacks or other adverse conditions.
- Secure embedded systems are engineered so that compromising one device does not make compromise of similar devices trivial for an attacker. It should be just as hard to extract crypto material from the second meter as from the first.
- Devices are fail-safe as well as fail-secure as a design goal, and the PEV infrastructure is interoperable and secure. Finally, secure interoperability standards are in place and regularly updated to accommodate technological advances as well as changing circumstances and adversaries.
- Intrusion response is robust.

### *Threats*

The smart grid logical plane is vulnerable to inadvertent events and an attractive target for a cyber adversary with varying motives. The logical plane impacts the generation, transmission, distribution, metering, third party markets and integrated customer equipment (including DER). Therefore, compromise allows an adversary new ways to commit traditional crime such as theft of service, as well as opportunities for new modes of malfeasance. Some example threats from deliberate attacks include:

- Improper remote access to critical equipment. The attacker may cause a malfunction of the equipment, or demonstrate access to the asset owner and then extort payment under threat of causing a malfunction.
- Inserting false information, possibly at different points, so that the smart grid mechanisms are used to attack the grid itself. The impact can range from needless automated response such as load shedding to more serious and large-scale instability.
- Fraud or dangerous trading practices by third-party power wholesalers.
- False provision of DER: If an attacker can deceive a meter and falsely claim to have provided power to the grid.
- Improper remote disconnect. On a sufficient scale, this can lead to instability.
- Theft of service: For example, if an attacker can deceive the meter as to the amount of power used or the time of use.

### *Interfaces to be Secured*

Key interfaces between the logical and power plane, in approximate order of wide area to home, include:

- Large, distributed, high-speed monitoring initiatives such as NASPI enable wide-area monitoring of grid state and distributed state estimation.

- Utility-to-utility interfaces permit efficient trading of power, while maintaining grid stability as well as business confidentiality.
- Interfaces must support appropriate data sharing with ISOs, regulators, and commissions, at varying time resolutions and level of aggregation.
- Distributed autonomous optimization systems support microgrids, zero-net communities and buildings, and micro-islanding, while maintaining stability of grid operation as a whole.
- Interfaces to systems providing near real-time weather information enable grid planning of such functions as spinning reserve and reactive power to accommodate intermittent renewables such as wind and solar.
- Secure interfaces connect distributed generation, storage, and PEV.
- Other third party businesses interface to distribution and possibly AMI to support power wholesale functions.
- Increasingly sophisticated pole-top equipment will interface to distribution over routable networks, and support remote monitoring via hand held devices.
- Third party businesses interface to home area networks to provide home energy management services.
- Bidirectional meters support small-scale distributed energy resources, including renewables.
- AMI networks interface to distribution SCADA/EMS, communicate prices, and support outage detection, remote reading, and remote disconnect.
- Home area networks manage power use in response to price signals, received at the AMI/HAN interface.
- Smart appliances interface to a home energy management portal and modify their use according to price signals.

It is apparent that the smart grid integrated communication and control vision is not "connect everything to everything" but rather to identify interfaces and protocols for what information is exchanged across the interface and with whom, and then implement mechanisms to ensure that these protocols and information exchanges are supported, and nothing more.

A major concern in securing the smart grid is how to assess and manage the security of a heterogeneous system of a very large number of components under diverse administrative control with various levels of security. This issue, termed security composability, addresses the challenge that it is possible to connect two systems, both of which are judged to be secure, such that the composite system is not secure.

It is also essential that smart grid security procedures and technologies are implemented to reflect actual risk assessments, are balanced to ensure the cost of the security measures closely match the cost of the possible impacts of a security breach, and are adequately adaptable to avoid possibly increasing security risks. Defining and securing interfaces is just one step of the requirement for end-to-end security.

The effectiveness and benefits of the smart grid strongly depend on customer acceptance and participation. As such, cyber security of smart grid components must:

- Safeguard customer privacy.
- Provide auditable mechanisms that relate billing to usage and generally ensure that data sent is properly received by authorized entities and only by those entities.
- Interoperate in a community of heterogeneous devices under diverse administrative control in such a way that grid stability is maintained, even in the face of cyber attack.

*Assumptions*

Technology will continue to advance, and it is a reasonable assumption that the technological evolution of the logical plane will be more rapid than the more capital-intensive equipment that makes up the power plane. Intelligent devices from appliances to generation and transmission equipment will probably undergo numerous firmware upgrades as well as several swap-outs of logical and communication hardware components over their service life, in order to make the smart grid "future proof." As an example, a device class that currently is too limited computationally to support strong crypto may be upgradable as embedded processors for the device class become more powerful, but this upgrade must be planned in the design.

The increased complexity of the smart grid will be a security risk in itself. Therefore, not only must the logical plane be used to monitor and analyze the health of the power plane, but security components within the logical plane must monitor and analyze the health of the logical plane itself.

Adversary capabilities will continue to increase. In general, every enumerated interface for smart grid provides at least a potential attack surface.

The smart grid will allow new methods for traditional adversary actions such as theft of service. A considerable fraction of the new intelligent smart grid logical plane components, such as smart meters, are outside of a utility's physical security perimeter. It is essential that these devices be fenced as much as possible in the logical security perimeter.

The smart grid may enable new adversary capabilities, if the adversary can compromise the control functions of the logical plane. In this case, widespread disruption is possible, at least in principle. An adversary may threaten this, and even demonstrate it on a small scale, in order to extort money from utilities.

The attacker may not even need to compromise many logical assets in order to do harm. For example, if a malicious wholesaler provides inconsistent price and usage information across various interfaces, can they bring about a destabilizing imbalance of supply and demand? Can "program trading" bring about an unstable condition, even in the absence of malicious intent?

The "flash crash" of May 6, 2010 in financial markets may have been due at least in part to computerized high-frequency trading, even if there is no evidence of malice at present (BusinessWeek, May 10).

Increased computational power may make a direct attack on crypto more feasible, but these are likely to remain difficult, particularly if crypto is strengthened as part of logical plane upgrades discussed above.

### *Enablers*

There is considerable activity promoting smart grid security, and much of this is synergistic with the CEC smart grid mission. Members of the EPRI project team are active in one or more of these initiatives. Of particular importance are EPRI/DOE initiatives such as the Advanced Security Acceleration Program for Smart Grid (ASAP-SG), the DOE cyber security roadmap, NIST CSWG, the IEC TC57 WG15, and activities of groups such as the Open SG Users Group.

The NERC Critical Infrastructure Protection Standards (CIPS) provide a set of guidelines for such security concerns as identification of critical cyber assets, definition of an electronic security perimeter, and security management. Requirement 1 of CIP-002-3 calls for cyber risk management for any cyber asset that supports a critical grid asset capable of shedding 300MW or more of load. Definition of critical assets and establishment of a perimeter will be a challenge in the case of distributed assets, such as AMI (for example, is an AMI access point potentially defined as a grid asset capable of shedding 300MW of load).

Communication standards that are based on information models such as IEC 61850 and CIM are well-suited to smart grid goals Their powerful capabilities will enable interoperable and secure interactions far better than the older, simpler protocols.

Strong price and transaction integrity enables secure smart grid operation at all interfaces. In the case of AMI and DER, logical and physical interfaces may correspond exactly (a smart, bidirectional meter), so the challenge is to provide a trusted, verifiable, and auditable mechanism to tell how much power crossed the interface when and at what price. Wholesale markets require an accurate, but aggregate view of demand for a number of consumers, presented in a way that is transparent, yet does not compromise the privacy of any consumer.

Role-based access control defines limits the access of an entity (human or device, under utility or external administrative control) to those capabilities required for the entity to perform its role, as determined by policy. The smart grid requires better tools for formal policy definition and mapping the policy to implementation.

Intrusion detection/prevention is increasingly deployed in SCADA, and log management is increasingly assuming a security information event management functionality. Security monitoring will be part of the overall grid self-awareness framework.

Key management for a very large number of devices with limited computational power may be a challenge if, for example, key revocation is required. The smart grid community should carefully monitor advances in elliptic curve and identity-based methods. Key management is a key enabler for transaction integrity, and requirements are being addressed by NIST and IEC. For power equipment, confidentiality is not always a concern, but key management may be required to support authentication.

PEV will require a number of enabling technologies, including key management and transaction integrity but with the added challenge of mobility.

Hardware mechanisms will be needed for many smart grid components, especially for devices outside of physical security perimeters, such as smart meters.

Beyond secure mechanisms to share price, usage, diagnostic, and other information needed for smart grid operation, there is a need for secure, real-time sharing of the security information itself. This enables identification of sector-wide emerging threats, attack containment, response, and future mitigation.

**Table 5: Technology-Ready Roadmap for Cyber Security**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(2010-2015) | Domain-specific security mechanisms<br><br>• Manage secure migration from proprietary protocols to mainstream Internet protocols<br>• Systems for Intrusion Detection & Prevention (IDS/IPS)<br>• Solutions to secure mixed legacy/modern systems | • Cyber security solutions are increasingly adopted in generation and T&D<br>• Utilities are compliant with standards such as CIPS | • National Security - through improved defenses against cyber-threats | • Activities such as ASAP, NIST CSWG, Open SG<br>• Consistent policies for security, management<br>• Limited intrusion protection in routers<br>• Role-Based Access Control (RBAC)<br>• Elemental Key Management<br>• Standards such as IEC 62351 |
| | Advanced meter deployments<br><br>• Secure AMI communications<br>• Transaction Integrity<br>• Security that is usable by customers | • Utilities can read meters remotely and communicate price signals to customers<br>• Bi-directional capability allows supplying power to the grid<br>• Demand management and response<br>• Utility operational improvements through outage detection and remote disconnect | • National Security - through improved defenses against cyber-threats | • Encryption advances<br>• AMI security requirements are clarified<br>• Role-Based Access Control |
| | Third party services for home-energy management<br><br>• Secure HAN standards<br>• Secure communications between third parties and utilities as well as customers | • Customers find it economically advantageous to outsource home energy management<br>• Customer-side demand response is simplified and unified | • National Security - through improved defenses against cyber-threats | |
| | DER integration<br><br>• Secure bidirectional monitoring and control<br>• Transaction Integrity<br>• Security standards with object models for DER | • DER increasingly integrated with secure interconnections.<br>• The grid integrates DER in a manner that the grid is not adversely impacted by errors on the part of DER providers or malicious attack at the GRID/DER interface | • National Security - through improved defenses against cyber-threats | |
| **Medium**(2015-2020) | Converged security | • Formerly domain-specific security mechanisms evolve into a unified security framework<br>• Utilities are able to assess and exchange security information | • National Security - through improved defenses against cyber-threats | • Maturing encryption Key Management<br>• Intrusion detection/prevention for end-use equipment<br>• Advances in IDS/IPS<br>• Log management includes security information event management |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| | Basic grid self-awareness (including security awareness) | • Grid automation and self-sensing provide situational awareness to stakeholders<br>• Stakeholders awareness for human and limited automated response to dynamically changing conditions | • National Security - Through improved defenses against cyber-threats | • NASPI and supporting analytical models<br>• Distributed state estimation<br>• Integrity of information exchanged |
| | DER integration | • Independent DER resources provide power to the grid<br>• Utilities meet goals for renewable | • National Security - through improved defenses against cyber-threats | • Secure interfaces to third-party storage and DER<br>• RBAC to restrict allowing third party DER systems too much access |
| | PEV support infrastructure | • PEV can optionally supply power to the grid ("mobile storage")<br>• GHG and imported fuel impact is reduced in the transportation sector | • National Security - through improved defenses against cyber-threats | • Device-level Role-Based Access Control<br>• Transaction integrity |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Long**(2020+) | Advanced grid self-awareness | • The grid has a distributed, near real time awareness of its state with respect to load, reserves, reliability, and stability, prices, as well as security<br>• Stakeholders are able to optimize locally while maintaining global stability | • National Security - through improved defenses against cyber-threats | • NASPI and supporting analytical models<br>• Distributed state estimation<br>• Integrity of information exchanged<br>• "Fully Smart" Security<br>• Full Key Management |
| | Energy marketplace | • Markets function fairly and efficiently from an economic standpoint while grid operation is assured<br>• Secure, tailored information exchange between utilities, third party markets, and consumers supports a broad range of energy market functions | • National Security - through improved defenses against cyber-threats | • Price and transaction integrity<br>• Role-Based Access Control |
| | Seamless response to adverse events | • The grid automatically reconfigures so as to maintain maximum operational function<br>• Abnormal conditions are detected before they lead to outages<br>• Impact from inadvertent events, mis-configurations, and malicious attack is isolated, mitigated, and prevented | • National Security - through improved defenses against cyber-threats | • Securely connected ubiquitous sensor framework<br>• Secure, reliable micro-islanding<br>• Logical islanding |
| | Secure advanced DER and PEV infrastructure | • DER and PEV are used to support distribution efficiency and emergency situations<br>• Distribution operations are very efficient and very reliable through interactive demand response with DER and PEV | • National Security - through improved defenses against cyber-threats | • Communication protocols have necessary security to interact between power system operations and customer sites |

# Domain 2: Customer Systems

## 2010 Baseline Summary

Advanced Metering Infrastructure (AMI) is being deployed to provide a platform for the next generation of demand-side management applications in California. Dynamic pricing implementations are ramping up to leverage smart meters and home area network (HAN) infrastructure in the future. Limited-scale HAN deployments are taking place to improve understanding of the technical challenges and consumer impacts of HAN technologies. All utilities are actively engaged in shaping industry standards. Other activities include opportunistic exploration into the integration of energy storage, plug-in electric vehicles, and other distributed energy resources.

## 2020 Vision

The smart grid enables customers to actively support the reliable, sustainable, economic delivery of power by providing feedback to help customers manage the timing and quantity of their energy usage; enabling third-parties, including utilities, to manage energy usage on behalf of customers; and allowing customers to adopt environmentally-friendly technologies (e.g., PEVs, solar PV) without sacrificing grid reliability.

## Benefits

The Customer Systems domain of the smart grid will result in tangible utility technical efficiency improvements, energy (kWh) and power demand (kW) reductions, maintained or enhanced service reliability, safety, environmental improvement, energy independence/ national security and sustainable economic prosperity.

The introduction of customer energy management systems in residential, commercial and industrial sectors will stimulate local economies leading to job creation in manufacturing, retail and services as these systems are built, installed and maintained. A reliable electric charging mechanism in the customer premises will accelerate the adoption of electric vehicles leading to more energy independence and national security. Finally, demand response (DR) programs will reduce peak demand that will lead to lower cost of electricity to rate payers and greater sustainable economic prosperity.

## Smart Grid Uses Within Customer Systems

- Demand Response
- Customer Energy Management
- Electric Transportation Integration

### *Demand Response*

DR involves the active management of customer loads on a day-to-day basis to balance electricity supply and demand. The stages of DR readiness include:

- Reliability-based demand response
- Day-ahead energy market integration
- Day-of energy market integration

- Distribution management system integration
- Ancillary service market integration
- Renewable integration
- Challenge: Large number of loads that can be potentially harnessed, each at varying levels of availability, flexibility, responsiveness, and cost

By Year 2020, DR is envisioned to play a major role in minimizing the need to build costly new energy delivery capacity, even as California incorporates increasing levels of renewable generation and other disruptive technologies such as plug-in electric vehicles. DR will occur through (non-dispatchable) real-time pricing signals, as well as through event-based programs that are triggered by wholesale market prices or emergency situations. The various DR programs will be optimized for operational value and targeted at specific customer segments that are most able to respond. Communication and load management technologies will be fit-for-purpose, thereby helping to maximize DR cost-effectiveness.

**Table 6: Technology-Ready Roadmap for Demand Response**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Now**(2010) | **Reliability-Based Demand Response:** DR events triggered based on emergencies and other critical conditions (e.g., hottest summer days)<br><br>Large commercial and industrial customers provide automated response (e.g., with EMS)<br><br>Direct load control programs for basic customer loads (e.g., residential HVAC) | Reliability-Based Demand Response to Reduce Peak Demand, Reduce GHG Emissions, Defer Capital Expansion, and Provide for Emergency Support | • Utility Technical Efficiency<br>• kWhs and kWs reductions | • Equipment retrofits with communications capability<br>• Retrofits with remote control capability<br>• Customer awareness and engagement |
| **Short**(2011-2015) | **Day-Ahead Energy Market Integration:** DR events triggered based on day-ahead wholesale market prices<br><br>Real-time pricing tied to day-ahead wholesale market prices (large customers only)<br><br>Residential EMS and smart appliances provide automated response to pricing and event signals<br><br>Direct load control programs expand to other customer loads (e.g., PEVs, commercial lighting) | Day-Ahead Energy Market Integration to Reduce Peak Demand, Reduce GHG Emissions, and Defer Capital Expansion | • Utility Technical Efficiency<br>• kWhs and kWs reductions | • Home Area Network implementation<br>• Tariff approval for dynamic/day-ahead energy pricing<br>• Customer adoption and program participation<br>• Smart end-use devices and residential EMS |
| | **Day-Of Energy Market Integration:** DR events triggered based on day-of wholesale market prices<br><br>Real-time pricing tied to day-of wholesale market prices (large customers only) | Day-Of Energy Market Integration to Reduce Peak Demand, Reduce GHG Emissions, and Defer Capital Expansion | • Utility Technical Efficiency<br>• kWhs and kWs reductions | • Tariff approval for dynamic/day-of energy pricing<br>• Customer adoption and program participation |
| **Medium**(2016-2019) | **Distribution Management System Integration:** DR programs triggered to reduce facility loading and extend asset life (e.g., PEV charging to avoid transformer overloads) | Distribution Management System Integration to Reduce Peak Demand, Reduce GHG Emissions, Meet Customer Need, Enhance Service Innovation, Reduce Losses, Reduce Facility Loading, and Improve Voltage Regulation | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• Safety<br>• Service Reliability | • Utility DMS implementation<br>• Localized event triggers (vs. system-level triggers)<br>• Smart end-use devices with two-way communications<br>• Tariff approval for demand-based rates and pricing (e.g., demand subscription)<br>• Configurable demand limit (e.g., PEV charging with remote configuration capability) |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Medium**(2016-2019) | **Ancillary Service Market Integration:** DR resources providing spinning and non-spinning reserves to support grid operations<br><br>Participating load across customer classes (for revenue)<br><br>Self-supply of reserves thru DR (for avoided cost) | Ancillary Service Market Integration to reduce peak demand, reduce GHG emissions, meet customer need, enhance service innovation, and provide for emergency support/ancillary service | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• Service Reliability (customer choice) | • Automation capability for all customer classes<br>• Smart end-use devices with integrated communications & controls<br>• Cost justification for telemetry or relaxed ISO telemetry requirements<br>• Cost allocation method for avoided costs from self-supply of reserves<br>• Value proposition |
| **Long**(2020-2050) | **Renewable Integration:**<br><br>DR resources balancing intermittent supply by providing regulation and other fast-response services | Renewable Integration to reduce peak demand, reduce GHG emissions, meet customer need, enhance service innovation, provide for emergency support/ancillary service, meet RPS, and for system protection and restoration | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• Environmental Improvement<br>• National Security<br>• Sustainable Economic Prosperity | • High Sampling Rate Wide Area Monitoring<br>• Utility DMS implementation<br>• Smart end-use devices with integrated communications and rapid automated control<br>• Value proposition |

*Customer Energy Management*

- Value-added web tools to help customers understand their energy usage on a day-after and historical basis (e.g., trend analysis, benchmarking).
- Near real-time view of energy usage and marginal retail price of energy (via HAN).
- Authorized third-parties have access to customer data in machine-readable format and can help customers manage their energy usage.
- Customers have the ability to obtain and install devices that automatically trade-off energy cost, comfort, and environmental impact based on user preferences; devices also provide remote control capabilities (via Web).
- Residential applications to primarily target HVAC, EV charging, household appliances, and other large loads.
- Commercial applications to also include lighting, refrigeration, and other unique loads.
- Advanced automation, control, and optimization applications to further help educate customers and manage their energy usage.
- Energy management applications to include distributed generation and storage, facilitating zero-net energy residential and commercial construction.
- Zero net energy residential and commercial built environment construction.
- Micro-transactions and markets.
- Community supply source optimization.

**Table 7: Technology-Ready Roadmap for Customer Energy Management**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(2011-2015) | **Customer Situation Awareness:**<br>Value-added web tools to help customers understand their energy usage on a day-after and historical basis (e.g., trend analysis, benchmarking)<br>Near real-time view of energy usage and marginal retail price of energy (via HAN)<br>Authorized third-parties have access to customer data in machine-readable format (ONLY with explicit customer permission) and can help customers manage their energy usage | Customer Situation Awareness to Meet Customer Need, Enhance Service Innovation, Reduce GHG Emissions, Reduce Peak Demand, and Defer Capital Expansion | • kWh and kW reductions<br>• Utility Technical Efficiency<br>• Environmental improvements | • Home area network implementation<br>• Standards development<br>• Customer privacy issues addressed<br>• Customer awareness and engagement |
| | **Energy Usage Automation:**<br>Customers have the ability to obtain and install first generation devices that automatically trade-off energy cost, comfort, and environmental impact based on user preferences; devices also provide remote control capabilities (via Web)<br>Residential applications to primarily target HVAC, EV charging, household appliances, and other large loads<br>Commercial applications to also include lighting, refrigeration, and other unique loads | Energy Usage Automation to Meet Customer Need, Enhance Service Innovation, Reduce GHG Emissions, Reduce Peak Demand, and Defer Capital Expansion | • kWh and kW reductions<br>• Utility Technical Efficiency<br>• Environmental improvements | • Standards development<br>• Tariffs and incentives in place<br>• Proven reliability and robustness of HAN<br>• Customer awareness and engagement |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Medium**(2016-2019) | **Customer energy optimization:**<br>Advanced automation, control, and optimization applications to further help educate customers and manage their energy usage<br>Energy management applications expanded to include distributed generation and storage, facilitating zero-net energy residential and commercial constructions | Customer energy optimization Meet Customer Need, Enhance Service Innovation, Reduce GHG Emissions, Reduce Peak Demand, and Defer Capital Expansion | • kWh and kW reductions<br>• Utility Technical Efficiency<br>• Environmental improvements | • Standards development<br>• Tariffs and incentives in place<br>• Proven reliability and robustness of HAN<br>• Customer awareness and engagement<br>• Distributed Generation and Energy storage commercially viable, and available at price points that make sense for consumers |
| **Long**(2020-2050) | **Energy Smart Communities:**<br>Zero net energy residential and commercial constructions<br>Micro-transactions and markets<br>Community supply source optimization | Energy Smart Communities for reducing Losses, reducing GHG Emissions, providing for Microgrid Operation, reducing Peak Demand, and deferring Capital Expansion | • kWh and kW reductions<br>• Environmental Improvements | • Energy Storage<br>• Proven reliability and robustness of HAN and Energy Storage Technologies<br>• Implementation of a 2-way Energy Flow and 2-way Communication Network (i.e. smart grid) |

*Electric Transportation Integration*

- The integration of electric transportation into the smart grid will depend on the rate of PEV proliferation, consumer charging behavior, technology, standards development, and the deployment of advanced vehicle customer programs.
- In the short term (2010 – 2015) California utilities will be mainly concerned with deploying basic smart charging programs including rates that require discrete measurement such as Time-Of-Use and simple demand side management techniques such as PEV demand response.
- Basic smart charging programs will enable utilities to offer their PEV customers with cost saving "grid friendly" methods of charging their vehicles, while still meeting possible regulatory requirements.
- In the long term (2020+) with expected high level of PEV penetration, utilities may have an opportunity to use PEVs for advanced smart charging techniques such as energy storage or vehicle to grid (V2G), which can ultimately support the integration of increased renewable resources into the grid.
- By Year 2030, the California smart grid will allow for the timely incorporation, monitoring, and control of renewables and PEVs in a user-friendly manner. Utilities will have the devices and communication systems in place to determine the actual state of operations and to manage economic operation of renewables, PEVs, and storage.

**Table 8: Technology-Ready Roadmap for Electric Transportation Integration (Plug-in Electric Vehicles and Electric Rail)**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short** (2011-2015) | **Smart Charging for Electric Vehicles:**<br><br>Off-Peak Charging<br><br>Demand Response and Load Control<br><br>Critical Peak Pricing/Dynamic Pricing | Smart Charging to leverage RPS for low carbon transportation<br><br>Meeting customer need, enhance service innovation, reduce peak demand, reduce GHG emissions, defer capital expansion, and reduce facility loading | • Utility Technical Efficiency<br>• Environmental improvements<br>• Sustainable economic prosperity<br>• Service Reliability | • Bidirectional Communications (Grid<-->Vehicle)<br>• Standards Development<br>• Vehicle Manufacturer Implementation of standards based communications in vehicles<br>• 2-way electric flow and 2-way communication network grid implementation<br>• Integration with grid operations<br>• Smart Electric Vehicle Supply Equipment (EVSE)<br>• Customer awareness, education, and adoption.<br>• Regulatory clarity on pricing |
| **Medium**(2016-2019) | **Vehicle to Home:**Standby PowerRooftop solar integration Household load shifting<br><br>**High-speed Passenger Rail:**<br>Switcher Locomotives<br>Short-haul Freight Locomotives | V2H to meet customer need, enhance service innovation, reduce peak demand, reduce GHG, defer capital expansion, reduce facility loading, and provide for microgrid operation<br><br>High-speed Passenger Rail to reduce GHG emissions and meet customer need | • Utility Technical Efficiency<br>• kWh and kW reduction<br>• Energy independence/National security<br>• Environmental improvement<br>• Sustainable Economic Prosperity | • Bidirectional Power Transfer on-board the vehicle<br>• Proven Value Proposition<br>• Standards development<br>• Battery warranty provisions<br>• Technical grid issues resolved (e.g., safety for first responders)<br>• Infrastructure cost justification<br>• Policy (e.g., rights of way) |
| **Long** (2020-2050) | **Vehicle to Grid:**<br><br>Voltage and Frequency Regulation | V2G for emergency support/ancillary service, improve voltage regulation, reduce peak demand, provide for microgrid operation, defer capital expansion, and reduce GHG | • Utility Technical Efficiency<br>• kWh and kW reduction<br>• Service reliability<br>• Sustainable economic prosperity | • Bidirectional Power Transfer on-board the vehicle<br>• Smart grid communication capability<br>• Integration with grid operations<br>• Proven Value Proposition<br>• Battery warranty provisions |
| | **Renewable Integration:**<br><br>Creating more demand wind and solar generation for powering low carbon electric transportation<br><br>**Cross-country Freight Locomotives:**<br><br>long-haul freight transport | Renewable Integration to meet Renewables Portfolio Standards and enhance service innovation<br><br>Cross-country Freight Locomotives to reduce GHG emissions and meet customer needs | • Utility Technical Efficiency<br>• Environmental improvements<br>• Service reliability<br>• Sustainable Economic Prosperity | • Sufficiently high available installed base of PEVs<br>• Smart grid integration with vehicle or EVSE<br>• Proven Value Proposition<br>• Mature standards<br>• Upstream integration with bulk Generation<br>• Infrastructure cost justification<br>• Policy (e.g., rights of way) |

## Domain 3: Grid Operations and Control

### 2010 Baseline Summary

In 2010, projects in the area of Grid Operations and Control are being developed and deployed by the California investor-owned utilities on a case-by-case basis. All of the IOUs are heading toward similar goals in this area, but they are presently at different stages in the journey.

Some of these projects are geared towards distribution automation, fault location and distribution management systems. Others are aimed at accommodating all new generation and storage options, including wind and solar generation. Others are targeted at providing reliable electric service that is relatively interruption-free for customers (i.e., service reliability) and self-healing grid. Finally, some are targeting the monitoring and control of the transmission grid.

Although this domain has a large number of projects, they can be grouped into the following major categories:

- Wide area situational awareness
- Synchrophasor applications
- Outage management systems
- Distribution management system
- Renewables and PEV monitoring & control
- Volt/Var optimization
- Advanced energy management systems
- Remedial action schemes
- Substation and distribution automation
- Microgrid

### 2020 Vision

By 2020, the California transmission grid will be well on its way to being fully monitored in real-time with an integrated set of advanced sensors and monitoring devices and robust communication systems. It will have adaptable and trainable, fast control algorithms that will utilize advanced technologies to enhance or maintain system security and reliability and to maximize transmission throughput to enable high penetrations of renewable resources.

By 2020 the California transmission grid is envisioned to: ensure power quality and reliability are maintained and/or enhanced, achieve better efficiency, allow the expanded use of renewable energy sources, and improve system planning and engineering processes for future grid development. It aspires to achieve characteristics of a "self-healing" power grid by anticipating and responding to system disturbances and risks to physical infrastructure due to natural disasters, vandalism or cyber attack.

By 2020, California utilities will reach high levels of distribution automation and will have the devices and communication systems in place for more ideal operation and better protection. Achieving self -healing grids will be also easier.

By Year 2020, the California electric grid development will allow for the timely incorporation, monitoring, and control of renewables, PEV and energy storage.

## Benefits

- National Security/Energy Independence
- Utility Technical Efficiency
- Power Quality
- Reliability
- Environmental Improvements

The Grid Operations and Control domain of the smart grid will result in maintained or improved reliability, shorter outages, increased efficiency, high levels of security, timely incorporation of renewable energy and potential customer energy/cost savings.

Since Grid Operations and Control will be an enabler for more renewable integration in California, uses under this domain will help drive the formation and growth of "cleantech" supplier companies and enhance the competitiveness of the state, potentially lowering costs compared to not improving smart grid operations. The combination of lower costs and maintained or improved reliability will raise satisfaction among all types of customers (residential, commercial, industrial, institutional). Maintaining and/or improving reliability will help retain important California companies and jobs.

## Smart Grid Uses Under Grid Operations and Control

- Wide Area Situational Awareness & Control
- Distribution System Management
- Supporting Electric Transportation, DER, Renewable Integration (all types) and Energy Storage

### *Wide Area Situational Awareness and Control*

- Wide-Area Situational Awareness (WASA) refers to the smart grid's ability to monitor the power system across wide geographic areas
- WASA includes:
    - Monitoring the state of various power system components
    - Managing and controlling the power system components for a specific application (e.g., voltage profile control)
- Challenge: Large number of complex components

## Table 9: Technology-Ready Roadmap for Wide Area Situational Awareness and Control

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(Now to 2014) | Cross utility, regional area Phasor Measurement Units (PMU) data integration to provide the state of power system components | Provide wide-area timely perspectives necessary to maintain grid situational awareness which can contribute to:<br>- Adding more renewables and meeting RPS Standards<br>- Meeting Customer Need<br>- Deferral of Capital Expansion<br>- Reduce Facility Loading<br>- System Protection and Restoration<br>- Improving Voltage Regulation<br>- Providing Emergency Support/Ancillary Service | • Service Reliability<br>• Power Quality<br>• National Security | • Accurate 3-phase measurements and tight time synchronization maintained to IEEE 1588 Standards or better<br>• Open Standards Development<br>• OEM Implementation of smart grid technologies<br>• Wide area communications must have proven reliability, security and robustness and meet latency and real-time applications requirements<br>• Robust 2-way Communications<br>• Fast contingency analysis tools to identify and prioritize events<br>• Fast Dynamic Stability Assessment (DSA) and Voltage Stability Assessment (VSA) tools<br>• Tools to exploit the capabilities of existing assets under emergencies<br>• Good weather data availability |
| | PMUs to predict potential problems on the grid | Provide “precursor signals” before an irreversible system collapse and hence avoid huge economic losses. In addition contribute towards:<br>- Facilitating larger use of renewables<br>- Reducing Harmonics and other PQ issues<br>- Enhancing System Protection and Restoration<br>- Improving Voltage Regulation | • Utility Technical Efficiency<br>• Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | |
| | Integrated grid monitoring system (e.g., SCADA/EMS with PMU) to exploit the capability of existing assets during emergencies | Enable less constrained operation of facilities and timely mitigation action to avoid dangerous system insecurity conditions contributing towards:<br>- Meeting Renewables Portfolio Standards<br>- Deferral of Capital Expansion<br>- Providing Emergency Support/Ancillary Service<br>- Reducing Facility Loading<br>- Enhancing System Protection and Restoration<br>- Improving Voltage Regulation | • Utility Technical Efficiency<br>• Environmental Improvements<br>• Power Quality<br>• Service Reliability<br>• National Security | |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Medium**(2018) | PMU data used in tools and applications to enhance system stability for Inter-Area Oscillation prediction and damping schemes | Allow maximum transfers on the grid through enhancing the stability. Contributing towards:<br>- Deferral of Capital Expansion for reinforcements<br>- Providing Emergency Support<br>- Providing Ancillary services<br>- Reduce Facility Loading<br>- Supporting System Protection and Restoration<br>- Improving Voltage Regulation<br>- Reducing Harmonics and other PQ issues | • Utility Technical Efficiency<br>• Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | • Proven reliability and robustness of PMUs<br>• Low error-rate 2-way communications<br>  • Low latency<br>  • High Availability<br>  • High security<br>• Advanced Optimum Power Flow (OPF) tools which will be integrated with the state estimator (including appropriate PMU data when available)<br>• FACTS devices and capacitors for voltage and VAR support and control, integrated with state-wide communications and synchrophasor systems<br>• Remote feedback controllers must have valid secure communications from the remote sites; the controlled generator must be up and running with validation of status |
| | PMU data used for volt/var and watt control, voltage security<br>- Tools to eliminate voltage violations<br>- Tools to provide reactive power support and voltage security<br>- Increased use of FACTS devices triggered by PMU data analysis | Improve voltage regulation, enhances voltage stability and defers capital expansion. Contributing towards:<br>- Reducing Peak Demand<br>- Reducing Losses<br>- Improving Voltage Regulation<br>- Meeting Customer Need<br>- Deferral of Capital Expansion<br>- Providing Emergency Support<br>- Providing Ancillary services<br>- Reducing GHG Emission due to reductions in peak demand and losses | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• National Security<br>• Sustainable Economic Prosperity | |
| | PMU applications in wide area Special Protection and remedial Action Systems (arming and/or triggering) | Enhancement of existing or new special protection systems which will contribute towards:<br>- Better Grid Protection and Restoration<br>- Serving Isolated Remote Load<br>- Provide Emergency Support<br>- Provide Ancillary services<br>- Reducing Facility Loading<br>- Improving Voltage Regulation<br>- Reducing interruptions and other PQ issues | • Safety<br>• Improvements<br>• Power Quality<br>• Service Reliability<br>• National Security | |
| | - Tools to identify potential risks to the California grid when integrating all time stamped data from MPUs, DFRs, and other sources | Provide a coherent wide-area situational awareness which will contribute towards:<br>- Supporting System Protection and Restoration<br>- Improving Voltage Regulation<br>- Reducing Harmonics and other PQ issues | • Service Reliability<br>• Power Quality<br>• National Security | |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Long** (2020) | PMUs used to enable self-healing grid<br>- Tools to prevent wide-area cascading and blackouts<br>- Tools for fast recovery from an emergency state and partial or total system collapse | Increase the system resiliency and minimizes restoration time for major disturbances, natural disasters and terrorist attacks. Contributing towards:<br>- Meeting Customer Need<br>- Serve Isolated Remote Load<br>- Providing Emergency Support<br>- Providing Ancillary Service<br>- Support for Microgrid Operation<br>- Supporting System Protection and Restoration<br>- Improving Voltage Regulation<br>- Reducing Harmonics and other PQ issues | • Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | • Self-healing capabilities are enabled by proven fast-computing applications (to real-time model, calculate, prioritize, and control) consistent with operational parameters, trainable centralized logic and distributed controllers and empowered robust wide area communications<br>• Remote Feedback Controller with valid secure communications at remote sites, and controlled generator running with validation of status |

*Distribution Line and System Management*

- Distribution line management refers to the smart grid's ability to monitor, manage and control the distribution lines for specific applications.
- Distribution systems have lagged behind transmission systems in the advent of supervisory control.
- Automated switching in distribution systems has the promise of not only enabling the operator to change the topology of the network, but also reducing demand on field crews.
- Distribution line and system management will require area-wide solutions and visualization with centralized modeling. This area will give way to true reactive, software-driven intelligence with central or distributed control.

**Table 10: Technology-Ready Roadmap for Distribution Systems Management**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(Now to 2014) | Distribution system monitoring and control<br>- distribution SCADA<br>- DMS | Distribution monitoring and control that will contribute towards:<br>- Meeting Renewables Portfolio Standards<br>- Reducing GHG Emission<br>- Meeting Customer Need<br>- Reducing Facility Loading<br>- Enhancing System Awareness<br>- Supporting Better Protection and Restoration<br>- Deferral of capital | • Power Quality<br>• Service Reliability<br>• National Security | • Basic distribution systems modernization<br>• In general, distribution systems management will need standards development and OEM smart grid technology implementation<br>• Availability of tools for information gathering, modeling, decision-making, and controlling actions<br>• Standards Development<br>• OEM Implementation of smart grid Technologies |
| | Tools for distribution systems automation including sensors and corresponding applications across the distribution system that monitor the system and provide data to enable applications leveraging existing communications infrastructure (AMI, cellular networks) | Substation automation features that contributes towards:<br>- Meeting RPS<br>- Reducing GHG Emissions<br>- Meeting Customer Need<br>- Reducing Peak Demand<br>- Reducing Losses<br>- Deferring of capital expansion<br>- Serving Isolated Remote Load<br>- Providing Emergency Support/Ancillary Service<br>- Reducing Facility Loading<br>- Providing for Microgrid Operation<br>- Enhancing System Protection and Restoration<br>- Improving Voltage Regulation<br>- Reducing Harmonics and other PQ | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | • Area-wide solutions and visualization with centralized modeling. Implementations need to leverage installed infrastructure and deploy a scalable, cost-effective, approach to automation, using as much current hardware as possible<br>• Based on IEC 61850, and other standards |
| | Advanced Outage Management systems/Restoration/Self-healing<br>- Improved Outage Mgmt. from integration of SCADA, AMI and other SG data into OMS<br>- Automatic feeder and line isolation and service restoration | Provide advanced means for outage mgt that contribute towards:<br>- Meeting Customer Need Deferring of capital<br>- Providing for Microgrid Operation<br>- Supporting System Protection and Restoration<br>- Improving Voltage Regulation<br>- Reducing PQ issues | • Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | • Proven reliability and robustness of smart grid technologies<br>• Cyber security countermeasures, addressing capability to entities in the network and devices attached to it |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Medium**(2018) | Tools for enhanced distribution feeder fault location:<br>- Fast fault analysis on Distribution Networks<br>- Identification of failed component by installation of enhanced monitoring and detection equipment | Enhance speedy fault location on distribution feeders that contribute towards:<br>- Allowing more renewables hence meeting Renewables Portfolio Standards<br>- Providing Emergency Support<br>- Providing Ancillary Service<br>- Enhancing System Protection and Restoration<br>- Reducing Facility Loading<br>- Improving Voltage Regulation<br>- Reducing PQ issues Deferring of capital | • Utility Technical Efficiency<br>• Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | • Low error-rate 2-way communication channel<br>o Low latency<br>o High Availability<br>o High security<br>• Secure protocols to protect information and authenticate infrastructure components |
| | Voltage/Var Control and Demand Control for system reliability and stability<br>- Demand and energy reduction<br>- Voltage/Var optimization | Applications of Volt/Var control can contribute towards:<br>- Meeting Renewables Portfolio Standards<br>- Reducing GHG Emission<br>- Meeting Customer Need<br>- Reducing Peak Demand<br>- Reducing Losses<br>- Deferring of Capital Expansion<br>- Providing Emergency Support<br>- Providing Ancillary Service<br>- Reducing Facility Loading Operation<br>- Enhancing System Protection and Restoration | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• Service Reliability<br>• National Security | • Low error-rate communication channel, with<br>o Low latency<br>o High Availability<br>o High security<br>• Customer acceptance of demand reduction through voltage optimization<br>• Advanced real time voltage-VAR based software tools |
| **Long** (2020) | Automatic System Topology Reconfiguration:<br>- Tools to automatically reconfigure distribution system and feeders for emergencies and to achieve higher efficiencies<br>- Coordinating reconfiguration among multiple substations and feeders<br>- Full integration of DMS and Distribution Automation<br>- Tools for achieving self-healing grid | Distribution system topology and reconfiguration which can contribute towards:<br>- Meeting Renewables Portfolio Standards<br>- Reducing GHG Emission<br>- Meeting Customer Need<br>- Reducing Peak Demand<br>- Reducing Losses<br>- Serving Isolated Remote Load<br>- Deferral of Capital Expansion<br>- Providing Emergency Support<br>- Reducing Facility Loading<br>- Providing for Microgrid Operation<br>- Enhancing System Protection and Restoration | • Utility Technical Efficiency<br>• Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | • A set of computing applications is needed for information gathering, modeling, decision-making, and controlling actions. All of these applications and system components can then operate in a coordinated manner and adapt to the actual situations |

### *Supporting PEV, Renewables, and Energy Storage Integration*

- Support of PEV, Renewables and Storage refers to the smart grid's ability to monitor and control these technologies that are attached to the transmission and distribution systems.
- California's Renewables Portfolio Standard of 33 percent by 2020 will create challenges on the state's transmission and distribution system.
- Beyond the familiar problems of transmission congestion created by insufficient transmission capacity, the smart grid needs to ensure that remotely located wind generation is not constrained from reaching load centers.
- Regional synchrophasors will enhance the visibility and monitoring of the grid and maintain or improve its reliability in the presence of variable-output resources including intermittent wind energy and solar resources. The grid also needs to support and use energy storage devices as (at least partial) solutions to the renewable intermittency issue.

**Table 11: Technology-Ready Roadmap for Supporting PHEV, Renewables, and Energy Storage**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(Now to 2014) | Supporting Integration of Electric Transport, DER, and Bulk Renewables<br>Monitor DER, PEV, and ES equipment, and integrate with SCADA and market systems to determine level of generation versus demand in localized areas (CAISO MRTU Nodes)<br>Computing applications for information gathering, modeling, decision-making, and controlling actions operating in a coordinated manner and adaptive to the actual situations | Enhancements to monitoring of DR, DER, PEV, and ES will enable:<br>- Meeting Renewables Portfolio Standards<br>- Reducing GHG Emission<br>- Meeting Customer Need Serving Isolated Remote Load<br>- Deferring Capital Expansion of Central Station Generation<br>- Reducing Facility Loading and losses on existing feeders<br>- Providing Emergency Support<br>- Providing Ancillary Service<br>- Supporting service innovation<br>- Providing for Microgrid Operation | • Utility Technical Efficiency<br>• Safety<br>• Power Quality<br>• Service Reliability | • Standards development<br>• Proven reliability and robustness of supporting technologies<br>• A set of computing tools for information gathering, modeling, decision-making, and controlling actions<br>• Standards Development<br>• OEM Implementation of smart grid technologies<br>• 2 way communications<br>• Cyber security |
| | Advanced protection and operation approaches that manage bi-directional power flow in distribution circuits<br>Advanced technologies on Low Voltage ride-thorough Technology (LVRT) and Anti-islanding (e.g. DER integration) | Enhancements to distribution protection system to accommodate DR, DER, PEV, and ES systems which can contribute to:<br>- Meeting Renewables Portfolio Standards<br>- Reducing GHG Emission<br>- Meeting Customer Need<br>- Serving Isolated Remote Load<br>- Supporting service innovation<br>- Deferring Capital Expansion of Central Station Generation<br>- Reducing Facility Loading on existing feeders<br>- Providing for Microgrid Operation<br>- Enhancing System Protection and Restoration<br>- Improving Voltage Regulation | • Safety<br>• Environmental Improvements<br>• Power Quality<br>• Service Reliability | |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Medium**(2018) | Advanced remote and automated control of DR, DER, PEV, and ES equipment integrated with SCADA | Advanced controls of DER, PEV, and ES which can contribute to:<br>- Meeting Renewables Portfolio Standards<br>- Reducing GHG Emission<br>- Meeting Customer Need<br>- Serving Isolated Remote Load<br>- Deferring of Capital Expansion of Central Station Generation<br>- Reducing Facility Loading on existing feeders<br>- Reducing peak demand<br>- Providing for Microgrid Operation<br>- Enhancing System Protection and Restoration<br>- Improving Voltage Regulation<br>- Balancing generation versus demand in localized areas (CAISO MRTU Nodes) | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• Safety<br>• Power Quality<br>• Service Reliability<br>• National Security | • A combination of solutions for transient mitigation, intermittency handling, advances in forecasting (especially for wind) and coordination between the renewables and storage<br>• Customer acceptance of demand reduction through voltage optimization<br>• Advanced real time voltage-VAR based software tools |
| | Voltage/Var Control and Demand Control for system reliability and stability<br>- Demand and energy reduction<br>- Voltage/Var optimization | Advanced controls of DER, PEV, and ES which can contribute to:<br>- Reducing GHG Emission<br>- Deferring of Capital Expansion of Central Station Generation<br>- Reducing Facility Loading on existing feeders<br>- Reducing peak demand<br>- Improving Voltage Regulation | • Utility Technical Efficiency<br>• kWhs and kWs reductions<br>• Environmental Improvements | |

## Domain 4: Renewable and DER Integration

### 2010 Baseline Summary

California's Renewables Portfolio Standard (RPS) is one of the most ambitious in the country. California's governor has ordered the State to increase its RPS from 20 percent to 33 percent by 2020. Achieving this target will require large increases in the number of photovoltaic, small wind and bio-gas fueled distributed energy resources (DER). To achieve this standard, system impact studies have been conducted for renewable and distributed energy resources. Along with these studies, bulk solar and wind generation projects have been evaluated and developed through the American Recovery and Reinvestment Act (ARRA), which is funding advanced grid technology and integration solutions, such as the smart inverter. Various energy storage technologies and applications are being investigated and demonstrated under pilot projects to support the integration of intermittent renewable energy resources and to provide grid support. The California Public Utilities Commission (CPUC) continues its policy development efforts to facilitate the renewable and DER integration.

Four main categories of baseline activities where the most progress is occurring include 1) solar, 2) energy storage, 3) wind and 4) renewable & DER studies.

IOUs in California have undertaken these projects to meet the state's policy targets. Such targets include:

- Renewables Portfolio Standard (RPS)
- Solar Initiative
- Greenhouse Emission Initiative
- Distributed Energy Resource initiatives
- Electric Transportation
- Energy Efficiency initiative
- State economic development goals

Meeting these policy targets is the key driver for existing utility projects. Major projects that are carried out by California utilities are shown in Appendix A.

### 2020 Vision

The 2020 vision for this domain is to utilize, integrate and develop bulk renewable and distributed energy resources (DERs) to meet the varying customer and market demands. Renewables and DERs are developed to ensure secure and reliable service, promote energy independence, achieve RPS goals, and attain sustainability. This is accomplished through the use of intelligent monitoring, climate micro-forecast, protection and control technology, storage technology, and advanced information technology and infrastructure that are integrated with the underlying power delivery systems.

### Benefits

- Reduced greenhouse gas emissions
- Improved public perception
- Meeting the RPS target
- Deferred capital investment
- National security/energy independence
- Maintained or improved reliability
- More options for managing energy
- Create a renewable/clean technology economy in California

### Smart Grid Uses Under Renewable and DER Integration

There are three main areas of smart grid uses under the Renewable & DER Integration domain:

- Bulk Renewable Integration (wind & solar)
- Bulk Energy Storage Integration
- DER Integration (PV, CHP, microturbine, distributed storage)

#### *Bulk Renewable Integration*

The vision of integrating bulk renewable generation into the utility transmission and distribution grid is cast to support public policies on reducing greenhouse gases and detrimental environmental impacts due to contributions from conventional generation resources. There are numerous issues that will need to be resolved with integrating bulk renewable generation into the existing utility transmission and distribution systems such as managing intermittent generation ramp rates, avoiding congestion and maintaining adequate system protection.

The following summarizes the roadmap for Bulk Renewable Integration including key enablers, value statements, benefits, and applications.

**Table 12: Technology-Ready Roadmap for Bulk Renewable Integration**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| Short | Ready to deliver MW-Hrs to meet 20% RPS Goals: Base Load & Peak Shaving Resources & Models to Evaluate Impacts of Integration on Grid for<br>• Wind Generation<br>• PV<br>• Biogas | Ready to deliver MW-Hrs to meet 20% RPS Goals to Meet RPS standard and Reduce GHG emissions | • Environmental Improvement<br>• National Security<br>• Sustainable Economic Prosperity | • IEEE1547 and NIST for power interconnection and inverter designs<br>• Energy storage technology development (e.g., batteries, flywheel, pumped storage, CAES)<br>• More favorable regulatory treatment (e.g., feed-in tariff) for renewable<br>• Market development of ramping products for fast regulation |
| Medium | Ready to deliver MW-Hrs to meet 25% RPS Goals: Base Load & Peak Shaving<br>• Increased deployment of Solar, Wind, PV, Biogas, and Geothermal | Ready to deliver MW-Hrs to meet 25% RPS Goals to Meet RPS standard and Reduce GHG emissions | • Environmental Improvement<br>• National Security<br>• Sustainable Economic Prosperity | • IEEE1547 and NIST for power interconnection and inverter designs<br>• Energy storage technology development (e.g., batteries, flywheel, pumped storage, CAES)<br>• Favorable regulatory treatment (e.g., feed-in tariff) for renewable<br>• Renewable generation modeling for dynamic stability assessment |
| Long | Ready to deliver MW-Hrs to meet 33% RPS Goals: Base Load & Peak Shaving<br>• Concentrated Solar | Ready to deliver MW-Hrs to meet 33% RPS Goals to Meet RPS standard and Reduce GHG emissions | • Environmental Improvement<br>• National Security<br>• Sustainable Economic Prosperity | • IEEE1547 and NIST for power interconnection and inverter designs<br>• Energy storage technology development (e.g., batteries, flywheel, pumped storage, CAES)<br>• Favorable regulatory treatment (e.g., feed-in tariff) for renewable |

### *Bulk Energy Storage Integration*

Bulk energy storage systems are sometimes designed to complement the operation of bulk renewable integration. Because of this, the Bulk Energy Storage Integration roadmap is closely related to that of Bulk Renewable Integration (see above). The roadmap outlines a variety of advances and further research of related applications, technologies, and environmental effects. Applications could include providing quick power system regulation (e.g., frequency regulation, operating reserve, and load following). Bulk energy storage systems are usually located near the bulk renewable source area, and they are not without environmental concerns.

Bulk energy storage systems (e.g. CAES, pumped hydro storage, large battery systems) to complement utility-scale intermittent renewable resources will require collaboration among the California Independent System Operation, California utilities, resource providers, and other key stakeholders.

The following table shows the roadmap and the associated key applications, value statements, benefits, and enablers.

**Table 13: Technology-Ready Roadmap for Bulk Electric Storage Integration**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| Short | Limited Energy Storage (High Power/Low Energy Density – Limited Charge/Discharge Cycles Available):<br>< 1 hour (5 min – 1 hour)<br>• Ancillary Services for generation including: frequency regulation, "smoothing" of variable output, Black start support<br>• Short term load support and outage mitigation for T&D potentially resulting in upgrade deferral<br>> 2 hour<br>• Ramp mitigation<br>• Energy/Capacity Markets<br>• Reduce Peak | Limited Energy Storage (High Power/Low Energy Density – Limited Charge/Discharge Cycles Available) to reduce GHG Emissions, reduce peak demand and provide emergency support/ancillary service | • kWhs and KWs reduction<br>• Reliability | • Regulatory (CAISO, FERC, CPUC Municipal) Rule Changes<br>  • Eligibility (i.e. Large Storage as generator)<br>  • Transmission or market parity<br>• Technology – T&D Planning, tools to include storage and combined T&D modeling<br>• Market Rules: Models Needed |
| Medium | Power Quality Improvement:<br>• Volt/Var Support<br>• PQ Support for system asset deferral (i.e. defer substation transformer replacement)<br>• Power Factor Correction<br>• Harmonic reduction (if advance inverters are used) | Power Quality Improvement leading to improved voltage regulation, reduced Harmonics & other PQ issues, and deferred capital expansion | • Power quality<br>• kWh reduction by reducing line losses<br>• Environmental Improvement | • Power Electronics advancements<br>• An understanding of storage and inverter characteristics and capabilities by distribution planners<br>• Distribution Planning Tools to include inverters and Solar PV Variability<br>• Substation Load Models improved by advances in and the use of CIM |
| | Storage used to facilitate/support Renewable Generation:<br>• Harvest Renewable Energy Credits (RECs)<br>• Smoothing and shaping | Storage used to facilitate/support Renewable Generation to meet RPS, and reduce GHG emissions | • Utility Technical Efficiency<br>• kWhs and KWs reduction<br>• Environmental improvements<br>• National Security/energy independence | • Models for energy storage at interconnection substations<br>• Intelligent Agent Software<br>• Smart Energy Management system development for home applications |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
| --- | --- | --- | --- | --- |
| Medium | Load Shifting for economic arbitrage or load leveling:<br>• Large Scale Energy Shifting (Day Ahead, Real-Time Arbitrage, Dump Energy Mitigation, etc.)<br>• Black Start<br>• Load Center Support – as a substitute for or supplement to existing in-basin generation in Southern Cal by, leveraging storage as a resource in resource-constrained area, i.e. charge at night | Load Shifting for economic arbitrage or load leveling to reduce peak demand, store off-peak production for on-peak use, levelize line loading, reduce losses | • Utility Technical Efficiency<br>• KWs reduction<br>• Environmental improvements<br>• Service reliability<br>• Sustainable economic prosperity | • Access to day ahead & real-time energy markets<br>• Standard model for storage to provide black start power for combined cycle power plant<br>• Planning models for storage in load pockets |
| Long | Grid Stabilization:<br>• High power sub-second burst for grid stabilization and therefore increased transmission capacity<br>• Replace all or part of RMR fossil fuel facilities, the existing in-basin generation in Southern California | Grid stabilization enhances service innovation and defers capital expansion | • Utility Technical Efficiency<br>• Power quality<br>• Service reliability | • R&D to prove energy burst triggered by PMU can stabilize grid oscillations |

*DER Integration*

The term DER generally describes the use and operational attributes of a technology rather than a specific technology type. DER includes resources located close to the load they serve and, therefore typically sized to match the load(s) they are paired with. DER includes distribution-side generation, energy storage and demand response technologies. DER technologies tend to supplement, rather than replace, the primary generation resources employed by California's utilities.

Widespread DER use and deployment requires significant advances in grid design and resource integration technology, including intelligent and programmable inverter (power conversion) systems and more adaptive protection and control systems. Today's electric grid was not designed with current DER technologies and RPS policy goals in mind. Therefore, a significant effort is underway across the industry and academia to address the necessary re-design of electric systems to accommodate increased uses of DER. It is also recognized that many of the renewable DER generation technologies to be deployed in support of the State's RPS goals will be variable or intermittent in nature. Depending on their capacity (size), operational characteristics, and the nature of the electric system to which they are connected, these resources will need to be paired with energy storage and control technologies. This will help better control and accommodate the ups and downs in output levels, and address some fundamental changes in utility grid operations such as bidirectional power flow on radial distribution systems.

One of the inherent positive aspects of an expanding population of DER installations is that DER use in most utility applications will be evolutionary in nature. Existing DER installations are typically small in size and widely dispersed. They are also passive in nature in that, for economic reasons, they are specifically designed and operated to shut down at the slightest disturbance of the grid. They normally operate autonomously to satisfy their owner's needs without supervision or communications from the grid. The information below provides a roadmap for integrating DER into the smart grid. The roadmap identifies the types of technologies and projects that should be pursued over the course of the next decade to make DER integration and the smart grid vision a reality.

**Table 14: Technology-Ready Roadmap for DER Integration (PV, CHP, Microturbine, Distributed Storage)**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| Short | **Customer Applications:**<br>• Backup Power | Customer Applications to meet CSI and RPS objectives, reduce GHG emission, reduce losses, and defer distribution capacity expansion | • kWh and kW reduction<br>• Service Reliability<br>• Environmental Improvement<br>• Utility Technical Efficiency | • Commercially available now<br>• Feed-in tariff<br>• Smart Energy Management System development<br>• Backup Power<br>• Receive Renewable Energy Credits (RECs) |
| Medium | **Power Quality Improvements:**<br>• Volt/Var support<br>• Mitigate secondary level PQ issues<br>**Customer Applications:**<br>• Receive Renewable Energy Credits (RECs) | Power Quality Improvements to meet CSI and RPS objectives, reduce GHG emission, reduce losses, and defer distribution capacity expansion | • kWh and kW reduction<br>• Service Reliability<br>• Environmental Improvement | • Advanced Power Electronics<br>• Distribution Planning Tools (steady state and transient dynamics) to include inverters and Solar PV Variability and other DER technology characteristics & capabilities<br>• IEEE 1547 and NIST for power interconnection and IT comm |
| | **Support Regulatory, Policy, Law:**<br>• Feed-in Tariffs<br>• Meet RPS Goals | Support Regulatory, Policy, Law to meet CSI and RPS objectives, reduce GHG emission, reduce losses, and defer distribution capacity expansion | • kWh and kW reduction<br>• Service Reliability<br>• Environmental Improvement | • Regulatory (CAISO, FERC, CPUC, Municipal)<br>• Technology – T&D Planning, tools to include storage and combined T&D modeling (though more of distribution system focus)<br>• Feed-in tariff<br>• Smart Energy Management System development |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| Medium | **Limited Energy Storage:**<br>**< 1 hour (15 min – 1 hour)**<br>• Ancillary Services<br>• Regulation<br>**> 2 hour**<br>• Ramp mitigation<br>• Energy/Capacity Markets<br>**Reduce Peak** | Limited Energy Storage to reduce GHG emissions, reduce peak demand and provide emergency support/ancillary service | • kWh and kW reduction<br>• Service Reliability<br>• Environmental Improvement | • Regulatory (CAISO, FERC, CPUC)<br>  • Eligibility (i.e. Large Storage as generator)<br>  • Transmission or market party<br>• Technology – T&D Planning, tools to include storage and combined T&D modeling<br>• Market Rules: Models Needed<br>• Feed-in tariff<br>• Smart Energy M |
| | **Cross Asset Utilization:**<br>• Minimize impact of intermittent renewable resources<br>• Electric Vehicle Charging from Parking Lot Solar PV Stations<br>• Move Generation Closer to Load<br>• Minimize Impact of EV Charging<br>• Vehicle to Grid<br>• Flatten generation profile (wind, solar, etc. vs. fossil) | Cross Asset Utilization to meet CSI and RPS objectives, reduce GHG emission, reduce losses, and defer distribution capacity expansion | • kWh and kW reduction<br>• Service Reliability<br>• Environmental Improvement<br>• National security | • Customer acceptance<br>• Smart Energy Management System development<br>• Enterprise IT system and robust communications infrastructure for EV integration<br>• EV Charging stations and home infrastructure<br>• Technology development & enhancements, reduced costs |

## Domain 5: Grid Planning and Asset Efficiency

### 2010 Baseline Summary

The Grid Planning and Asset Efficiency domain focuses on improving the existing and future design of the grid to ensure maximum efficiency and performance of the assets. It also addresses the integration of distributed energy resources into the system planning process. Existing and completed projects under this domain can be categorized by smart grid use to provide insights on the 2010 baseline of the California utilities.

- Grid efficiency and voltage reduction:
    - Real-time data collection systems are being implemented (AMI – completion planned for 2012)
    - Conservation voltage reduction is in pilot or deployment phase and volt/var control systems are tested on selected circuits
    - Advanced and highly efficient equipment is being tested such as smart substations and distribution transformers
- Asset management and performance optimization:
    - Condition-based maintenance programs are in pilot or deployment phase for substations
    - Dissolved gas sensors are tested and installed on transmission substation transformers
    - Dynamic ratings of equipments are tested at the transmission level, though not yet widely deployed
    - Asset investment optimization tools are used by some utilities
- Planning for grid growth:
    - Advanced planning tools are tested and progressively integrated to take advantage of new smart grid field data available from a variety of new devices and equipment
    - Advanced equipment such as composite core conductors, superconducting transformers or power electronics based devices are in demonstration phase
    - Impacts of electric vehicles and plug-in electric vehicles on the distribution and transmission grid are studied and demonstrated
    - New circuit design are tested and demonstrated (e.g., integrating with microgrids, looped circuit designs, etc.)

### 2020 Vision

The smart grid of 2020 will operate assets and resources more efficiently by dynamically controlling voltage and optimizing power flows. Monitoring and sensing capabilities will be expanded to enhance asset maintenance and investment decisions. Advanced planning tools will facilitate and leverage the integration of distributed energy resources (PV, PEV) to meet customer needs and ensure system reliability and performance.

## Benefits

The Grid Planning and Asset Efficiency domain will implement technologies aimed at enhancing the efficiency and performance of the system resulting in a decrease in the overall losses along the supply chain as well as maintaining or improving reliability and power quality for end-users. This may result in overall utility technical efficiency improvements as well as environmental and safety improvements.

Another important outcome will be the implementation of a system design that will enable utilities to integrate distributed energy resources (including customer systems, PV, PEV) and meet customer needs.

## Smart Grid Uses Under Grid Planning and Asset Efficiency

- Grid Efficiency and Voltage Reduction
- Asset Management and Performance Optimization
- Planning for Grid Growth

### *Grid Efficiency and Voltage Reduction*

The scope of this sub-area is to improve the power factor of the power flow, and in the process reduce line losses, to increase the utilization factor for the grid asset, and to reduce the peak loading of assets. Moreover, such improvements will also enhance efficient operation of customer loads by reducing customer system losses and thus contributing to the overall peak demand reduction.

The implementation of grid efficiency, voltage reduction and voltage regulation approaches and solutions will require more monitoring and data collection from the grid in order to increase the knowledge and understanding of its current operating state. Deployment of AMI, SCADA systems and PMU systems for the transmission level are all key enablers to achieve this function. In order to transform the data generated by these devices and systems into actionable information that can be directly used by operators, data management and processing systems are needed as well as optimization algorithms. Finally, the advancement of materials such as composites, superconductors, next generation semiconductors, and FACTS devices will also provide highly efficient and flexible solutions to improve overall grid efficiency and performance.

**Table 15: Technology-Ready Roadmap for Grid Efficiency and Voltage Reduction**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short** (2014) | **Conservation Voltage Reduction**:<br>• Transformer Load Management<br>• Phase Balancing<br>• Optimization of customer loads operation (loss reduction)<br>• Customer systems integration in volt/var regulation (first advanced inverters, 4 Quadrant Control) | Conservation Voltage Reduction to reduce losses and optimize for efficiency | • kWhs and kWs reductions<br>• Environmental Improvements | • AMI system & other data<br>• SCADA (increasingly at distribution system level)<br>• TLM/phase & transformer to meter mapping<br>• PMU for transmission level |
| | **Planning for optimal voltage/VAR regulation**:<br>• Optimal Volt/VAR Control scheme<br>• Capacitor control automation<br>• Customer systems integration in volt/var regulation (advanced inverters, 4 Quadrant Control)<br>• Demand Response/Load Control | Planning for optimal voltage/VAR regulation to Improve voltage regulation/optimize for efficiency | • kWhs and kWs reductions<br>• Power Quality<br>• Service Reliability<br>• Environmental Improvements | • Communications end points<br>• Manufacturing designs/products (inverters, capacitors)<br>• Operation algorithms |
| **Medium**(2019) | **Advanced equipment integration**:<br>• Advanced conductors implementation and monitoring<br>• Voltage stability & system resiliency<br>• Smart transformers (highly efficient) & substations | Advanced equipment integration for increased efficiency and to meet deferral of Capital expansion | • kWhs and kW reductions<br>• Environmental Improvements<br>• Utility Technical Efficiency<br>• Service Reliability<br>• Power Quality (minor) | • Materials advancements (composites, superconductors, Fault Current Limiters)<br>• Next generation semi conductor<br>• Transformer, Conductors, FACTS devices |
| **Long** (2020+) | **Advanced grid design for real time system efficiency optimization**:<br>• Load shaping<br>• Voltage stability<br>• Distributed intelligence<br>• Automated Command & Control | Advanced design for real time system efficiency optimization to meet deferral of Capital expansion, improve voltage regulation and reduce losses | • kWhs and kW reductions<br>• Utility Technical Efficiency<br>• Service Reliability<br>• Power Quality | • Optimization Algorithms<br>• Data management & processing<br>• Automated switching technologies (power electronics based)<br>• Secure peer-to-peer communications |

### *Asset Management and Performance Optimization*

The scope of this sub-area is to enhance the value to be derived from grid assets. This is usually accomplished through asset condition monitoring, leading to condition-based maintenance.

Asset condition monitoring will be enabled by the installation and use of different sensor technologies in order to collect data relevant to the state of assets through an adaptive communication infrastructure. The new generation of embedded and automated field devices, such as smart transformers and communicating fault indicators among others, will integrate the monitoring and data collection capability. Advanced data analytics functions such as tracking and monitoring algorithms, expert systems, predictive analysis, and enhanced visualization tools will enable transformation of field data into useful information to be used in asset management and performance optimization processes.

**Table 16: Technology-Ready Roadmap for Asset Management and Performance Optimization**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short** (2014) | **Improved transmission assets**:<br><br>Monitoring & Visualization (Manual data collection-Manual data analysis)<br><br>Transmission substation:<br>• Condition Based Maintenance (CBM)<br>• Dissolved Gas Analysis (DGA)<br><br>Dynamic Ratings on transmission lines (pilots) and substation banks | Improved transmission assets to reduce operation and maintenance costs, and improve overall performance and efficiency | • Service Reliability<br>• Environmental Improvements<br>• Utility Technical Efficiency | • Sensor technology<br>• Communication: Point to point – substation based<br>• Visualization tools<br>• Tracking & Monitoring algorithms<br>• Expert systems for data analysis in the CBM model |
| **Medium**(2019) | **Improved distribution substation assets**:<br><br>Monitoring & Visualization<br>(Automated data collection – Manual data analysis)<br><br>Distribution substation:<br>• Condition Based Maintenance (CBM)<br>• Dissolved Gas Analysis (DGA)<br><br>Dynamic Ratings on distribution substation (pilots) | Improved distribution substation assets to reduce operation and maintenance costs, and improve overall performance and efficiency | • Service Reliability<br>• Environmental Improvements<br>• Safety<br>• Utility Technical Efficiency (operational) | • Sensor technology<br>• Infrared inspection tools<br>• Visualization tools<br>• Tracking & Monitoring algorithms |
| **Long** (2020+) | **Improved Distribution Feeder Equipments**:<br><br>Monitoring & Visualization (Automated data collection – Automated data analysis)<br><br>Distributed intelligence (equipment auto-control based on configurable parameters)<br><br>Distribution feeder equipments:<br>• Condition Based Maintenance (CBM)<br>• Dissolved Gas Analysis (DGA)<br><br>Dynamic Ratings on distribution feeder equipments | Improved Distribution Feeder Equipments to postpone capital investment, mitigate fire risk, improve safety, and reduce operation and maintenance costs | • Service Reliability<br>• Environmental Improvement<br>• Safety<br>• Utility Technical Efficiency (operational) | • Embedded & automated field device<br>• Data/Information presentation and analysis<br>• Communication: ubiquitous umbrella<br>• Predictive analysis<br>• Smart Transformers<br>• Communicating Fault Indicators |

### *Planning for Grid Growth*

The scope of this sub-area is to improve planning tools and processes to increase the return from future system planning. This is accomplished by developing an innovative planning methodology that considers and incorporates many of the DERs, EVs, DR and renewable resources that are part of the smart grid vision. Newly acquired data types from various smart grid sensor devices can be analyzed to support planning decisions, and new design standards will emerge that allow for new technology to be more readily incorporated into the grid.

The planning process will benefit from more granular data (especially digitized waveform data) made available by the deployment of AMI systems and smart grid sensors. More generally, the collection of load data (banks, feeder breakers, reclosers, switches, "main devices") and the further integration of GIS and back office systems will also enable more accurate planning particularly to handle the integration of DER. As far as equipment is concerned, the development and installation of smart transformers, advanced inverters, solid state equipment (FACTS, SVC, STATCOM) or high speed transfer switches will act as key enablers for the planning process. Finally, the use of optimized stochastic planning tools that are able to integrate location- and time-differentiated tariffs will enable a more accurate and granular planning process that will be needed to handle distributed energy resources.

**Table 17: Technology-Ready Roadmap for Planning for Grid Growth**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short** (2014) | **Expanded Resource Planning (integration of more granular data) & identify potential problems**:<br>• Hourly Planning Enhanced system design tools (Algorithms/analysis tools for: optimization, volt/var analysis, CVR, load forecasting, Demand Response, PV and DER integration)Integration of DER & Demand Response in the planning process<br>• Integration of Environmental concern in the planning process (SF6, energy efficient equipment)<br>• Modeling & Simulation (using expanded standard models) | Expanded Resource Planning (integration of more granular data) & reduce Losses; reduce Peak Demand and Improve Voltage Regulation | • Service Reliability<br>• Utility Technical Efficiency<br>• kWh & kW reduction<br>• Power Quality<br>• Environmental Improvement | • AMI generated data (e.g. customer hourly loading, HAN, voltage data, etc.)<br>• GIS/backoffice systems<br>• Load data (banks, feeder breakers, reclosers, switches, etc. "main devices")<br>• Smart Transformers<br>• Advanced inverters |
| **Medium**(2019) | **Dynamic Planning for DER integration & characterize possible solutions**:<br>• Active Circuit Planning<br>• Automation by design (integrating circuit reconfiguration capabilities)<br>• Microgrid designs integrated into standard planning process<br>• Inertia consideration (understanding the impact of inertia problems resulting from once-thru-cooling policy)<br>• Modeling & Simulation (integration of new circuits design models) | Dynamic Planning for DER integration & increased design efficiency to minimize capital outlay, provide for Microgrid Operation, and meet Customer Need | • Service Reliability<br>• Utility Technical Efficiency<br>• kWh & kW reduction | • Solid state equipments – FACTS, SVC, STATCOM<br>• Communication & Control<br>• High speed transfer switches |
| **Long** (2020+) | • **Optimized Planning for DER integration & Deploy solutions/systems**:<br>• Flexible Accommodating Design<br>• Inertia compensation mitigation<br>• Sophisticated Modeling & Simulation (multiple input type models) | Optimized Planning for DER integration & Deploy solutions/systems to meet deferral of Capital Expansion, reduce Losses, reduce Peak Demand, and improve Voltage Regulation and meeting Customer Need | • Service Reliability<br>• Utility Technical Efficiency<br>• kWh & kW reduction | • Optimized stochastic planning tool,<br>• Use location and time differentiated tariffs |

# Domain 6: Workforce Effectiveness

## 2010 Baseline Summary

Technologies to improve workforce safety or to increase productivity are deployed on a case-by-case basis, and workforce training typically involves substantial seat time. Cost-effective technologies in safety improvement are beginning to emerge, while workforce automation technologies are beginning to be integrated into the grid. Although utilities realize that increasing amounts of available smart grid data could be analyzed to prevent or mitigate problems, and are beginning analysis, they currently remain focused on deploying underlying infrastructure.

## 2020 Vision

Smart Grid Workforce Effectiveness involves preparing the workforce to support smart grid technologies and tools while enhancing safety and productivity. Utilities will be organizationally prepared through internal skills development, external education, recruiting, and knowledge management. The tasking, scheduling and routing of work will be more efficient and seamless. Ultimately, sensor technologies, advanced visualization tools and robotics applications extend to both the "office" and "field" workforce, with a focus on training, safety and situational awareness.

## Benefits

- Utility Technical Efficiency
- Environmental Improvements
- Power Quality
- Reliability
- National Security/Energy Independence
- Sustainable Economic Prosperity

All of the customer benefits listed above are the result of Workforce Effectiveness through a smart grid. The most observable value to the customer will likely come in the form of customer satisfaction through the increased efficiency and accuracy of field workers and other utility personnel. Such benefits as customer satisfaction can be achieved, for example, through shorter outage times.

## Smart Grid Uses Under Workforce Effectiveness

- Workforce Management
- Workforce Safety

### *Workforce Management*

- Workforce Management in the short term involves preparing today's personnel to deploy, operate and maintain the smart grid equipment of tomorrow. The short-term roadmap also calls for future planning and partnering with universities and institutions to develop a pipeline that can provide tomorrow's talent needs.

- Over the next 10 years, field workforce personnel will acquire better access to data and up to date information on training, tools and equipment. Similarly, operators will be able to visualize actionable data and perform their functions through automated systems and remote control tools.
- By 2020, multiple elements of the utility, from field personnel to the engineering and operations workforce, will be integrated with advanced smart grid technologies. Faster, more reliable information will allow for the enhanced situational awareness of grid operations, work processes and equipment conditions.

**Table 18: Technology-Ready Roadmap for Workforce Management**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(Now to 2014) | **Workforce Preparedness**<br>• New hire supplemental training on advanced technologies<br>• Tiered support network of SG experts and WIKIs to assist field force (knowledge transfer)<br>• Online checklists to ensure workers are well-prepared to safely deploy/operate/maintain SG equipment<br>• Technical Advisory Committees involving utilities, research groups and universities to identify SG workforce needs | • Meet Customer Need<br>• Enhance Service Innovation | • Utility Technical Efficiency<br>• Environmental Improvements<br>• Service Reliability<br>• Sustainable Economic Prosperity | • Mobile Devices<br>• Social Media, Wiki<br>• Vendors<br>• Other Utilities<br>• Curriculum Development<br>• Student/ Faculty Interest<br>• Emerging Technologies<br>• Policy Evolution |
| **Medium**(2015 to 2020) | **Field Workforce Information and Automation**<br>• Applicable to line crews, trouble, apparatus, inspectors, customer/meter service, etc.<br>• User friendly field workforce automation tools providing work order and asset tracking, automated equipment recognition<br>• Automated, rules-based work scheduling and GPS-based route optimization<br>• Field-based access to data / video / training / expertise / equipment info<br>• Safety and performance evaluation tools<br><br>**Operator Workforce - Analysis & Visualization Tools**<br>• Access to automation systems (operations centers) with remote configuration capabilities<br>• Data analytics and interpretation (smart alarming), actionable intelligence from data<br>• Visually enhanced and user-friendly presentation of control information<br>• Improved / automated communications with Customer Care organizations, outage information<br>• Just-in-time simulation-based training for operators (scenario and contingency evaluation) | • Meet Customer Need<br>• Enhance Service Innovation<br>• Reduce harmonics and other PQ issues<br>• System Protection and Restoration<br>• Improve Voltage Regulation | • Utility Technical Efficiency<br>• Environmental Improvements<br>• Service Reliability<br>• National Security / Energy Independence | • Develop models<br>• Ability to capture outage duration<br>• Knowledge of international (i.e., European) developments<br>• Gridwise Alliance |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Long** (2020+) | **Grid Integrated Field Workforce**<br>• Smart grid equipment communication and control; integrated field area network (FAN), real-time status information, limited field-based control over smart grid field equipment<br>• Hands-free and augmented reality assistance from technology experts; heads-up displays, etc.<br>• Beyond RFID tags to visual pattern recognition of utility equipment conditions<br><br>**Grid Integrated Engineering and Operations Workforce**<br>• Engineering and operations workforce has improved access to smart grid intelligence information, including TLM, circuit/segment aggregated AMI loading data, historical information on operations of automation equipment etc.<br>• Planners/engineers use SG information to assist in planning of system enhancements or grid design and construction standards<br>• Increased convergence of information to improve understanding of upstream / downstream system impacts (e.g. effect of increased DER on upstream Transmission, etc.)<br>• Closer to real-time data to improve decision making, both from grid operations and market operations perspectives | • Meet Customer Need<br>• Enhance Service Innovation<br>• Reduce Harmonics and Other PQ Issues<br>• System Protection and Restoration<br>• Improve Voltage Regulation | • Utility Technical Efficiency<br>• Environmental Improvements | • Knowledge Base<br>• Integrated Computer<br>• 4G-5G Wireless Network<br>• Support of Back Office Systems<br>• Remote Configuration<br>• FAN Integration<br>• Remote Automation Abilities |

### *Workforce Safety*

- In the near term, field workers will begin to see advancements in wearable equipment and devices related entirely to safety. Safety training will evolve in a direction more towards just-in-time delivery, and advancements in simulators will improve the effectiveness of safety training.
- Wearable workforce hardware will leverage technological advancements in visual display and sensing capabilities. Field worker appropriate devices allow for hands-free interaction with information and communications systems.
- By 2020, sensors, smart alarms, robotics and remote controlled vehicles will all play an important role in removing the field worker from dangers in the field, allowing them to more safely operate and maintain field assets.

### *Gaps and Recommendations*

Gaps and recommendations for each of the six technical domains are presented in detail in Appendix C.

**Table 19: Technology-Ready Roadmap for Workforce Safety**

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Short**(Now to 2014) | **Field Force Safety Technology Evaluations**<br>• Fall protection gear with accelerometer sensors<br>• Wearable personal voltage detection / live line warning<br>• Organic LED uniforms / vests<br><br>**Improved Safety Training**<br>• Just In Time safety training available on field based computing equipment<br>• Continually updated training with safety information and procedures<br>• Simulation based training, including technique / safety evaluation (for both operator and field workforces) | • Meet Customer Need<br>• Enhance Service Innovation<br>• Improve Safety | • Utility Technical Efficiency<br>• Environmental Improvements<br>• Power Quality<br>• National Security / Energy Independence | • Advancement in cost-performance of underlying safety technologies (accelerometers, voltage detection, LED technology, etc.)<br>• Simulation based training technology<br>• Complete safety training knowledge base<br>• OSHA involvement / co-operation<br>• Employee / Union Support<br>• Develop safety culture in world with smart grid<br>• Passive safety engineering<br>• Cultural changes that encourage acceptance of new technologies |
| **Medium**(2015 to 2020) | **Safety Focused Computing Technology**<br>• Wearable computer / heads-up displays for alarms / locations / requirements / asset information (automated recognition)<br>• Automatic prompts / warnings about equipment dangers<br>• Compromised worker or "man down" recognition (motion sensors, GPS)<br>• Virtual compliance manager provides and maintains digital checklists of safety protocols and procedures<br>• 3rd Party Access to Information (for safety purposes)<br>• First Responders - Integrated information sharing and communications networks with fire/police/etc. in case of emergency, including location and status information of compromised workers<br>• Underground Service Alert has access to updated electronic records (e.g., maps) as they become available | • Meet Customer Need<br>• Enhance Service Innovation<br>• Reduce Harmonics and Other PQ Issues<br>• Improve Safety | • Utility Technical Efficiency<br>• Environmental Improvements<br>• Power Quality<br>• National Security / Energy Independence | • Pervasive broadband field area communications network, accessible by field-based computing systems ( 4G-5G Network)<br>• RFID tags deployed on all critical equipment<br>• Accurate and complete utility field asset databases<br>• Significant Back End System Integration<br>• Widely accepted standards for data exchange with 3rd Parties |

| Stage | Application | Value Statement | Benefit Categories | Key Enablers |
|---|---|---|---|---|
| **Long** (2020+) | **Remote Management and Safety**<br>• Use of robotics / remote controlled vehicles for physical inspection and repair (e.g. remote operated helicopter)<br>• Increased remote situational awareness, automation, control, and data interpretation / analytical tools<br>• Field personnel monitoring of health / safety vital signs and live feeds of wearable camera streaming video<br>• Equipment recognition through pattern detection / object recognition provokes automatic prompts or warnings about equipment risks and dangers<br>• Live line detection built into trucks to prevent inadvertent contact between the bucket and line | • Meet Customer Need<br>• Enhance Service Innovation<br>• Reduce Harmonics and Other PQ Issues<br>• Improve Safety | • Utility Technical Efficiency<br>• Environmental improvements<br>• Power quality<br>• Service Reliability | • Advancements in cost-performance of remote controlled vehicle and personnel monitoring technologies<br>• Broad Deployment of sensors and automation equipment<br>• Augmented Reality Engine and Object Recognition<br>• Increased Back End System Integration |

# CHAPTER 8: Integral Perspectives Across Domains and Industries

This chapter presents three integral perspectives that cut across the six technical domains and across the electricity and natural gas industries. First, the cross-domain analyses based on each domain's study results are summarized. Through these analyses, the supports for priority objectives, energy policies, economic and reliability drivers are discussed. Second, four interdisciplinary smart grid subjects that present cross-domain opportunities and applications are described. Third, the different ways the natural gas industry supports the electric smart grid vision and California energy policies are summarized.

## Cross-Domain Analyses

### Commonalities and Differences in Perspectives

California smart grid use areas and technology roadmaps were developed through individual domain analyses, considering vision statements, baseline analyses, and application evolutions. Detailed summaries are provided in the previous section. As a result of domain analyses, an integral and common perspective for the California Smart Grid was furthered. The smart grid's ultimate goal is to support relevant energy and environmental policies. Through a collaborative process, the project team identified smart grid applications and foundational technologies in 19 different use areas across six domains. A common vision was also defined.

However, due to different geographical service areas as well as different stages of existing baseline activities, the expected time line of smart grid application development varies from one California utility to another. Individual utility rankings for smart grid objectives also vary. These differences affect implementation schedules. Nevertheless, the technology roadmaps for smart grid applications have received consensus among the utilities on the project team.

### Analysis on Meeting Regulatory Policies and Smart Grid Objectives

Chapter 2 discussed energy policy drivers for smart grid deployment include Renewables Portfolio Standards, Greenhouse Gas reduction, Energy Efficiency (EE), and Demand Response. Additional policy drivers include system economics and reliability. Table 20 shows how these drivers map to different objectives for smart grid use. The table is adapted from prior work in [1].

**Table 20: Smart Grid Objectives by Category and Types of Drivers Supported by the Objectives (Adapted from [1])**

| Category of Objective | Objective | Mapping to Drivers |
|---|---|---|
| Environmental Compliance | Meet Renewable Portfolio Standards | RPS |
| | Reduce GHG Emissions | GHG |
| Enhance Customer Choice | Meeting Customer Need | EE/DR |
| | Enhance Service Innovation | EE/DR |
| Improve System Economics | Reduce Peak Demand | EE/DR |
| | Reduce Losses | Economics |
| | Serve Isolated Remote Load | Economics |
| | Deferral of Capital Expansion | Economics |
| Maintain and/or Enhance System Reliability | Provide Emergency Support/Ancillary Service | Reliability, Storage* |
| | Reduce Facility Loading | Reliability, Storage* |
| | Provide for Micro-Grid Operation | Reliability, Storage* |
| | System Protection and Restoration | Reliability, Storage* |
| Improve Power Quality | Improve Voltage Regulation | Reliability, Storage* |
| | Reduce Harmonics and other PQ issues | Reliability, Storage* |

**Storage does not represent an existing policy in CA, but could be linked to several smart grid objectives.*

To ensure that sufficient smart grid applications were identified, an exercise was conducted analyzing applications identified in Chapter 7 that support the listed objectives and drivers for smart grid deployment. The analysis verified that smart grid applications included in the technology ready roadmaps of Chapter 7 support each of the objectives, policies, and other drivers listed in Table 20.

The reader will find a list of priority objectives for smart grid uses at the conclusion of Chapter 2. For each of these priority items, supportive smart grid applications were identified in Chapter 7. A majority of the smart grid uses were identified as providing significant support to energy policy or economic drivers. Through analyses of findings across domains, the project team confirmed that the technology readiness roadmaps outline pathways to achieving all the priority objectives for smart grid use identified in Chapter 2.

## Interdisciplinary Opportunities and Applications

Four opportunity areas for interdisciplinary smart grid development, which requires synthesis of findings across domain areas, are discussed next.

### Integrated Distributed Resources Management

In order to successfully implement DR and demand-side management (DSM) applications, as well as integrate with PEV, PV and other DER, effective distributed resources integration functions need to be addressed together as an integrated enterprise application.

Integrated distributed resource management considers all types of “resources” at the distribution system level as a whole. DR and DSM applications facilitate “contractual relationships” between utilities and customers, providing “virtual energy resources” that can be used to balance demand and supply, hedge operation risks, and/or enhance power system security. DER and PEVs are “physical assets” that can also supply electrical power.

Management and integration of all types of energy resources collectively are major challenges for future smart grid advancement. Grid operators need to be able to manage all types of distributed resources and interact with new players, while financial settlement rules are also to be defined. Effective communication methods and infrastructures to transfer control signals and measurement values are essential. The needed distributed resource management and integration functions are similar to those of market and grid operation systems (e.g. EMS) that are used in the wholesale market by independent system operators, such as the California ISO.

### Unified Grid Operation and Planning

SCADA and EMS are common grid operation systems. Special Protection Systems (SPS) or Remedial Action Schemes (RAS) with fast-acting protective devices are used to mitigate contingencies. These systems serve as the essential basis for today's grid control and protection methodologies. In addition, data from SCADA/EMS and SPS/RAS are also used for planning purposes. As part of smart grid activities, close to 1,000 synchrophasors will be deployed in North America. The additional real-time data provided by synchrophasors can help support further optimization of grid utilization and operation. Managing different granularities of real-time data and maximizing the benefits for grid operation and planning, will present challenges to electric utilities, as well as opportunities to unify grid operation and planning approaches under a unified framework.

The future grid will operate with both lower granularity real-time data from SCADA and higher granularity real-time data from synchrophasors. Both sources of data need to be unified and then the appropriate data provided to new, integrated, advanced applications for operation and planning. The hierarchy of grid control and protection also need to be redesigned to maximize benefits. Detailed system behavior data from SPS/RAS and synchrophasors can support yet-to-be-developed renewable generation models. The proliferation of smart grid technologies may blur the lines between protection, control, and planning. The emphasis here is an all-encompassing approach for grid-wide operation and planning as well as control and protection.

### Comprehensive Resource Portfolio Management

In order to address some of the impacts of new resources, on May 18, 2010, the CAISO approved new reliability rules for renewable energy resources. The new reliability requirements apply FERC Order No. 661-A and WECC Criteria for Frequency to intermittent resources, basically requiring that renewable generation meet the same voltage and reactive power requirements as conventional fossil-fuel generation. Also all new resources are required to be equipped with fault ride-through capabilities to minimize tripping and down time when a fault occurs. However, there are many issues that have to be addressed in a holistic approach to resource planning with non-conventional energy resources, such as renewables, energy storage, demand response, PEV, etc.

The current resource planning approach (e.g., production simulation or unit commitment) does not address the complexity and different characteristics of non-conventional types of resources. Renewable generation introduces fast and frequent intermittencies that require finer resolution generation capacity planning in order to address ramping and frequency issues. DR and PEV introduce demand uncertainties. On the other hand, DR and PEV may also be applied to establish a financial contract relationship in hedging generation supply. Comprehensive portfolio management is needed for resource planning and chronological optimization on a much finer time scale, considering generation capacity, ramp rate, GHG reduction, voltage and frequency regulation, financial contracts, etc.

### Effective Workforce Education and Training Programs

To support smart grid advancement, an interdisciplinary approach to education and training must be established.

#### *Engineering Programs*

Engineering programs are foundational for any smart grid education efforts. Obviously, areas of new and emerging technologies will receive special emphasis in the context of smart grids. In addition to studying specific technologies and applications, however, smart grid education will require a new emphasis on integration of components.

#### *Community Colleges*

In addition to a cadre of engineering graduates from California universities, a substantial industry workforce is needed that is conversant in smart grid technologies. Therefore community colleges play a critical role in providing specific technical job preparation and continuing education for a wide spectrum of workers in the field.

#### *Supporting Activities*

In addition to formal coursework, other avenues of knowledge sharing provide critical supports for student learning and research outcomes. Effective smart grid education therefore hinges not only on course offerings and curriculum development, but also on the cultivation of active learning communities that include academics and professionals at different stages in their careers, and across a broad range of sub-specialties. Cultivation of professional relationships and information sharing can be facilitated by providing opportunities and introducing frameworks that support interaction.

## Role of Natural Gas to Support the Electric Smart Grid

The majority of the project team's effort focused on the electric power grid rather than the natural gas delivery network. California electric and gas IOU representatives agreed that the smart grid of Year 2020 is an *electric* smart grid. Emphasis therefore was to collect perspectives on the role of natural gas infrastructure and technologies to support the electric smart grid vision. This section identifies differences between electricity and natural gas and summarizes findings on the supports for the smart grid that have been identified. Appendix E provides background on the natural gas industry and a more in-depth summary of findings.

There are three fundamental differences between the electric power and natural gas industries:

- The electric power industry is moving further to enable greater bidirectional energy flows between electricity consumers and the electric grid. However, natural gas flows in one direction from the distribution pipeline to gas consumers.

- Natural gas can be economically stored. With the exception of pumped hydro storage, electric energy storage solutions are still being developed.

- Electricity travels at the speed of light, and all power system disturbances must be mitigated in real-time. Gas flows much slower, and impacts of disruptive events are less severe.

The project team identified priority areas for considering the role of natural gas technologies and infrastructure in supporting the California Smart Grid vision. The priority areas and the "natural gas supports" identified are discussed at length in Appendix E. Among the findings are natural gas supports the smart grid in two key ways: (a) gas is a fuel for generating electricity and (b) there is potential for customers to arbitrage between gas and electricity in total energy use management.

### *Fuel for Electricity Generation*

The types of fuels used to generate electricity directly impacts reductions of GHG emissions. From this point of view, natural gas offers an effective and efficient, less carbon-intensive, generation solution compared to other fossil fuels like coal. This applies to gas-fueled DERs, large-scale gas-based generation, as well as natural gas vehicles (NGVs). Natural gas-fired bulk and distributed electric generation resources and advanced metering of natural gas consumption contribute to overall utility operational efficiency by providing more alternatives to meet energy demand, and more information to guide particular decisions. This improves asset utilization and helps optimize decisions regarding infrastructure improvements.

CHP and other types of DER can support the grid by achieving kWh and kW reductions, while potentially lowering overall customer energy costs. Moreover, a decrease in the peak load experienced by the grid may diminish reliance on natural gas-fired bulk electric generation.

Natural gas-fueled DERs and large-scale generators are generally fast ramping and dispatchable, and can be located strategically to support grid reliability and stability. Natural gas-fueled units not only provide relatively "clean" generation to the overall electric power supply, but also facilitate the integration of more renewable generation into the grid. Hence, optimally planning an entire suite of generation resources, considering the use of natural gas as fuel, is a strategically important linkage between the electric and gas industries.

### *Total Energy Management by End Users*

Over the years, natural gas has been an alternative energy resource for industrial, commercial, and residential customers. With the advanced information and energy technologies that are to be deployed under the smart grid, end users will have more opportunities to select the type of energy they use (gas or electricity) for certain applications.

Advanced metering may in the future provide residential and commercial end-use customers with information to engage in arbitrage between natural gas and electric uses, much like some large industrial customers do today, although customers would need to have multiple appliances serving the same requirement or appliances that could be fueled with multiple fuel types. Such actions by consumers can lower the demand for electricity at peak times through direct natural gas use (or vice versa) to lower overall energy costs. Homes and businesses with advanced metering can thus maintain comfort and run processes at reduced overall energy costs, and potentially relieve the electric grid at peak times (e.g., using electric floor heating instead of natural gas space heating when economics dictate a fuel switch opportunity).

Sharing AMI information between electric and gas utilities can be useful to end users for supporting demand response and optimizing energy efficiency. Developing multi-fuel end-use appliances can also enable consumers to adopt a holistic approach to energy management by considering different fuel usage.

In summary, an evolutionary approach to total energy management for end users includes three technical steps: (a) information and infrastructure (e.g. AMI), (b) instrumentation and technology (e.g. choices of end-use appliances that apply to both gas and electricity), and (c) intelligence and automation (e.g. easy-to-use energy management tools that consider both gas and electric usage).

# CHAPTER 9: Identifying Benefits From Smart Grid Investments

## Introduction

A smart grid roadmap provides a pathway for achieving the California Smart Grid vision to support achieving the state's energy policy goals. The policy goals are the primary drivers that shaped the vision and roadmap developed in this report.

To be both insightful and actionable, the roadmap must include a means for measuring progress toward reaching these end-state goals. It must specify at any point in time how to measure how far California has gone, and how much farther it must go. Impacts are measures of changes in the output or activity of the electricity sector that contributes to the achievement of the goals the state has set. The remainder of this chapter is dedicated to describing a framework for identifying the costs and benefit impacts of smart grid roadmap items, and ultimately compiling them into a cost-benefit analysis that could be used as a common means to seek regulatory approval for investment in smart grid initiatives.

The roadmap described in this report represents the California utility vision of the technical infrastructure and corresponding operating environment that are needed to meet the policy goals. It identifies the technical developments that are needed in different domains, and recommends supporting activities and expected time frames of those activities to support smart grid deployment.

This chapter primarily focuses on describing the benefit impacts that are expected from smart grid implementation, including state-of-the-art solutions to well-specified needs. Smart grid implementations are expected to address needs established by the policy goals and extend additional benefits to consumers. They are selected because they not only address expressed needs, but also they take advantage of opportunities to improve or maintain electricity service under almost any foreseeable electricity sector structure and circumstance.

Impacts define the changes in the physical character and operation of the electric system that the roadmap seeks to effect. A logical next step, after affirmation of the roadmap, is to devise a system for measuring these impacts and tracking progress toward achievement of policy goals. The discussion that follows lays out a foundation for how that can be accomplished. A subsequent effort is needed to develop detailed analytical procedures. Such an effort can draw from existing initiatives, like the collaboration between EPRI and DOE to define comprehensive methods to ensure comparability of findings among the many ongoing smart grid demonstrations.[9]

The impact categorization scheme described in this chapter stops short of defining a traditional cost and benefit assessment methodology. Costs for emerging technologies are difficult to specify at the conceptual stage of technology advancement. A more detailed characterization of the exact nature, scale and scope of deployment, and of the technologies involved are needed

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[9] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*. EPRI, Palo Alto, CA: 2010. 1020342.

before capital and operating costs can be estimated to any reasonable degree of certainty. This will flow from the engineering studies and demonstrations that are undertaken in California, buttressed by related activities across the country, many of which are part of ARRA funded smart grid demonstration projects.

Impacts indicate the physical manifestation of the technologies that are to be deployed. Examples include kW and kWh savings; maintained or improved reliability and power quality; operating efficiencies at all levels of the electric system; reduced emissions; and improved health and safety. A conventional cost/benefit analysis would monetize these impacts so that the attributed benefits can be compared with the costs associated with their realization. As discussed above, it is premature to estimate the costs associated with the roadmap's execution. Moreover, measuring benefits is beyond the scope of the roadmap effort—to develop a pathway to a smart grid that supports existing policy goals applicable to the electricity sector. The goals presumptively are predicated on expectations of benefits that need to be further articulated. Monetizing the impacts will be an important element of going-forward activities, subsequent to vision and roadmap development. As is the case with assessing costs, initiatives to assess monetized benefits can leverage EPRI and DOE cost/benefit assessment methodologies, such as that described in *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*.[10]

## Criteria for Impact Categorization

Achieving goals for smart grid deployment involves the commitment of funds (costs) in order to realize positive impacts. The impacts include, among others, reduced consumer energy use and cost, changes in how electricity is produced, and the associated environmental improvements (public or societal goods) that accrue to consumers.

The following criteria were used to develop a schema for identifying and classifying smart grid impacts and constructing protocols for their measurement.

1. Comport with the protocols used by California utilities to evaluate AMI investments. A considerable effort was expended to ensure conformity in how utilities characterized the expected costs and impacts of AMI investments they proposed to undertake. Using this structure as a foundation for the Roadmap allows for comparing the relative levels of impacts between AMI and smart grid investments, and to avoid redundancy and oversight in counting impacts.
2. Allow mapping of costs and impacts into the protocols that DOE has adopted for stimulus funded projects (under the ARRA). Some California utilities have been awarded stimulus grants that involve smart grid technology elements. Moreover, there are almost 100 grant-funded programs that will be undertaken around the country. Consistency with the DOE protocols for measuring costs and impacts ensures that they

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[10] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*. EPRI, Palo Alto, CA: 2010. 1020342.

can be compared to that of other similar initiatives to gauge the relative progress and provide sources of information and inspiration for modifications in the Roadmap.

3. Maintain consistency with EPRI protocols for evaluating host smart grid demonstration projects. EPRI is sponsoring several smart grid demonstration projects that involve technologies similar to those specified in the Roadmap. They represent another source of insight. This may not require any additional accommodation since EPRI intends to design its protocols so that they will map to those of DOE.

4. Costs are to be categorized and arranged to be consistent with accepted California regulatory financial and accounting practices to facilitate tracking the impact on capital and operating costs.

5. Utility operating costs (some of which may increase or decrease) attributable to smart grid investments also are to be categorized and arranged to be consistent with accepted regulatory financial and accounting practices.

6. Impacts are to characterize smart grid investments via: 1) utility costs attributable to the investments in smart grid technology, 2) electrical output and generation requirements to serve electricity demand and electric delivery reliability and quality; and 3) how they affect economic prosperity, the environment, quality of life, national security, or other energy and environmental policy mandates. The first two are direct impacts, and the latter are derivative or collateral impacts.

## Impact Categorization Scheme

Smart grid impacts and costs can be classified at a high level as follows:

- Costs are the investment and operating costs that utilities undertake to place and maintain in service smart grid technologies. In some cases, the costs are associated with at-scale technologies placed into full-service duty. In others, the costs are incurred by utilities to conduct pilots and demonstrations to establish the performance of promising, but not yet proven, technologies. Cost incurred by others (e.g., renewable project developers, consumers adding solar or PV devices to their homes) are typically not included in utility assessments of smart grid deployment costs.

- Impacts can be further classified as follows:

  - Utility system operating cost changes (i.e., increases or decreases) based upon productivity changes, the need to increase resources to manage an increasingly complex system, increased maintenance expenses as the infrastructure expends to accommodate renewable resources, and other factors. Operating costs are utility expenses associated with operating the electric power system, excluding the direct costs associated with energy generation and delivery. They include labor (direct and overhead), materials, services, taxes, insurance, and other operating expenses.

  - Consumer impacts that result from changes in the electricity sector's performance. They include changes in the level or source of electricity production (kWh), capacity requirements to serve peak demand, maintained or enhanced system or localized reliability and power quality, improved economic prosperity, and increased national security and a cleaner living environment.

While they have been classified separately from consumer impacts, net utility system expenditures also accrue directly to consumers because they are pass-throughs in utility rates.

Smart grid cost and impacts are described in the next section, followed by a discussion of procedures for utilizing them.

## Smart Grid Costs

Costs are distinguished by whether they are incurred to build the smart grid (i.e., capital costs) or incurred in its operation (i.e., operating costs).

Capital Costs. Utility capital costs are those associated with purchasing and installing the equipment that constitute smart grid technologies. These investments include field equipment, communications equipment, and information technology systems integration.

Operating costs are the ongoing costs incurred to run and maintain smart grid technologies. Examples of smart grid operating costs include IT and field/communications equipment maintenance, as well as system operator labor costs.

Capital and operating costs are further divided according to their functional impact and which segment of the system they influence (e.g., generation, transmission, distribution or customer). The use of this functional designation facilitates associating smart grid costs with conventional regulatory and financial accounting conventions. Once capital costs have been identified, they can be integrated into utility accounting systems to calculate the revenue requirements associated with the investments. Furthermore, associating operation costs with functions allows them to be ported into conventional cost accounting systems.

## Impacts

Impacts are defined as improvements associated with the smart grid investments that ultimately inure to consumers. These improvements are categorized below as either “utility expenditures”, “direct consumer impacts“, or “collateral customer impacts.” As stated previously, any utility expenditure is ultimately also returned to customers as pass-throughs in rates.

Utility Expenditures

Smart grid investments may result in productivity gains that reduce utility operating expenses, although some expenses may increase. For example, distribution automation systems may reduce and expedite the number of times crews are dispatched to resolve intrusions that jeopardize customer service continuity, or ameliorate circumstances that have interrupted service. Many envisioned smart grid utility expense savings are manifested through reduced wear and tear on generation, transmission and distribution equipment, thus extending their lifetime and reducing maintenance and replacement costs. Potentially lower insurance costs and reduced lost-time are the immediate impacts of investments in workforce safety equipment and systems.

Direct Customer Impacts

Directly attributable potential customer benefits include:

- *Utility technical efficiency*. A smart grid uses an extensive system of monitoring and associated controls to improve the overall performance of the power system. Anticipated outcomes include: lower transmission and distribution losses and improved utilization of available generation resources. It also enables demand response tariffs and programs that induce customers to adjust load at times when the marginal cost to serve load is high. Additionally, smart grid investments are intended to enable the faster and more widespread proliferation of distributed, renewable generation. The output of these units displaces conventional generation, which may add to the avoided kWh attributable to smart grid investments.

  The result is a likely reduction in generation output required to meet demand, an allocative or operational (short-run) efficiency to the extent to which available resources are used according to the value consumers realize. These translate into lower recorded kWh usage at customer meters. The impacts are commonly referred to as avoided energy costs because they reflect reductions (but for the smart grid investment) in the costs (fuel, maintenance) associated with electricity generation to meet energy demand.

  Smart grid investments, and the demand response actions they enable, may also reduce the overall load profile, and more importantly the level of peak load to be served. Lowering the peak load reduces the amount of generation required, and hence associated investment costs. This is referred to as dynamic (long-run) efficiency because the result is that societal resources are invested to provide services commensurate with their value to consumers.

- *Reduced Production of kW and kWh*. These potential impacts are measured as reduced kWh generation output and reduced capacity requirements (kW) to serve load reliably. They are commonly referred to as avoided capacity costs because they reflect reductions in what otherwise would be the required generation investment portfolio. There is also a conservation effect associated with providing more (and near real time) information to customers regarding their energy use over the course of a billing cycle. Moreover, there may also be an impact from reduced exposure to fossil fuel price volatility due to the smart grid enabling increased renewable generation and integration of electric transportation, which shifts transportation costs away from highly volatile petroleum prices.

- *Maintained or Enhanced Service Reliability*. Some elements of the smart grid are focused on maintaining or improving the reliability of delivered electric service. Distributed automation Var/Volt management technologies and automated metering infrastructure (AMI) systems will use the data from extensive instrumentation to monitor the physical aspects of electric service not only at the distribution station, but at individual premises. This monitoring capability allows system operators to potentially foresee situations that could result in either an attenuation of service reliability or power quality (momentary voltage and harmonic fluctuations) that cause inconvenience to some, but can result in more substantially adverse impact for others.

Collateral Customer Impacts.

Collateral impacts are derivative outcomes of direct customer impacts, or a consequence of utility operating expense changes. While designated as customer impacts, they are more accurately labeled as consumer or citizen benefits because they inure to all California consumers and in some cases to those in other states. Collateral impacts include:

- *Achievement of Environmental Goals*. Lower kWh consumption reduces the amount of emissions from electricity generation. The extent of the impact depends on when the reductions materialize, and the generation source whose output was avoided.

  The primary impact anticipated from avoided generation output and a shift towards a renewable portfolio is a reduction in emissions. Hence the appropriate impact metric is tons of avoided $PM_{10}$, SOx, NOx, and $CO_2$. The smart grid also supports increased penetration of renewable resources to achieve renewables portfolio standards, increasing overall GHG reduction.

  Another anticipated result of smart grid investments is faster adoption of plug-in electric vehicles. Electric vehicle charging results in additional electricity consumption, which produces more adverse environmental impacts associated with generation, not abatement of same. However, even though electric transportation results in more electricity consumption, electric motors are more efficient than internal combustion engines. In addition, the California generation mix for electricity is already significantly renewable (carbon free) and on a path to 33 percent renewable by 2020.

  The net impact is the sum of the negative and positive elements associated with added or avoided pollutants, measured in tons of $CO_2$, $PM_{10}$, NOx and SOx, respectively.

- *Sustained Economic Prosperity.* Smart grid investments alter the nature of the goods and services consumed by the electricity industry. Increased purchases of communication and sensor devices, computer and software, and planning services will be required. Constructing and operating a smart grid will require the increased utilization of engineers, business analysts, and purchases of labor-intensive materials and services. These can produce changes in state (and regional) economic output, employment, and wages because the new bundle of goods and services may create more jobs locally, and heighten economic activity.

  These impacts are derivatives of changes in utility expenditures. The basic metric is a vector of value that indicates how utility capital and operating expenditures are modified over time, some going down, others up, evaluated in terms of economic impacts such as changes in jobs, wages and state output.

- *National Security*. Reducing energy imports adds to national security. This proposition flows from the assumption that markets for energy (including oil, natural gas and coal) are inextricably linked. Increased efficiency in the use of energy sources will ultimately decrease dependence on foreign sources and hence decrease our vulnerability to outside and adverse pressures (economically) and threats (geopolitically). The largest effect in California may be the reduced use of petroleum for transportation fuels that results from replacing combustion engine-driven vehicles with electric drive vehicles.

The change in the use of imported energy (for example, barrels of oil) in California is the impact metric.

- *Worker Safety.* Worker safety will increase with the adoption of improved safety technologies, materials, and equipment; as well as new access to safety information and remote access to safety training material. These enhancements may increase worker productivity as well as safety, and contribute to reductions in employee health and welfare costs.

## Impact Assessment

Impact metrics, stated as physical measurements of a flow or stock, are summarized in Table 21. The categorization and metric measurement scheme provides a means for associating impacts to individual technologies. Any particular smart grid technology may be associated with any or all of these impacts.

**Table 21: Impact Metrics**

| Impact Metrics |
|---|
| • **Costs**<br>o Utility costs – $<br>• **Impacts**<br>o Utility expenses – $<br>o Customer Impacts<br>– Electricity usage reductions (kWh, kW)<br>– Improved service reliability – fewer, shorter service interruptions or compromises<br>– Achieved environmental improvements – $CO_2$, particulate emissions<br>– Sustained economic growth – job creation, wages, gross state product<br>– National security – reduced reliance on energy imports<br>– Worker safety – reduced employee health and welfare costs |

A close examination of how each technology affects the electric system or consumers (or both) will reveal which impacts are likely to be realized, and specify how that impact is measured. Several factors must be taken into account to ensure that the individual impacts are properly measured and aggregated to fully characterize how the smart grid investments will contribute to the goals it was assembled to address. These factors are discussed below.

### Impact Baselines

In most cases, the impact defines a change in the state of a system component or element, or in customer circumstances. Impact levels (metrics) can be measured, if they can be defined in measurable terms, at various points along a roadmap. Establishing a net impact requires establishing starting or reference values so that a change in the metric can be established. In some cases the reference value or *baseline* is defined by the state of a system or system element (or customer circumstance) prior to the installation and operation of the smart grid technology.[11]

Baselines are generally constructed for each technology based on what the impact is expected to be, and how the technology produces that impact. For example, improvements in service restoration can be established by comparing outage measurements with smart grid technology against previously established measurements. Of course this requires historic measurements. The time to restore an outage may also have been recorded previously, providing a baseline for what is observed and measured once the smart grid technology is operative.

In other cases, the baseline must be established as a counterfactual, addressing what would have been the level of the applicable metric had the smart grid technology not been implemented? Demand response is an example because customer usage during a period when a program seeks to reduce load can be measured. But, how do we ascertain what level and rate of electricity the customer would have consumed otherwise, the counterfactual? That determination involves a behavioral element that is difficult to establish with certainty. A variety of baseline methods have been proposed to establish the counterfactual metric. They include using the customer's usage on days or hours prior to the event, data from after the event, or a combination of both.

Finally, in some cases a baseline must be synthesized by constructing a model of the operation of system interrelationships and then constructing scenarios that define the circumstance of key variables before and after the implementation of the smart grid technology. The impact of sensors that allow system operators to visualize changes in the utility's wave form prior to failure of the specific equipment requires positing circumstances under which an incursion would cause a system component to fail. Then, the performance of the forecasted equipment failure impacts can be overlaid, and the extent of the resulting impact measured.

### Scale and Scope Adjustments and Timing

Most smart grid technologies are in the design or piloting stage. As a result, the performance data available are for systems operating under highly controlled conditions, using prototype technologies, for limited periods or over a limited range of system conditions, or all of these. Estimating the impacts of the system-wide adoption of many smart grid technologies requires extending the available data to larger circumstances, which in many cases is well outside what has been observed. The timing and duration of deployments for these larger circumstances is also important. Large, rapid deployments will incur costs—but also produce impacts—more quickly than a partial or phased rollout, or a slow rollout that replaces old technology with new technology over many years.

The California Smart Grid vision and roadmap provide direction for achieving specific goals established for California. Care must be taken when extending available data to larger circumstances in determining the extent which recommended actions and investments achieve specific or collective goals.

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[11] For a discussion of baselines and how they are established, see [6] and [5].

### Comparability and Compatibility of Impacts Among Smart Grid Activities

The impacts identified in the impact categorization scheme correspond to that used to evaluate AMI investments by California utilities. The span and scale of AMI is less than that of smart grid investments, but the costs that are applicable map directly into what is proposed here. Hence there is consistency of treatment of the investments streams, and the means for sorting out potential redundancy in counting impacts, and discovering oversights.

The generality and transferability of the impact categorization scheme extend further. The impact categories are sufficiently detailed and differentiated, so that impact measurements can be mapped back and forth between the results of DOE smart grid demonstration projects and the experiences and finding that result from implementing the California Smart Grid. The transferability and extensibility of the results of the California Smart Grid experience are further ensured because the cost and impact categories comport with those that EPRI is developing. EPRI is preparing a guidebook to direct analysts engaged in cost/benefit assessment of smart grid technology. The impact categorization scheme established under the California vision and roadmap project has been specifically constructed to ensure correspondence with the protocols and methods that EPRI develops.

### Translating Impacts Into Benefits

Converting impacts into monetary benefits is beyond the focus of the current project, in which smart grid deployments are aimed at meeting policy mandates that have already been established. In such cases only a least cost analysis would typically be required to determine cost-effectiveness.

Other initiatives included in the roadmap may be for system improvements that may not be directly related to a policy mandate, but which are clearly part of the smart grid and simply make sense from a more traditional cost-benefit perspective. For this type of initiative, conversion of impacts into benefits may be required when developing business cases for regulatory approval through either general rate case or special application proceedings.

The impact categorization scheme proposed here corresponds closely to those being employed by EPRI and DOE. Other works describe frameworks that may provide useful references (e.g., for common conversion factors, etc.) for those projects which require monetization of impacts to produce benefits measured in dollars.[12]

## Summary

The California Smart Grid entails technology investments and operational improvements that will move the state toward the goals set for energy and environmental policy. At initial inception, it is difficult to ascertain if certain actions will achieve the desired end. Anticipating the eventual need to gauge progress, and in some cases develop frameworks for reference, this chapter specifies the kinds of impacts that are expected from smart grid advancement and establishes metrics for measurement. The chapter provides guidance on how to assess impacts

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[12] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*. EPRI, Palo Alto, CA: 2010. 1020342.

as means for tracking progress toward the goals once smart grid technologies are in place and operative. Moreover, the proposed scheme is aligned with protocols others are using to measure the cost and benefits of smart grid investments. This provides a way to measure progress through intrinsic evaluations (measuring state progress) and extrinsic assessment to gauge how well California is doing relative to what others are achieving.

# CHAPTER 10: Recommendations

Previous chapters define the utility vision of the California Smart Grid of Year 2020 and technology readiness roadmaps that identify applications and enablers needed to support achieving the vision. This chapter provides a summary of recommendations on critical activities to fill technology, policy, standards, process, and education gaps which need to be closed in order to fully implement the vision. Recommendations are associated with time horizons based on a set of assumptions that are also identified.

**Assumptions behind the Roadmap**

The project team examined various types of uncertainties that may influence the timing of achieving the smart grid vision, and made assumptions about those uncertainties, summarized below. Assumptions comprise a particular scenario in an analysis that explores alternative pathways for achieving the smart grid vision. By examining alternative configurations of internally-consistent assumptions, a range of pathways and time frames for achieving the California Smart Grid vision may be determined. For a more detailed discussion, see the Assumptions subsection in Appendix E.

## Drivers for a Smart Grid Remain Strong

In general, regulatory and public policy are the primary drivers for deploying significant aspects of the smart grid in California. The California Smart Grid will support achievement of multiple energy and environmental policy goals, as described in Chapter 3.

These types of regulatory policies serve as important drivers for smart grid deployment in the state. For roadmap development, such drivers are assumed to remain consistently strong.

## Basic Project Assumptions Are Not Violated

The following assumptions were identified early on during the first stage of the project to guide domain team efforts. Domain teams were directed to develop project findings that did not conflict with any of the identified assumptions below, which also comprise roadmap assumptions.

1. Existing California Energy Policy Targets for Year 2020 need to be met by Year 2020.
2. Uncertainties affecting grid and market operations are handled logically.
3. Rates and programs encourage behavior that is in alignment with energy policy goals.
4. The smart grid accommodates market enablement and customer-driven choices.
5. The smart grid accommodates the integration of alternative resources.

## Reasonable Outcomes Are Assumed

In an effort to define a pathway to achieve the 2020 vision, reasonable outcomes were assumed, beyond the continuation of strong policy goals driving smart grid deployment. The team identified five types of critical assumptions, some of which are related to developments in the natural gas industry, which will have bearing on the actual timing for achieving the electric smart grid vision. For each assumption, the project team identified reasonable outcomes, as follows.

- *Supportive regulatory policy for smart grid continues based on cost effectiveness.* Cost-benefit analysis of proposals for smart grid related deployment favors implementation on an objective basis, and there is broad support on the basis of subjective considerations of stakeholder interests. Implicit in this assumption is that the regulatory authorities arrive at a satisfactory allocation of authorized expenditure. Considerations are made of costs associated with both the electric smart grid and investments required to fully enable gas support of the smart grid vision. In the instances where infrastructure is required to support providing natural gas to a generating project, it is typical for the natural gas infrastructure alterations and additions to be paid for by the generator (developer) and not other gas utility customers.

- *Existing natural gas and competing technologies make incremental improvements.* Natural gas fired technologies and their alternatives continue to make modest improvements, and maintain their relative positions with respect to overall cost-effectiveness.

- *Customer acceptance of smart grid technologies is based on economics and environmental drivers.* Customers generally accept an increased role for technologies in support of the smart grid vision on the basis of favorable economics, and a perception of enabling a cleaner energy future. There is modest support for bulk and distributed renewable technology, due to high costs. There is positive customer perception of smart grid technologies to remedy safety-related concerns.

- *Natural gas and other infrastructure costs remain within historical norms.* The cost of natural gas piping, metering, and the underlying labor and technology costs remain stable and are consistent with recent history. Natural gas commodity costs are in the range of $4 to $10/MMbtu. This range is considered "business as usual" for natural gas commodity costs. It considers that natural gas prices in 2008 were anomalous, and confines gas price assumptions to a generally-accepted range of natural gas prices. This view is supported by the related assumption of shale gas availability at reasonable prices.

The assumptions above form the basis of an "expected case" of the roadmap effort. Each case or scenario in turn influences the timing of achieving the smart grid vision.

## Extreme Outcomes Are Not Assumed

The team also identified extreme outcomes for key uncertainties. Together the outcomes below define an "extreme case" for each type of uncertainty, as follows:

- Denial of cost recovery for natural gas related smart grid programs and infrastructure.
- The emergence of a breakthrough technology undercuts smart grid related technology.
- Safety concerns blunt customer acceptance.
- High infrastructure costs.
- High natural gas commodity costs ($14-20/MMBtu).

The 2020 vision and roadmap were defined assuming reasonable assumptions. Any of the extreme outcomes creates a different scenario that could significantly alter timing for achieving the 2020 vision and roadmap.

## Overall Approach to Developing the California Smart Grid

The California Smart Grid vision builds upon six critical domains, or areas of technical expertise. These areas are:

Domain 1: Communications Infrastructure & Architecture

Domain 2: Customer Systems

Domain 3: Grid Operations & Control

Domain 4: Renewable & DER Integration

Domain 5: Grid Planning & Asset Efficiency

Domain 6: Workforce Effectiveness

The conclusions and recommendations with respect to smart grid development that were developed within each of these domains are consolidated in this section. For most of the development needs, there are important activities and demonstrations already under way. These are identified by domain and provided in more detail in the tables found in Appendix D.

In developing an overall approach, it is important to recognize the interdependence of the recommendations stemming from the different domains. For instance, many of the developments are dependent on the definition of the overall architecture and at least an understanding of the approach for the communications infrastructure(s) that will support the smart grid. Figure 11 illustrates the general interdependence of the recommendations in the individual domains over the ten year period that is the focus of the roadmap. Note that the general flow of required developments is not absolute. Rather, each of the domains has ongoing development requirements throughout the period. However, the general dependencies are useful to recognize when identifying priorities for bridging development gaps or needs. Among the critical gaps include:

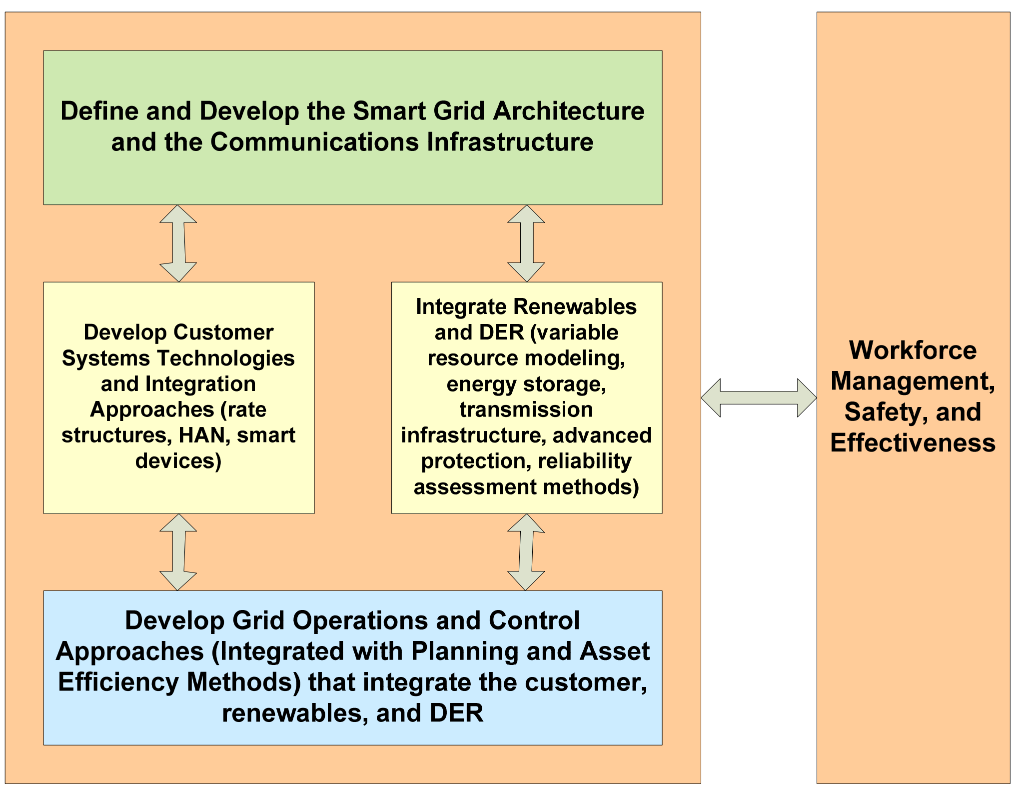
1. There is need for agreement on the architecture for the smart grid. This need is consistent with the priorities of the NIST Smart Grid Interoperability Panel and the work of the Smart Grid Architecture Committee.
2. The structure of the communications infrastructure and general approaches must be defined and understood so that new technologies can be developed that will interface with this infrastructure.
3. Technologies for customer integration with the grid will build on the definition of the communication infrastructure. Much will depend on rate structures and other incentives for customer involvement. An overall approach for the integration of electric vehicle charging is included, as PEV is an example of an important controllable load.

4. Requirements for integration of higher penetrations of renewables are needed at both the transmission and distribution levels. Analysis tools, forecasting, transmission infrastructure, compensation technologies, monitoring technologies, and distribution management approaches must all be developed.

5. Grid planning, operations, and control will go through a metamorphosis in support of the developments described above. Real time grid management approaches at the transmission level will incorporate demand response and distributed resources that are part of the distribution infrastructure, requiring close coordination between advanced distribution management and overall grid management. New models that support both planning and real time grid management will be needed and must be supported. The models will reach all the way to individual customers and associated distributed resources. Monitoring and control of this integrated grid will require management of widespread sensors (e.g., PMUs at the transmission level and smart nodes throughout the distribution infrastructure) that are integrated with the real-time system models. Reliability and security technologies must take advantage of these real time models for system awareness. However, system security cannot be completely dependent on a communication infrastructure, in light of ongoing requirements for distributed intelligence and the ability to operate safely with local controls.

6. Worker and public safety must remain the top priority as new technologies and system management approaches are implemented. New requirements for worker skills and training must be supported as the technology base for system management and operation changes.

**Figure 11: Interdependence of Domain Recommendations**



## Recommended Strategies for Bridging Development Gaps by Domain

Appendix D includes tables summarizing ongoing utility activities and demonstrations within each domain. These ongoing projects and demonstrations depict a foundation of activities that support smart grid development. Using these activities as a starting point, the discussion below outlines strategies for dealing with important development gaps in each of the domains and timelines for implementing the strategies.

The reader will note that the development gaps identified for Domain 3 (Grid Operations & Control) and Domain 5 (Grid Planning & Asset Efficiency) are combined below to simplify presentation and to eliminate overlap.

### Domain 1 – Communications Infrastructure and Overall Architecture

Developments in this domain are fundamentally required to support developments in all other domains. The overall architecture for the smart grid must be defined in conjunction with national (NIST, OpenSG) and international (CIGRE, IEC, ITU) activities.

The IOUs in California have been leaders in national efforts to define the smart grid. Southern California Edison hosted the meeting where the conceptual model for the smart grid architecture was developed for the NIST Smart Grid Interoperability Roadmap. All three utilities are leaders in the OpenSG efforts to define the architectural and security requirements for the smart grid. The SDG&E Borrego Springs project will help define how microgrids can be leveraged as part of the smart grid architecture. The SCE smart grid project will help focus on the need for the architecture that is a system of systems by demonstrating control system hierarchy. All three utilities are actively participating in PMU deployment and developing the architecture to manage PMU data for more intelligent control of the transmission grid (under the WECC Synchrophasor Initiative).

Ongoing development streams should continue to refine the smart grid information and communications architecture so that all interested stakeholders can develop products and systems for application within a defined architecture. Building on the foundation established, efforts should be coordinated with the NIST Smart Grid Architecture Committee (SGAC).

A major development stream focuses on continued definition of the overall information model for the smart grid and the information exchange requirements at all the points of interoperability. This is the major focus of the NIST Smart Grid Interoperability Panel (SGIP). The relevant NIST work should be supported in California as a leader in deployment.

Also needed is the continued assessment of communication technologies and the potential for a broadband communications infrastructure to support a variety of smart grid requirements. Particular focus on next generation wireless technologies is appropriate.

The transmission communications infrastructure will become integrated with enhanced substation data systems and will incorporate PMU information.

Security considerations must be addressed in the architecture, in the communications infrastructure, and in all the information exchange requirements at points of interoperability. This is an ongoing development requirement that will require significant research, demonstrations, and interoperability testing procedures (in coordination with NIST CSWG and the SGTCC).

**Table 22: Summary of Recommended Strategies for Research Needs in the Architecture and Communications Infrastructure Domain**

| Gap/Need | Strategy | 2010-2015 | 2015-2020 | >2020 |
|---|---|---|---|---|
| 1.1 Architecture for integration of utility back office systems with substations, field equipment, customer interfaces, and customer-side devices | NIST SGAC, OpenSG | | | |
| 1.2 Interface requirements and technologies for integrating substation data | 61850/CIM harmonizing, ICCP, DNP mapping and related standards | | | |
| 1.3 Interface requirements and data exchange standards (object models) for integrating field devices and sensors with both substation systems and enterprise data management systems | MultiSpeak, 61850 for distribution, DNP, CIM integration (NIST PAP 8) | | | |
| 1.4 Interface requirements and data exchange standards (object models) for integrating customer systems and devices with both substations and enterprise data management systems | Continued SEP development, CIM (Part 9) and Multispeak implementation | | | |
| 1.5 Interface requirements and data exchange standards (object models) for distributed and renewable generation technologies and storage with both substations and enterprise data management systems | IEEE 1547 (1547.8 for integration with distributed resources), NIST PAP 16 for wind, IEC 61850-7-420 for object models (WG 17) | | | |
| 1.6 WAN communications technologies and interfaces to support widespread substation integration for real time management, PMU integration, etc. | WAN technology assessments | | | |
| 1.7 Application of wireless technologies for field area network implementation | NIST PAP 2, IEEE 802 standards | | | |
| 1.8 HAN Communications technologies options (wired, wireless, PLC) and interoperability with utility interfaces | NIST PAP 15 (PLC), SEP Development and application across multiple technologies | | | |
| 1.9 Guidelines and technologies for security implementation as a function of risk assessments | NIST CSWG, ASAP-SG, DOE, NERC CIPS development, EPRI Security Program | | | |
| 1.9a Key management technologies for large numbers of field devices | NIST, IEC | | | |

## Domain 2 – Customer Systems

A key requirement of the smart grid is that it must facilitate integration of customer systems with the overall operation of the grid and markets. This is a tremendous challenge but there are many existing activities under way that are paving the way for this integration. California and Texas utilities, in particular, are leaders in this integration and are defining the architecture for the integration primarily through efforts in OpenSG. The work in OpenSG to define the requirements and specifications for the Smart Energy Profile (SEP 2.0) should be the foundation for ongoing development of the interface between the customer and the utility (or third parties). This is the focus of development in multiple NIST Priority Action Plans.

Demand response is already a tremendous asset in the California energy mix. However, there are significant opportunities to grow this resource through customer integration. Open ADR provides a foundation that has been adopted within NIST as a starting point for international standards. However, many questions need to be answered about how to integrate residential customers and make them part of the market.

Customer systems can be integrated through dynamic rate structures and all three IOUs have programs under way to evaluate the response to different rate structures and incentive approaches. California is already a leader in defining innovative rate structures to encourage energy savings and facilitate customer system response to system contingencies and emergency system conditions. Defining and evaluating innovative rate structures (and other options to provide customers incentives to participate) to accomplish particular goals requires ongoing research that can be coordinated with other major trials around the world (e.g. Exelon Commonwealth Edison and ESB Ireland).

All three utilities are leaders in developing the infrastructure for plug-in electric vehicle integration. There are numerous ongoing challenges associated with incentives, control schemes, and communications to derive available benefits from PEV charging flexibility. Particular challenges (e.g., architecture, data formats, certification requirements, etc.) need to be addressed in the structure and requirements for sub-metering of PEV charging and in the development of standards for high powered direct current charging.

Within customer systems, technologies for home energy management and smart appliances will need to be evaluated within the overall architecture. There will be many different proposals and technologies for customer systems. Careful development of requirements for these technologies is needed to assure that security and information management requirements can be met.

Finally, there will be a tremendous effort required to expand overall enterprise information systems to accommodate the additional information associated with widespread integration of distributed resources in grid and market systems. Trials are addressing this need at the present time but this will be an ongoing development need as the requirements for customer system integration are defined in more detail.

**Table 23: Summary of Recommended Strategies for Research Needs in the Customer Systems Domain**

| Gap/Need | Strategy | 2010-2015 | 2015-2020 | >2020 |
|---|---|---|---|---|
| 2.1 Demand Response Information Model that includes dynamic pricing, direct load control, distributed generation for normal conditions, emergency conditions, local conditions, etc. | Open ADR, NIST PAPs, integration with SEP 2.0 | | | |
| 2.2 Rate structures that can incorporate demand response incentives associated with market conditions and local conditions (e.g., dynamic rates) | Range of technical approaches that can be considered by state regulators for both widespread and local adoption - build on results of demonstrations | | | |
| 2.2a Specific rate structures and approaches for integration of smart appliances and enabling participation in ancillary services | NIST PAPs, research efforts, regulatory participation | | | |
| 2.2b Specific rate structures and approaches for integration of electric vehicle charging and enabling participation in ancillary services (HAN information model, protocols, etc.) | NIST PAPs, research efforts, regulatory participation | | | |
| 2.2c Specific rate structures and approaches for integration of distributed generation and storage (e.g. PV, storage inverters) with the operation of the grid | NIST PAPs, research efforts, regulatory participation | | | |
| 2.3 HAN devices that meet requirements associated with architecture, information models, and communication technologies | SEP 2.0, Appliance Interface project, AHAM, etc. | | | |
| 2.4a Infrastructure, information models, protocols for integrated transaction management associated with electric vehicle charging at locations other than home<br>2.4b Metrology structure, information exchange requirements, certification requirements, etc. for sub-metering of PEV charging<br>2.4c DC charging infrastructure, connector standards, and interface requirements for fast charging | Financial model must be adopted - needs to be consistent across states<br>NIST PAPs, research efforts, regulatory participation<br>NIST PAPs, research efforts, regulatory participation | | | |
| 2.5 Utility energy management systems and other enterprise information management systems that incorporate information from customer systems as part of the grid management and asset management functions | EMS vendor development based on standards<br>Implementation in demonstration projects | | | |

## Domains 3 and 5 – Asset Efficiency, Grid Planning, Operations, and Control

These domains deal with grid development and management of the grid to support widespread distributed resources, electric vehicles, reliability objectives, dynamic system protection, etc.

All three IOUs have many programs that are supporting this migration.

Distribution management system requirements are being developed along with initial projects to assess performance for applications like volt/var control. This is an early application under implementation at California utilities and many other utilities across the country that will help provide the foundation for DMS expansion and model-based management. This work can be coordinated with an EPRI initiative to develop industry standard load models that include the voltage response characteristics of the load.

Significant development is required to support the ongoing migration to model-based management of distribution systems. Initial efforts will be associated with utility trials using DMS technology that will help establish the requirements for integration with GIS and other enterprise applications. New modeling approaches and management tools will be developed in the future to optimize system performance, even with widespread distributed resources.

At the transmission level, the WECC synchrophasor initiative and coordination will provide the foundation for significant expansion of synchrophasor applications and development of advanced system management and control applications that take advantage of synchrophasor information.

Asset management and maintenance strategies will also take advantage of widespread sensors and automation. Ongoing development will build on efforts underway in the areas of dynamic asset rating and condition based maintenance (CBM), both of which require real time information integration.

**Table 24: Summary of Recommended Strategies for Research Needs in the Grid Operations and Control Domain (Includes Grid Planning and Asset Efficiency)**

| Gap/Need | Strategy | 2010-2015 | 2015-2020 | >2020 |
|---|---|---|---|---|
| 3.1 Standards for information models, protocols, and communication technology options for integration of widespread phasor measurement units (PMUs) with the operation of the grid, including sharing across systems. | NIST PAP, IEEE 1588, testing criteria | ■ | | |
| 3.2 Applications for data management and processing that can derive information from vast amounts of data from sensors, IEDs, etc. | Research initiatives, demonstrations | ■ | ■ | |
| 3.3 Wide area system management applications (EMS, real time state estimation incorporating PMU data, system analysis functions, visualization functions) that work within standard architectures (1.2). | Research initiatives coordinated with demonstrations | ■ | ■ | ■ |
| 3.4 Dynamic protection systems, applications for managing IED settings and coordination with wide area system management applications. | Standard approaches for managing IED settings in the real time (IEC 61850-6 SCL) | ■ | | |
| 3.5 Model-based management and planning of distribution systems that incorporates information from distributed sensors, customer models, distributed resources, etc. - both reliability applications and steady state optimization applications. Coordinates with architecture 1.3. | GIS standards and implementation, CIM development, real time model maintenance approaches, integration of applications - research and demonstrations | ■ | ■ | ■ |
| 3.6 Planning and implementation of voltage optimization at the distribution level incorporating advanced customer models, integration of distributed resources, and integration with system reconfiguration management. | Load modeling initiative, inverter voltage control integration, integration with DMS for reconfiguration coordination and model management - research and demonstrations | ■ | ■ | |
| 3.7 Distribution planning and operations to optimize performance with increased electric vehicle, renewable, and storage penetration. | Improved planning and design approaches, DMS advancements for PV, PHEV, storage integration | ■ | | |
| 3.8 Asset management applications that incorporate information from widespread sensors, equipment diagnostics applications, and risk assessment methods, integrated with system operation. | Research and demonstrations | ■ | ■ | ■ |
| 3.9 Improved system maintenance strategies based on conditions, widespread sensors, etc. - vegetation management, equipment maintenance, etc. | Research and demonstrations | ■ | ■ | ■ |

### Domain 4 – Renewables and DER Integration

California is a world leader in the integration of renewables and distributed energy resources at both the transmission and distribution level. All three IOUs have many programs that are supporting this migration. However, numerous challenges remain to be solved in order to achieve the 2020 targets and beyond.

Reliability assessment methods must be developed that address the much more complicated and interdependent nature of a grid with widespread penetration of distributed resources integrated with grid management. This will be an important industry-wide development need.

The overall development of model-based system management technologies will also include complete integration of distributed resource models and real time information. This starts with information models (initial and ongoing work in IEC 61850 standards – TC 57, WG 17) and must also include information exchange requirements for interoperability.

An initial meeting of IEEE 1547.8 was held in California to support development of procedures and guidelines that will allow distributed resources like storage inverters and PV inverters to participate in distribution management. PV generation is increasing at all three utilities and new distribution management technologies will be required to support their integration.

Modeling and forecasting improvements are needed to better integrate variable resources with markets and grid operations. Even with improved forecasting, technology advancements are needed to support frequency regulation, capacity and energy markets with higher penetration of renewables. Needed advancements include new storage technologies (flywheels, new battery technologies), new control approaches, and integration with improved models. Work is required to develop appropriate market structures for ancillary services to better accommodate participation of new technologies and systems like distributed storage, electric vehicles, and other demand responsive resources. Existing studies of grid impacts, battery applications, other storage initiatives, and high penetration PV all provide a foundation for these ongoing project needs.

**Table 25: Summary of Recommended Strategies for Research Needs in the Renewables and DER Integration Domain**

| Gap/Need | Strategy | 2010-2015 | 2015-2020 | >2020 |
|---|---|---|---|---|
| 4.1 Reliability assessment methods that take into account smart grid technologies, communications infrastructure, data management requirements and impacts, distributed resources integration and role in operating system, security implementations | collaborative research initiative across industry, including IEEE, to develop improved reliability assessment approaches and demonstrate them | ■ | | |
| 4.2 Transmission infrastructure required to integrate increased levels of renewable resources (including effect of technologies like var control, HVDC, demand response integration, etc.) | build on DOE-sponsored assessments | ■ | | |
| 4.3 Improved modeling and forecasting methods and applications for variable resources (that can be integrated with system operations at all levels) | Both PV and Wind - research and demonstrations | ■ | ■ | |
| 4.4 Characterize new technologies and costs that are required to manage higher penetration levels of variable resources - grid level (HVDC, var control, capacity requirements, ramping requirements, etc.) | research and demonstrations | ■ | ■ | |
| 4.5 Characterize new technologies and costs that are required to manage higher penetration levels of variable resources - distribution level (storage, demand response, smart transformers, inverter controls, var control, voltage control, protection, system reconfiguration, etc.) | research and demonstrations | ■ | ■ | |
| 4.6 Advanced applications for distribution protection and management that allow dynamic protection for DG integration, system reconfiguration, and microgrids | IEC 61850-6 SCL extended to distribution applications, DG, microgrids, etc. | ■ | ■ | ■ |
| 4.7 Power electronics technologies for advanced inverters with lower cost, reduced losses, and integration of technologies (transformer, storage, PV, electric vehicle charging) | research and demonstrations | ■ | ■ | |
| 4.8 Ancillary service infrastructure for integrating participation of distributed storage, demand response, etc. so that these resources can help facilitate increased levels of renewables on the grid | research (utilities, ISOs, universities, etc.) and demonstrations | ■ | ■ | |
| 4.9 Improved planning tools and methods that integrate demand response, customer systems, distributed storage, renewable characteristics, and advanced load projection approaches (T&D) | research (cooperation between universities, industry and utilities) and demonstrations | ■ | ■ | ■ |

### Domain 6 – Workforce Management and Effectiveness

The smart grid imposes new challenges on the workforce in terms of developing the necessary skills, providing training, assuring safety, and managing the workforce effectively.

Mobile workforce management is a particular area of development that will benefit from smart grid development. Implementation of new outage management systems (OMS) and distribution management systems (DMS) integrated with GIS and mobile workforce management systems has the potential to improve response times to disturbances, reduce repair times, and maintain or improve reliability. All three utilities have programs under way that are providing the foundation for these advanced systems. As the migration to model-based management of the distribution system occurs in the future, new opportunities to integrate with workforce management will be explored (for advanced fault location, condition based maintenance, etc.).

Tools and workforce training will have to keep up with the technologies being deployed in the field. This results in a need for coordination with educational facilities so that curriculum can be developed that is appropriate for technologies and systems that are being designed and deployed. New approaches like labs and simulators are being explored by SCE and others to provide more effective training opportunities. As the EMS and DMS technology continues to advance (real-time state estimation and risk assessment), these training systems will become increasingly important.

Finally, utility organizational structures may need updating to deal with the cross-functional nature of the smart grid and the new skill requirements for the workforce.

**Table 26: Summary of Recommended Strategies for Research Needs in the Workforce Management and Effectiveness Domain**

| Gap/Need | Strategy | 2010-2015 | 2015-2020 | >2020 |
|---|---|---|---|---|
| 5.1 Improved operator tools to manage the grid (T&D) - integration of information from sensors, analysis to identify problem conditions, visualization and notification approaches, etc. | research and demonstrations | | | |
| 5.2 Advanced mobile workforce automation - integration with real-time model based management of the grid, GIS, OMS, fault location, asset management systems (e.g. sensors and RFID tags), advanced systems for dispatching and tracking crews, standards for contracting work crews | research (utilities, universities, industry) and demonstrations | | | |
| 5.3 Improved training and information resource tools - on line training, guidelines available to mobile crews, integration with mobile devices (mobile phones, etc) | research (utilities, universities, industry) and demonstrations | | | |
| 5.4 Application of smart grid technologies to improve workforce safety - advanced protection systems, awareness of conditions, improved models linked to worker safety requirements (e.g. arc flash), warning systems for live lines, arcing, etc. | Research initiative | | | |
| 5.5 Organizational structures to facilitate smart grid - skills and capabilities matrix updates, role of IT and communications across organization, advanced maintenance and asset management integrated with operations, integrated planning, crew skills and training, etc. | research (utilities, universities, cross-functional) | | | |
| 5.6 Educational infrastructure linked to smart grid skills requirements and resource needs | Research initiatives and programs that are conducted jointly between universities, industry, and utilities - cross-fertilization | | | |

## Summary of Major Recommendations

This subsection summarizes major recommendations. They are organized into research or project *streams*, and not broken down by specific domains since many of them incorporate gaps that cut across domains. The research or project *streams* would be conducted in California and coordinated with national and international efforts. More detailed descriptions of the specific research needs under the major headings are provided in the individual domain chapters.

There is an emphasis on architecture, information models, and interoperability requirements, in terms of the focus recommended for development and coordination efforts. There are also important technology development needs that are documented underneath the headings below (e.g., power electronics technologies such as smart inverters, storage technologies, modeling and simulation technologies, advanced switchgear and protection to support microgrids, and sensor technologies). Technologies will continue to advance due to market pressures and manufacturer developments. However, projects to demonstrate these technologies should be combined with projects that also focus on the interoperability requirements for the technologies.

All of the streams represent ongoing efforts to be coordinated with efforts in other streams. They are organized below in basic order of when they need to be started. However, all essentially need to be started together and build on existing California and industry initiatives.

1 **Smart Grid Architecture Development and Specification**. The smart grid architecture must extend from the utility back office systems, through field equipment, all the way to customer-side devices.

   a. SGIP SGAC provides a coordinating point for definition of overall smart grid architecture needs – points of interoperability, basic assumptions, etc.

   b. Architecture that builds on "system of systems" concept, supporting needs for distributed controls and integrated management.

   c. California is one of the early adopter states for implementation of the architecture but should be consistent with overall industry requirements.

   d. Support interoperability development efforts in OpenSG, NIST PAPs and associated standards efforts. All three IOUs in California are supporting these efforts.

2. **Integrated Communications Infrastructure Plan and Specification.** Develop a plan and migration strategy for implementing an integrated communication infrastructure that incorporates needs of communications, reliability, and security across all levels of the smart grid.

   a. Map of existing and near-term communications infrastructures to support specific sets of applications (defined by use cases and requirements).

      i. Transmission infrastructure management, including phasor measurement units with wide area monitoring and control.

      ii. Substation automation and integration with both transmission and distribution management systems.

iii. Distribution automation and management with communication for distribution smart nodes, sensors, automation devices, volt/var control devices, and distributed resources.

iv. Advanced metering communications infrastructure.

v. Communications with customers for energy use information.

vi. Communication infrastructure options for demand response and electric vehicle charging management.

b. Technology assessments and demonstrations for integrated communications infrastructure that can support the applications described above.

i. Integrated broadband communications options (wireless, fiber, and others) for supporting integrated smart grid communications.

ii. Demonstrations to assess performance, reliability, security issues.

iii. Feasibility and recommendations for integrated broadband communications.

c. Migration and deployment strategy.

3. **Information Model Development that is Consistent with Smart Grid Architecture.** The Common Information Model (CIM) provides the overall concept for an integrated information model that supports both operations and planning requirements for the smart grid. Support for this development consists of continually identifying the use cases that define information requirements, extending the models accordingly, demonstrating the information models within enterprise architectures, and developing approaches for testing the information models.

a. Harmonizing of CIM and IEC 61850 to support interoperability and management of substations for energy management systems and distribution management systems.

b. Information model support for renewable generation assets and their operation.

c. Extend CIM to incorporate next generation distribution system model requirements, including for smart nodes and widespread distributed sensors, new technologies for voltage and var control, distributed storage, renewables, and advanced customer models. (See ensuing discussion below.) Coordinate the information model requirements with the requirements for next generation simulation tools.

d. Model extensions to represent customer characteristics in the smart grid, including advanced load profiles (stochastic and dependent on important variables like temperature), electric vehicle charging control, voltage sensitivity, demand response characteristics, distributed generation, local storage, etc.

4. **Demand Response and Customer Integration Strategies and Technologies.** This is a critical area for the entire industry and there are many different approaches being considered. Different approaches for customer integration include economically-

triggered demand response, direct load control, emergency demand response, or other variations of these basic approaches. It is possible that basic economically-triggered schemes can be used in combination with direct control options under some conditions (e.g. response to both local and system-wide emergency conditions).

a. Develop approaches for integrating local condition constraints into price-based demand response approaches (development, demonstrations, trials, etc.).

b. Develop concepts and demonstrate combinations of direct control and price-based demand response systems. Assure that proposed architectures can support different approaches. Assess performance, customer participation, system benefits, etc.

c. Customer education and communication approaches to enhance customer understanding and appreciation. Best approaches for engaging customers should be addressed along with the technical requirements for customer systems integration.

d. Develop appropriate systems for commercial and industrial interfaces (e.g., price-based, contractual-based with direct control, contractual-based without direct control, etc.) Develop models to evaluate effectiveness of different approaches. Define range of approaches that must be supported in overall architecture. Define data exchange requirements for these interfaces.

e. Develop and assess market structure alternatives for demand side and distributed resources to provide ancillary service.

    i. Frequency regulation

    ii. Capacity markets

    iii. Generation markets

f. Develop appropriate systems as a function of different types of widely distributed resources (e.g., distributed generation, storage, electric vehicle charging, air conditioning, water heaters, and other smart appliances).

5. **Interoperability Requirements and Data Exchange Specifications at all Critical Interfaces in the Smart Grid Architecture.** This effort builds on the overall information model described above but focuses on actual data exchange requirements for smart grid applications. This work is the primary focus of the Smart Grid Interoperability Panel (SGIP) and work in California should be coordinated with this national effort.

    a. Substations – within the substation, support ongoing development of IEC 61850 standards for communications interfaces between equipment in the substation.

    b. Define the overall requirements for a **substation data manager** to integrate data within the substation for operations, planning, and asset management applications.

c. Define interoperability and data exchange requirements for distribution grid management applications, including the integration of distributed resources and storage as an integral part of grid management.

   i. Protection functions and interoperability requirements in the smart grid (probably building on IEC 61850 concepts but meeting requirements of the more distributed nature of protection requirements on the distribution grid – migration strategy from DNP).

   ii. Grid management requirements for optimization – volt var control, minimizing losses, reliability.

   iii. Interoperability and data exchange requirements for asset management.

d. Extend interoperability and data exchange requirements to customer systems, including electric vehicle charging, demand response integrated with automation systems, support for local microgrids, etc. Work in OpenSG to define the requirements for the Smart Energy Profile provides an initial foundation for this integration. Ongoing development is needed as the use cases are refined for advanced applications that integrate customer systems with the operation of the grid.

e. Define security requirements at each of these interfaces based on risk use cases and risk assessments. Such work has started under EPRI ASAP-SG efforts and is to be coordinated with the NIST CSWG. The effort should be supported in California to make sure that the interoperability requirements and protocols adopted can handle security requirements.

6. **Advanced Data Management, Analysis and Visualization Approaches.** The overall information model provides the foundation for understanding the important parameters, condition, and status of all the assets and equipment on the grid. Widespread sensors and condition monitoring, in addition to advanced metering and distributed resource monitoring, will result in massive amounts of data that must be managed, processed, and evaluated for important decisions. New approaches that combine distributed data management with advanced central data management and visualization approaches are needed. These are especially needed in the following application areas:

   a. Wide area monitoring and control – data analysis, management and visualization for PMUs and sensors throughout the grid to understand conditions and support advanced controls and decision making.

   b. Distribution grid management and control – distributed versus central data management and processing to understand conditions and control requirements throughout the distribution system; including advanced customer models, distributed resources, demand response, asset conditions, and maintaining the real time distribution model.

c. Distributed resource management, control, and integration – management of the tremendous range of controllable devices and resources on the grid, distributed vs. central management options for these resources, optimization approaches, etc.

7. **Wide Area Monitoring and Control Advancements for Large Scale Renewable Integration.** Meeting the needs for integrating 33 percent renewables with the grid requires advancements in both technologies and grid management approaches. Better forecasting and integration of changing forecasts with the operation of the grid will be combined with use of storage, flexible generation, and demand response for real time control.

   a. Integration with improved forecasting methods and tools.

   b. Integration of real time information from PMUs, etc. to support decisions and control of technologies like flywheels, batteries, var control systems, flexible generation and demand response. Development of analysis and optimization approaches with all these variables is needed.

   c. Integration with widespread electric vehicle charging control is an objective for next generation management.

   d. Visualization tools to support operator requirements.

8. **Advanced Technology Assessments and Integration.** Many new technologies will be needed to support widespread distributed resource integration and associated grid management. Customer side technologies were addressed in Stream 4. This stream addresses grid technologies that will enhance smart grid performance.

   a. Sensor technologies. Various sensor technologies will support understanding conditions on the grid in close to real time. This will support condition-based maintenance, asset management, risk assessment, and real time control of the grid.

      i. Voltage and current sensors for grid management

      ii. Equipment condition sensors (temperature, leakage current, dissolved gas, etc.)

      iii. Electric and magnetic field antenna sensors and systems

      iv. Infrared sensors and systems

   b. Power electronics technologies for advanced grid integration functions in distribution systems.

      i. Smart inverters with voltage and var control functions (e.g. storage and PV)

      ii. Solid state switchgear for automation and microgrids

      iii. Fault current limiters

      iv. Solid state transformers for integration of PV, storage, and EV

c. Advanced technologies for transmission grid management and renewable integration.

    i. Advanced storage technologies (e.g., flywheels, batteries, etc.)

    ii. Advanced technologies for volt/var control (e.g., static var systems, advanced wind turbine inverters, and advanced inverters for large storage)

    iii. Role of HVDC

d. Advanced protection technologies and systems.

    i. Dynamic protection systems

    ii. Advanced relays that incorporate distributed resource integration and support of microgrids

    iii. Fault and incipient fault detection and location, including effects of distributed generation

    iv. Integrated communications

9. **Model-Based Management of the Grid for both Real Time and Planning-Based Applications.** Information model development provides the foundation, while communications infrastructure provides the basis for the actual implementation of advanced model-based management of the grid. This does not mean that all decisions must be made from a central system. Rather, the architecture must support a combination of distributed and central management. But the concept emphasizes a model that is maintained to support management and decisions from real time control to long time asset management. Key requirements can be addressed in a range of individual projects and coordination efforts.

    a. GIS-based model development and definition in conjunction with information models.

    b. Model maintenance requirements .

        i. GIS and workforce interfaces, asset management

        ii. EMS/DMS interfaces for real time status

        iii. Customer models and conditions (AMI interfaces)

        iv. Distributed resource conditions

    c. Customer and distributed resource integration with the model, including voltage response characteristics for energy efficiency and demand management.

    d. Distributed resource control characteristics integrated with the system models – PV inverter controls, storage inverter controls, generator controls, etc.

    e. Advanced simulation approaches for real time management – parallel processing, distributed processing combined with central optimization, etc.

f. Advanced reliability assessment methods utilizing risk-based analysis with distributed resources. Identification of approaches for maintaining or improving reliability with technology, simulation tools, and workforce management (fault location, asset condition assessment, advanced maintenance).

g. Incorporation of microgrid concepts into model-based management approaches. Modeling of microgrids, integration with microgrid controllers, etc.

h. Operator interface requirements and technologies for managing widespread resources.

**10. Workforce Development and Workforce Management for the Smart Grid.**

a. Workforce skills development.

  i. Skills development within utilities

  ii. University-led skills development programs

  iii. Trade-based skills development programs

b. Mobile workforce management and technologies.

c. Tools and technologies for safety of workforce and the public.

  i. Workforce technologies (e.g., wearable technology, detection technologies, and communications)

  ii. Arc flash detection and tools

  iii. Detecting ground faults and arcing conditions

  iv. Workforce management and tools for safety improvement

d. Training tools.

  i. Simulators

  ii. On line training programs

  iii. Coordination with universities and other resources

e. New organizational structures to support smart grid integration throughout the company.

# CHAPTER 11: Conclusions

## Benefit Impacts of the California Smart Grid

The California Smart Grid offers an array of potential benefits to customers, society, and the environment. Advanced monitoring and control capabilities will increase utility technical efficiency to improve overall performance of the power system—increasing asset utilization, limiting T&D losses, and enabling many smart grid capabilities including integration of renewable resources, reliability-based demand response and customer energy management to reduce peak demand. Results include kWh and kW reductions and associated environmental improvements in the form of reduced emissions of greenhouse gases and pollutants including $PM_{10}$, SOx, and NOx. ). Improvements in grid operations, communications, and data integration contribute to maintained or improved service reliability, which in turn can result in fewer or shorter outages than would otherwise occur. Advanced grid monitoring and condition assessment will help maintain or improve power quality by predicting potential problems to reduce harmonics and improve voltage regulation. Widespread adoption of plug-in electric vehicles will help reduce greenhouse gas and pollutant emissions and strengthen national security by reducing consumption of imported petroleum. Security is also enhanced by the smart grid's improved resistance to cyber threats as well as physical attack. Finally, safety will be enhanced by the design, development and adoption of advanced tools and training methods, for the benefit of the existing and future workforce in the electric power industry.

## Project Achievements

This project synthesized utility perspectives on development of the California Smart Grid in light of key energy policy and other drivers, including greenhouse gas reduction, renewables portfolio standards, DER integration, energy efficiency, system reliability, transportation electrification, and security and privacy.

The project team defined the utility vision of the California Smart Grid of Year 2020 and defined pathways to reach the vision, using Year 2010 as a baseline. The team also developed assumptions about factors that will continue to drive smart grid development. California has many existing initiatives, projects and demonstrations that put it in a leadership position for implementing the smart grid at all levels.

The team performed a detailed assessment of technology, policy, standards, process, and education gaps that need to be closed to fully implement the smart grid vision. This report identifies approaches for addressing these gaps reported by technical domain area. It provides technology roadmaps and recommendations for addressing gaps, towards realizing the 2020 vision of the California Smart Grid.

The project team proposes ten research and development streams that cut across domain areas to coordinate ongoing development of the smart grid. These streams are interrelated and require coordination across streams and with both national and international efforts.

The proposed RD&D activities also reflect common themes that the team identified during the project. For utilities, a key driver for smart grid development is maintaining or improving reliability in the face of the increased grid complexity. Efforts to meet ambitious energy and environmental policy targets could degrade power system reliability. For utilities, the smart grid represents the most appropriate technical and cost-effective approach for maintaining or increasing power system reliability while achieving policy targets.

Utilities have traditionally introduced technologies to improve power system reliability, increase operational efficiency and improve safety. The selected technologies were new, but proven and mature. Now, however, energy policies are driving the adoption of new technologies, including some that are less mature or still in development. As a result, utilities are presented with the considerable challenge of maintaining reliability while achieving ambitious policy targets and also dealing with technologies at different levels of maturity. Utilities will thus be simultaneously deploying new smart grid infrastructure while also engaged in research and development and laboratory testing of new technologies.

Recognizing these challenges, the project team has taken a careful, detailed, and systematic approach to developing a vision for the California Smart Grid and roadmap to achieve the vision. The findings shared in this report provide a structured framework and foundation for achieving the California Smart Grid and capturing many types of benefit impacts.

# CHAPTER 12: References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# CHAPTER 13: Glossary

| | |
|---|---|
| AB | Assembly bill. A state law passed by the legislature. |
| AC | Alternating current. An electrical current whose magnitude and direction vary cyclically, as in a sine wave or other waveform, for more efficient transmission of electric energy. |
| AGC | Automatic generation control. |
| AHAM | Association of Home Appliance Manufacturers. A trade association based in the U.S. consisting of the home appliance manufacturers. |
| AMI | Advanced metering infrastructure. |
| ANSI | American National Standards Institute. |
| ASAP-SG | Advanced Security Acceleration Project for Smart Grid. An EPRI project focused on security for the smart grid. |
| ASHRAE | American Society of Heating, Refrigeration and Air Conditioning Engineers. An international organization with the "mission of advancing heating, ventilation, air conditioning and refrigeration to serve humanity and promote a sustainable world through research, standards writing, publishing and continuing education." (Source: http://www.ashrae.org/aboutus.) |
| ADR | Automated demand response. Demand response enabled through automation and communications with customer end-use equipment. |
| ARRA | American Recovery and Reinvestment Act. Legislation passed by the U.S. Congress in 2009 in support of retaining and creating jobs, economic activity and investment in long-term growth. |
| CAES | Compressed air energy storage. |
| CAIDI | Customer Average Interruption Duration Index. A reliability index commonly used in the electric power industry indicating the average outage duration experienced by customers, or average restoration time. |
| CAISO | California Independent System Operator. The regional transmission and market system operator of the state of California. |
| CARB | California Air Resources Board. An organization with the objective "to promote and protect public health, welfare and ecological resources through the effective and efficient reduction of air pollutants while recognizing and considering the effects on the economy of the state." (Source: http://www.arb.ca.gov/html/mission.htm). |
| CBM | Condition based maintenance. An application of sensors, monitoring systems, and processes to support maintenance of equipment in service as the need arises. |
| Energy Commission | California Energy Commission. |
| CHP | Combined heat and power. Refers to a system in which heat and electricity are generated simultaneously, with the thermal energy used for end-use requirements such as water heating, process heating, or cooling. |
| CIM | Common information model. A standard developed in the electric power industry that has been officially adopted by the IEC and is aimed at enabling application software to exchange information about the configuration and status of an electrical network. |
| CIP | Critical Infrastructure Protection. |
| CIPS | Critical Infrastructure Protection Standards (CIPS). A set of NERC guidelines for preparedness and response to security concerns involving critical infrastructure of a region. |
| CIS | Coordinated information system. |
| CPUC | California Public Utilities Commission. |
| CSI | California Solar Initiative. |
| CSWG | Cyber Security Working Group. |
| CVR | Conservation Voltage Regulation. |
| DA | Distribution Automation. |

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|---|---|
| DER | Distributed energy resources. Electric energy sources that typically include distributed generation and storage and may be interconnected with the power system at transmission or distribution level voltages. |
| DFR | Design for reliability. |
| DG | Distributed generation. Active energy sources such as a microturbine, diesel backup generator, or other standby generation that may be interconnected with the power system at transmission or distribution level voltages. |
| DGA | Dissolved gas analysis. |
| DMS | Distribution management system. A control system to manage distribution power operations through a combination of communications with field equipment and hierarchical control algorithms. |
| DNP/DNP3 | Distributed Network Protocol. A set of communication protocols developed to facilitate communications between data acquisition and control equipment. DNP is primarily used by utilities and between components in process automation systems. |
| DOE | U.S. Department of Energy. |
| DR | Demand response. A dynamic change in electric load regarded as a valuable service to a system operator, such as customer response to prices, notifications, controls, or other signals designed to coordinate changes in electric power demand. |
| DSA | Dynamic Stability Assessment. |
| DSM | Demand Side Management. |
| EE | Energy Efficiency. |
| EMS | Energy management systems. 1) A centralized communication and control system for the management of power delivery operations or 2) a system for monitoring and controlling end-use equipment within a building. |
| EPRI | Electric Power Research Institute. |
| ES | Energy Storage. |
| ETO | Emitter turn-off thyristor. |
| EV | Electric Vehicle. |
| EVSE | Smart Electric Vehicle Supply Equipment. |
| FACTS | Flexible AC transmission systems. A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability. |
| FERC | Federal Energy Regulatory Commission. |
| GHG | Green house gas. A gas when in high concentrations in the atmosphere contributes to the greenhouse effect and global warming. |
| GPS | Global Positioning System. |
| GTO | Gate turn-off thyristor. A type of thyristor with fully controllable switches which can be turned on and off by the GATE lead. |
| GWh | Gigawatt-hour. |
| HAN | Home area network. |
| HVAC | Heating, Ventilating, and Air Conditioning equipment. |
| HVDC | High voltage direct current. |
| IEC | The International Electrotechnical Commission. This organization prepares and publishes international standards for all electrical, electronic and related technologies. |
| IED | Intelligent electronic devices. |
| IEEE | Institute of Electrical and Electronics Engineers. A professional engineering association for electrical, electronic, and other engineers. |
| IEPR | Integrated Energy Policy Report. A 2007 report that provides an integrated assessment of the major energy trends and issues facing the California's electricity, natural gas, and transportation fuel sectors, and provides guidance on state energy policy. |
| ICCP | Inter-Control Center Communication Protocol. |
| IDS/IPS | Intrusion Detection System/Intrusion Prevention System. |
| IOU | Investor-owned utility. |
| IP | Internet protocol. |
| IPv6 | Internet Protocol Version 6. |

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| IS | Interconnection system. |
| ISO | Independent System Operator. A regional system operator responsible for the reliable operation of the bulk electric transmission system in its FERC-approved geographic territory. |
| kW | Kilowatt. A unit of measurement of power equal to 1000 watts. |
| kWh | Kilowatt hour. |
| LED | Light-emitting diode. |
| LSE | Load serving entity. |
| LVRT | Low voltage ride-thorough technology. |
| MAIFI | Momentary average interruption frequency index. |
| MPU | Microprocessor Unit. |
| MRTU | Market Redesign Technology Upgrade. |
| MVA | Megavolt ampere. |
| MW | Megawatt. |
| NaS | Sodium sulfur battery. |
| NASPI | North American Synchro Phasor Initiative. |
| NERC | North American Electric Reliability Corporation. |
| NGV | Natural gas vehicle. An automobile, truck, or other transport vehicle fueled by natural gas. |
| NIST | National Institute of Standards and Technology. A federal institute with the objective of promoting "U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life." (Source: http://www.nist.gov/public_affairs/nist_mission.htm). |
| NREL | National Renewable Energy Laboratory. A national laboratory with research and technology development areas that "span from understanding renewable resources for energy, to the conversion of these resources to renewable electricity and fuels, and ultimately to the use of renewable electricity and fuels in homes, commercial buildings, and vehicles." (Source: http://www.nrel.gov/overview/). |
| OEM | Original equipment manufacturer. |
| OMS | Outage Management System. |
| OPC/UA | OPC Unified Architecture. The next generation of the OPC standard defined by a layered set of specifications providing a cross-platform framework for accessing real time and historical data. |
| OpenSG | Open Smart Grid Users Group. |
| OPF | Optimum power flow. |
| OSHA | Occupational Safety and Health Administration. |
| OSI | Open Systems Interconnection. An initiative that developed the OSI Basic Reference Model. |
| OSI BRM | Open Systems Interconnection Basic Reference Model. Also known as the OSI seven layer model, this is an abstract description for communications and computer network protocol design. It is comprised of seven layers with each layer representing functions providing services to the layer above and receiving services from the layer below. |
| PAP | NIST Priority Action Plan. |
| PAS | IEC publicly available specification. |
| PCT | Programmable communicating thermostat. |
| PDC | Phasor data concentrators. |
| PEV | Plug-in electric vehicle. |
| PIER | Public Interest Energy Research. |
| PMU | Phasor measurement unit. |

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|---|---|
| PQ | Power quality. A broad term used to describe the measurement of electrical power performance. Variations in voltage, frequency, wave shape (harmonics) and other aspects of power may make the power delivered to equipment less than ideal, creating compatibility problems. Electronic equipment may be especially sensitive to power quality problems. |
| PV | Photovoltaic. |
| RBAC | Role-based access control. |
| REC | Renewable energy credit. |
| RD&D | Research, development, and demonstration. |
| RFID | Radio frequency identification. |
| RMR | Reliability must run. A specially designated resource under contract to provide reliability services in a regional electric power system. |
| RPS | Renewables portfolio standard. |
| SAIDI | System average interruption duration index. |
| SAIFI | System average interruption frequency index. |
| SCADA | Supervisory control and data acquisition. |
| SEPv2 | Smart Energy Profile 2.0, a standard for communications and information exchange extending to and within customer premises for AMI/HAN. |
| SGAC | Smart Grid Architecture Committee. A NIST-organized committee responsible for developing a conceptual reference model for the smart grid and listing necessary standards for implementing the smart grid vision. |
| SGIP | Smart Grid Interoperability Panel. A broad group of smart grid stakeholders organized by NIST to provide an open process for participation in the coordination, revision, acceleration and harmonization of smart grid standards. Members of the SGIP develop and review use cases, identify requirements, and propose action plans. |
| SIS | System impact study. |
| SOA | Service oriented architecture. |
| SPS | Special protection systems. |
| STATCOM | Static Synchronous Compensator. |
| SVC | Static var compensator. An electrical device providing fast-acting reactive power compensation on high voltage electric transmission networks as part of a flexible AC transmission system. |
| T&D | Transmission and distribution. The power delivery system or business area. |
| TC | Technical committee. |
| TCP | Transmission control protocol. |
| TLM | Transmission line matrix. |
| TOGAF | The Open Group Architecture Framework. |
| VAR | Volt-ampere reactive. A unit of reactive power. For a two-wire circuit, the product of the voltage times the current times the sine of the angular phase difference by which the voltage leads or lags the current. VARs and watts combine in a quadrature relationship to form volt-amperes. |
| VSA | Voltage Stability Assessment. |
| V2G | Vehicle to Grid. |
| V2H | Vehicle to Home. |
| WAMACS | Wide area measurement and control system. |
| WAMS | Wide area measurement system. |
| WASA | Wide area situational awareness. |
| WECC | Western Electricity Coordinating Council. A regional forum that promotes electric service reliability in the Western United States and Western Canada. |
| WG | Working group. A subgroup of a larger community that typically conducts technical work surrounding a given topic. |
| WIKI | Wiki are websites of interlinked web pages that facilitate easy creation and editing by groups using a web browser and a simplified markup language. |
| WMS | Work Management System. |
| XML | Extensible Markup Language. A specification for creating custom markup languages to facilitate the sharing of structured data across disparate information systems over the Internet. |

# APPENDIX A: Baseline Projects by Domain Area

**Table 27: Sample of 2010 Baseline Projects of Four California Utilities for Customer Systems**

| PG&E | SCE | SDG&E | SMUD |
|---|---|---|---|
| Leadership in developing industry standards for in-premise smart appliance and consumer device communications | Active participant in interoperability and cyber-security standards development initiatives | Participant in interoperability and cyber-security standards development initiatives | Active participant in interoperability and cyber-security standards development initiatives |
| Smart Meters (In progress) | Edison SmartConnect Metering (In Progress) | Smart Metering (In progress) | Smart Metering (In progress) |
| | Home battery pilot program (In Progress)<br>Community energy storage program (In Progress) | | |
| | Energy smart customer devices (ARRA project, To Start 2010) | DOE/CEC Microgrid (In Progress) | Some Pilots in customer devices such as PCT's<br>Microgrid (In Progress) |
| | | Customer enhancements currently under way | |
| N Gateway Pilot currently underway | Home Area Network (HAN) In-Premise Display field trial (In Progress)<br>SCE.com provisioning of "Bill Assistant" next-day information (In Progress) | HAN Pilots: Low Income IHD PrePilot (complete)<br>Employee PCT evaluation (complete)<br>Low Income IHD continuation (in progress)<br>Residential Automated Control Technology Pilot (in progress)<br>Small and Medium C&I PCT Pilot (2011 expected) | |
| Broadband Over Powerline Pilot | | Demonstration of 1G Broadband Over Powerline (BPL) from 5 vendors | |
| Electric vehicle and system design impacts (In Progress) | PEV Integration & metrology technology development and testing(In Progress)<br><br>Hybrid Electric Medium and heavy duty vehicle evaluation (In Progress) | PHEV integration (In Progress)<br>eTec electric vehicle demonstration to start in 2010 (eTec is a wholly owned subsidiary of ECOtality ) | ARRA projects in PHEV |
| Dynamic pricing (PDP, PTR) (In Progress)<br>Real-time pricing integration (In Progress) | Proxy Demand Resource Pilot for aggregated air conditioning and a small agricultural pumping demonstration (to start 2010) | | |

**Table 28: Sample of 2010 Baseline Projects of Four California Utilities for Grid Operations and Control**

| PG&E | SCE | SDG&E | SMUD |
|---|---|---|---|
| Install/Replace control room w/Modular Protection, Automation and Control Technology | Application of Advanced Wide Area Early Warning Systems with Adaptive Protection – ARRA DOE Advanced Protection | | DOE FOA 58 – Smart Grid Investment Grant: substation and line automation, AMI, demand response, dynamic pricing, Integrated DMS |
| SCADA recloser program | | Intellirupter deployment | |
| Develop, Test and Evaluate Wireless Faulted Circuit Indicator | | Wireless fault indicators | |
| | 138kV Transmission FCL Research | | |
| eGIS – This is a project to deliver an enterprise GIS system at PG&E that supports all functional areas | | Geographic Information System (In progress) | |
| NaS BESS – Deploy a 6MW, 42 MWh, NaS Battery Energy Storage System (BESS), and its associated protection and control equipment | | 1 MW, 6 MWh storage technology for Borrego Springs microgrid project | Utility and residential scale battery storage (In progress) |
| Network Transformer with SCADA monitoring updates and historian applications | | | |
| Integrate Outage Management System (OIS) with Smart Meter | Enhanced Outage Management (In Progress)<br>Initiated Distribution Management system and Advanced Load Control – 2009 | Enhanced outage and distribution management systems (In progress) | |
| DG/DER Monitoring & Control | Distributed Energy Resource Integration | PV monitoring of utility owned systems | |
| Transmission System Dynamic Volt/VAR | PMU-Enabled Voltage and VAR Control Demonstration | Dynamic VAR system (In progress) | |
| Enhanced EMS | Upgraded EMS w/Advanced Applications – 2009 | | |
| Remedial Action Scheme– 500 KV/PACI RAS | Initiated Centralized Remedial Action Scheme – 2009 | RAS schemes in place | |
| PEV Monitoring and Control | | Nissan Leaf and charging station deployment | DOE FOA 85 – High penetration Solar, Anatolia subdivision (In progress) |
| Regional Synchrophasor Demonstration<br>Participation in Western Interconnection Synchrophasor Project (WISP) | Initiated Wide Area Situational Awareness System – 2009<br>Participation in Western Interconnection Synchrophasor Project (WISP)<br>Wide Area Controls (WACs) Roadmap Development | PMU installation (In progress) | |
| Transmission, substation and distribution system automation (In Progress) | Distribution Automation (switch and a half based scheme) | Significant penetration of SCADA, open loop 1.5 switch design | |
| | Ongoing Network based substation automation | Smart substations (In progress) | |
| | EPRI – Green Transmission Project | | |

**Table 29: Sample of 2010 Baseline Projects of Four California Utilities for Renewable & DER Integration**

| PG&E | SCE | SDG&E | SMUD |
|---|---|---|---|
| Solar<br>Received CPUC permission to implement a 500-MW PV program where we would install 50 MWs per year of 10-20 MW utility-owned projects over 5 years. There would be a comparable program for 50 MW per year of IPP-owned PV. | Solar<br>• Inverter Characteristics Evaluation and Documentation<br>• 250 MW solar rooftop + 250 MW IPP solar rooftop programs<br>• CSI Program | Solar<br>Solar Power Initiative | Solar<br>• 19 MW of customer and utility scale PV interconnected to SMUD's system as of 12/31/09<br>• Planned 100 MW of feed-in tariff derived PV in negotiations with expected commercial operation date of 2012.<br>• Planned PV modeling, resource data collection and forecasting research planned as part of CPUC CSI #1 award<br>Planned 1.5 MW of CPV in Solar Highways application as part of DOE FOA 122 award |
| Compressed Air Energy Storage (CAES)<br>Awarded a $25 million DOE grant and had matching funds approved by the CPUC to evaluate and design a 300-MW Compressed Air Energy Storage facility in Kern County. | | | |
| Energy Storage<br>• There are three energy storage activities underway. PowerGen has FERC preliminary permits to study two new Pumped Storage sites for up to 1,000 MW each.<br>There is a 4-MW Sodium Sulfur battery being installed in San Jose to improve power quality on that circuit. | Energy Storage<br>• Tehachapi Storage Project 8MW, 36MWh<br>• Community Energy Storage Pilot Program<br>• Home Battery Pilot Program<br>Distribution Grid Support System Storage Pilot | Energy Storage<br>Micro Grid Project includes utility owned battery storage installations | Energy Storage<br>• Awaiting FERC license for Upper American River Project hydro system which includes possible 400MW pumped hydro storage project (could be built by 2020)<br>• 15 residential and 3 community lithium ion storage devices being installed in SolarSmart Homes community as part DOE FOA 85 award<br>• 2 500kW/6 hour zinc bromine flow batteries to be installed at two sites as part of DOE FOA 36 award. |
| Wave Power<br>Filed for a preliminary permit in partnership with Vandenberg AFB for a wave project off VAFB's coastline. | | | |
| Fuel Cells<br>Customer Care recently received CPUC approval for a demonstration project with three fuel cells on two CSU campuses. | Fuel Cell<br>Generation Strategy & Planning Project | Fuel Cell planned as part of sustainable community project | Fuel Cell<br>Planned demonstration of 700 – 1000 kW Ztek SOFC operating on dairy biogas as part of DOE FOA 122 award |
| | Wind<br>Generation Strategy & Planning Project | | Wind<br>Collecting and evaluation wind resources in Northern California and Oregon for possible future development |
| | Studies<br>• Bulk Wind Power Storage Needs for integration Assessment<br>Bulk and Distributed Renewable Resource Integration Impact Studies | Renewable integration studies | Studies<br>• Total Renewable Portfolio mix as of 2009: 2246 GWh of delivered eligible renewables which equates to 23% retail sales (see accompanying graphs at end)<br>o 25% small hydro<br>o 49% biomass<br>o <1% PV<br>o 10% geothermal<br>o 25% wind<br>Mix of SMUD owned and PPA; and instate and out-of-state |
| | Renewable Integration Tech Development | | |
| | | Borrego Springs Microgrid project | Microgrid<br>300 kW natural gas reciprocating engine coupled with 10 kW PV microgrid in design phase for demonstration at SMUD HQ as part of Energy Commission PIER R&D award |

**Table 30: Sample of 2010 Baseline Projects of Four California Utilities for Grid Planning & Asset Efficiency**

| PG&E | SCE | SDG&E | SMUD |
|---|---|---|---|
| **Grid Efficiency & Voltage Reduction** | | | |
| **Metering** | | | |
| • Smart Meters | • SmartConnect Advanced Metering installation throughout the service territory (~ 5 M meters <200 kW) | • AMI Deployment, 2.3M meters by end of 2011 | • AMI Deployment, 600k meters by end of 2011 |
| **Grid efficiency** | | | |
| | • Grid Efficiency/Green Circuits Project | • CVR on 80% of distribution circuits | • Demonstration of Volt/Var control for selected 12 and 21 kV circuits |
| **Advanced equipments** | | | |
| • Smart Substations – Modular Protection & Control Systems, Electronic loading data | • Smart Distribution Transformers | Smart Distribution Transformers | |
| **Asset Management & Performance Optimization** | | | |
| **Asset Management, CBM** | | | |
| • Condition Based Monitoring pilot | • Transformer Dissolved Gas sensor installation on 500/230 and 230/66 kV transformers | • Condition-based maintenance program full rollout, 28 substation by year end 2010 | • Implemented Condition Based Maintenance |
| | | • Smart Substations CBM deployment system wide | |
| • Vegetation and pole test and treat handheld devices | | | |
| | | • Asset Investment Optimization tool | |
| **Planning for Grid Growth** | | | |
| **Planning** | | | |
| • Advanced Planning Tool | | • SynerGee distribution load flow program and new OMS/DMS by end of 2011 | |
| **Advanced equipments** | | | |
| • High capability conductors and real time ratings | • Superconducting Distribution Sub-Transformer | • Demonstration of composite core conductor installation, multiple DLR installations | |
| **EV integration** | | | |
| • Electric vehicle and system design impacts | • EV Readiness program underway<br>• Testing EVs and batteries at EV Technology Center | • DOE funded ETEC Electric Vehicle Demonstration, 1000 EVs and 2500 charging stations | |
| **Demonstrations** | | | |
| | • Circuit of the future/Avanti "Circuit of the Future" test bed extension | • DOE/CEC Microgrid | • CEC Microgrid |
| | • Y2020 Distribution System (Irvine Smart Grid Demonstration) | Self-Healing circuit pilots | • DOA 85- high penetration Solar (Anatolia subdivision) |

**Table 31: Sample of 2010 Baseline Projects of Three California Utilities for Workforce Effectiveness**

| PG&E | SCE | SDG&E |
|---|---|---|
| | Developed "Fieldworker of the Future" concept, inclusive of workforce safety equipment, mobile field tools and communications gear, heads-up displays, etc. | Deployment of field worker effectiveness tools such as Mobile Data Terminals (MDT) and an integrated forecast, scheduling and dispatch tool |
| | Instituted a workforce "Innovation Lab," that will determine how the next generation workforce will be equipped | Automated disabling of vehicle MDT's while field force is driving |
| | Technology evaluation of utility RFID applications, including RFID tags for device identification | Simulators used to support training of system operators |
| | Technology evaluation of safety equipment including fall protection vests, personal voltage detectors, etc. | Utilization of safety equipment including fall arrest protection and systems, personal voltage detectors, etc. |
| | Evaluation of Hiperwall technology for improved system operator visualization tools | Over 60% of SDG&E's circuits have (SCADA) automated devices on them |
| Upgrading of vegetation and pole test and treat handheld devices | Investigating robotics/remotely piloted vehicles for remote inspections | "Best in class" skills training facility: Real equipment for hands on learning (overhead, underground, gas installations, maintenance real world scenarios) |
| EMS has full simulator built in for operator training | EMS has full simulator built in for operator training | Sensors in substations to enable "conditioned based" maintenance |
| | | Practice and monitor and consistently anchor behavior based safety, Smith Driving |

# APPENDIX B: Educational Needs

In the design and implementation of the smart grid, colleges and universities can play a role in four areas:

1. Academic research: developing and analyzing new technologies and operating approaches in theory
2. Practical applications: working with industry to get promising technology ready for implementation
3. Education: training the next generation of industry professionals and researchers
4. Public outreach: identifying and communicating public interest dimensions of the "smart grid"

While the University of California (UC) generally is involved in areas (1) and (3) and the California State University (CSU) plays a more important role in (2) and (3), collaboration is important to assure meaningful integration and timely progress. Note that in (3), the emphasis in the UC/CSU system is on educating professional engineers and engineering researchers; the community colleges provide more specific technical training to industry workers. Few if any programs offer technical information on power systems for non-engineering professionals. Level (4) has not historically been emphasized but may have significant bearing on successful smart grid implementation.

Gaps and recommendations identified here will focus on area (3), with some reference to area (1).

*State of Power Systems Education and Research*

Smart grid education is necessarily built upon a broader, fundamental education in electric power systems. Unlike most cases of technological innovation, smart grid enhancements must be made to an existing legacy infrastructure without disrupting its function, while being interoperable with century-old components. A thorough understanding of legacy technology is therefore vital for all entrants into the field even though their focus may be on new devices, methods or applications.

Advanced power systems or smart grid research depends not only on qualified faculty, but also on a qualified cadre of graduate or advanced undergraduate students to participate as research assistants. Undergraduate and master's coursework and degree programs are therefore the foundation for research activities. However, among the University of California and California State University systems, only five campuses offer a standard concentration in power engineering within their electrical engineering departments, primarily through undergraduate programs.

Several campuses (Cal Poly Pomona and Cal Poly San Luis Obispo) offer master's degrees, and one campus (UC Berkeley) a master's and PhD in electrical engineering with some coursework in power engineering. Only one campus (Sacramento State) has an official program designation in power engineering at the master's level but is still in its early stages of growth (having recently received specific support from the California Energy Commission to build a "Smart Grid Center"). Leading universities in power engineering education across the United States are those affiliated with the Power Systems Engineering Research Center (PSERC), funded by the

National Science Foundation. PSERC has 13 member universities, of which a small minority have extensive course offerings in power engineering. UC Berkeley is the only California university currently affiliated with PSERC.

More characteristically, departments of electrical engineering and computer science focus on information technology, electronics and control system aspects and offer one or only a few elective courses related to power systems. In most cases, these are one-semester overview courses. The relative lack of power engineering programs is generally seen as a consequence of waning student interest over the past decades, after electronics and semiconductor technologies became a more promising and exciting field for many young people. This phenomenon is not unique to California, although it may be particularly pronounced here because of the central role Silicon Valley has played in our state's economy and culture.

Lacking student interest in turn has led to a reduction of resident faculty specializing in power engineering as they retire or relocate, often replaced by electrical engineering faculty with other areas of specialization. Very few new faculty positions were created in the area of power systems over the past decades. To compound this problem, creating new tenure-track faculty positions in the UC and CSU systems has become exceedingly difficult due to the recent budget crises.

Student interest in power and energy systems now appears to be increasing. Several important factors are:

- the recognition that the evolution from legacy to smart grids offers exciting intellectual challenges
- economic growth opportunities in the area of smart grid technologies and the Cleantech industry
- interest in energy and the environment, especially the environmental implications and the role of "green" energy

These factors should be leveraged in order to recruit the best and brightest students into the field.

### *Curricular Needs: Engineering Programs*

The main areas of power engineering curriculum can be categorized in terms of

- electrical engineering fundamentals (e.g. circuit analysis)
- power systems hardware and operation (e.g. three-phase transmission)
- emerging technologies (e.g. advanced control systems)
- economic analysis and policy (e.g. electricity markets)

The above areas are foundational for any smart grid education efforts. Obviously, the area of new and emerging technologies receives special emphasis in the context of smart grids. Examples include inverters, storage technologies, synchrophasor measurements and advanced protection schemes, to list only a few.

In addition to studying specific technologies and applications, however, smart grid education will require a new emphasis on integration of components. Integrative areas for smart grid education that have not traditionally been included in all power engineering programs include the following:

**a. Information and communication systems**

This area overlaps with existing curricula in electrical engineering and computer science, where it may focus on many applications other than electric power. Expertise here needs to be effectively integrated with knowledge of legacy power systems, both by including an information technology component in the power engineering curriculum and by exposing IT or computer science majors to power systems applications.

**b. Practical aspects of operations**

Academic and analytic work aiming to improve and optimize electric power systems must not lose sight of practical aspects and realities of grid operation at all levels, including generation, transmission, distribution, and interfacing with customers. Because many smart grid innovations involve changes to established operating and management strategies, curricula must include information about how the system actually works at present and cultivate an awareness of practical constraints for implementing new technologies. For example, innovative automation strategies must take into account the full complexity of tasks presently performed by human operators, while advanced metering or demand response programs must consider the broad spectrum of customer preferences and behaviors. Practical dimensions of engineering education include not only hands-on laboratory experience with equipment and simulation tools, but familiarity with the actual operations context through field visits.

**c. Human factors**

One common aspect of the many diverse technologies considered to represent "smart grids" is that they involve large volumes of data to be measured, communicated, and acted upon. At the same time, while the bulk of engineering education focuses on technology, human operators remain the critical nexus in making power systems work. A vital topic in smart grid education, therefore, is the management of information in order to support decision-making by human operators. This includes study of information aggregation, visualization tools, and other aspects of supporting situational awareness on the part of operators, of which design engineers must be cognizant. Simultaneously, smart grid workforce training should enable operators to interact most effectively with advanced information tools and media.

**d. Passive safety engineering**

Smart grid engineering curricula must include emphasis on passive safety and reliability. Since no new technology can be reasonably expected to launch without errors, a key aspect of smart grid innovation is designing for graceful failures (i.e. failures that are contained, correctable, and enable learning). Most important is assuring the physical safety of workers and the public during any and all failures of smart grid components; secondarily, systems should be designed to default into manageable operating states in the event of component, communication or control system failures.

**e. Complex systems theory**

Due to growing size and stronger interconnection, AC grids exhibit ever more behaviors characteristic of complex systems, including emergent properties that defy conventional analysis and modeling (for example, low-frequency oscillations across the Western Interconnect). Parallel to a solid foundation in practical aspects of power systems operation, smart grid engineering curricula should include academic components that address abstract and advanced mathematical understanding.

**f. Energy economics**

Because of the central role of markets dynamics on both the supply and demand side, smart grid education should provide increasing coverage of economic theory and applications to diverse aspects of power markets. Standard engineering curriculum typically addresses economic optimization approaches, but significant emphasis is also needed in the areas of changing utility regulation, changing markets, and changing rules, laws and standards that apply to diverse stakeholders interconnecting on the grid.

**g. Cross-disciplinary exchange and interdisciplinary research**

Smart grid design, implementation and operation is informed by different engineering specializations and disciplines as diverse as computer science, materials science, psychology, economics, and regulatory policy. Many universities have significant capabilities in these related areas, but no core focus on power systems. A collaborative meeting ground is necessary to bring together the expertise and ideas from the various disciplines.

### *Curricular Needs: Community Colleges*

In addition to a cadre of engineering graduates from California universities, a substantial industry workforce is needed that is conversant in smart grid technologies. The community colleges play a critical role in the area of providing specific technical job preparation and continuing education for a wide spectrum of workers in the field. Examples of technical skills include:

- connecting smart-grid devices
- understanding protocols
- providing data analysis
- operating computer systems
- utilizing and trouble-shooting advanced communications tools

Even though some human workers may be replaced with technology (e.g. automated meter reading), the number of technology-literate specialists needed in the workforce must be expected to increase dramatically with the penetration level of smart-grid devices—both because human decision makers are required at many levels for effective and secure system operation, and because automated processes do not always work as intended.

### *Supporting Activities*

In addition to formal coursework, other avenues of knowledge sharing provide a critical infrastructure for student learning and research outcomes; this is true in any field of study, but especially so in one with immediate practical applications for societal benefit. Effective smart grid education therefore hinges not only on course offerings and curriculum development, but on the cultivation of active learning communities that include academics and professionals at different stages in their careers, and with a broad range of sub-specialties. The cultivation of professional relationships and information sharing can be facilitated by providing opportunities and frameworks for interaction. For example, the “Smart Grid Workforce Development Network” is an effort by the Smart Grid Center at CSUS, which aims to coordinate workforce development initiatives among electric utilities, CSU campuses, community colleges, labor unions, and smart grid manufacturers. Other examples are colloquia and forums for “Smart Grid Information Sharing” regularly hosted at research institutions, including non-profit research institutes such as EPRI and private institutions such as universities.

# APPENDIX C: Gaps and Recommendations

## Domain 1: Communications Infrastructure and Architecture

### Smart Grid Systems Architecture

*Gap 1:* A scalable, event-driven smart grid architecture must extend from the utility back office through field equipment to customer-side devices.

Recommendations:

- Support continued interoperability standards development efforts and research aimed at improving the ability for individual smart grid systems to **participate in an integrated "system of systems."**
- **Support the use and adaptation of formal methods** for smart grid systems integration specification to ensure robust, reliable, and scalable design that places a priority on mitigating cyber security concerns.
- **Support research and policy development in data management** to ensure that the extensive increases in data generated by the smart grid can be readily stored, accessed, utilized, and archived, all while mitigating privacy concerns.

### Communications Networks, Systems, and Data Integration

*Gap 1:* The capabilities and vulnerabilities of wireless technologies, particularly meshed technologies, are not yet well identified with respect to which could or should or should not be used for different types of applications.

Recommendation:

- Support NIST PAP 2 to help develop guidelines on the use of wireless technologies.

*Gap 2:* Lack of co-existence capabilities of certain protocols over communication networks, particularly Power Line Carrier (PLC) in the Home Area Network.

Recommendation:

- Support NIST PAP 15 to ensure compatibility of PLC HAN networks for all appliances, DER, and other customer applications.

*Gap 3:* Lack of commercially available smart applications to sift through vast amount of data for key information from an assortment of data sources and loggers (PMUs, DFR, SER, Digital Relays).

Recommendation:

- Support activities for developing advanced and fast analytics for processing large amounts of information and for looking for abnormalities in the data.

*Gap 4:* Network software architecture has not kept pace with easy-to-use operating systems and network hardware.

Recommendation:

- Standardized system architecture design; enable data sharing; use as much as possible off-the-shelf products as much as possible; easily integrated and configured (highly scalable and flexible, easy to install/operate, and maintain) and easy to interface with other systems.

*Gap 5:* It is not clear how utilities will determine pricing signals with the goal of maintaining or improving power system reliability and efficiency.

Although there are many activities focused on demand response and how customers might respond to pricing signals, very little focus has been given to how utilities are going to determine these pricing signals with the goal of maintaining or improving power system reliability and efficiency. The little that has been done has targeted peak shifting—certainly an important capability, but by no means the only beneficial capability.

Recommendations:

- **Support utility determination of requirements for price-based algorithms for demand response, and assess impacts and customer reactions to demand response.** Although regulators and tariffs will provide the overall scope and rules, the actual determination of a pricing signal – or location marginal pricing at a feeder or regional bases – at the distribution level, will require detailed analysis of managed load, ES-DER availability, and customer reactions to pricing signals within the area targeted for demand response. Such analysis must consider that overreactions by customers and their programmed systems could be as problematic as under-reactions.
- **Support utility development of power-flow-based analysis requirements for managing ES-DER in support of distribution reliability and efficiency.** Since it is expected that ES-DER devices, some owned by utilities and others owned by customers, will be used to support distribution operations, it is critical that power-flow-based analysis tools be implemented to determine when, what, and how much ES-DER support will be needed for different situations.
- **Support utility development of data simulation models.** These models include control-feedback loops for diagnosing and responding to system problems, leading to improved self-healing, grid resiliency, and ultimately, optimized grid infrastructure.

## Interoperable Communication Protocols, and Information Models

Many gaps exist for Communications Protocols and Information Models, including the following key gaps:

*Gap 1:* A self-healing smart grid requires the use of smart, interoperable, and self-defining communication standards based on object models.

Recommendation:

- Transition in a timely manner to object modeling communication standards should become a key goal.

*Gap 2:* Many of the NIST PAP efforts are dominated by vendor perspectives, so the requirements developed in the PAP processes reflect vendor understandings of what utilities might need—which may not reflect the real needs of utilities. The same problem exists in the standards development activities, including the IEEE and the IEC. This participation is vital to ensuring the standards truly meet utility requirements.

Recommendation:

- Utility perspectives and requirements should help drive the NIST PAP activities and the subsequent standards developments. Funding or other mechanisms are needed to ensure this happens.

*Gap 3:* Specific object models need either to be developed or enhanced, and, more importantly, adopted by utilities and manufacturers.

Recommendation:

The following efforts in developing and enhancing object models should be recognized and supported:

- Wind power plants have been modeled in IEC 61400-25 (61850-based model), covering basic monitoring and control. Condition monitoring enhancements are being developed. Wind power plant operators should be encouraged to utilize these standards rather than relying on proprietary communications.
- Photovoltaic systems (PV) have been modeled in IEC 61850-7-420, covering monitoring and control. These models are being enhanced to include some ancillary services, such as var support by inverters and schedules of volt-var combinations. Implementation of these standards should be encouraged.
- Storage systems combined with DER have also been modeled in IEC 61850-7-420, with the same type of enhancements planed. Implementation of these standards should be encouraged.
- Object models of fuel cells, diesel generators, and combined heat and power systems have been developed in IEC 61850-7-420. Implementation of these standards should be encouraged.
- Distribution automation devices, such as reclosers, automated switches, capacitor bank switches, load tap changers, and voltage regulators, have object models in IEC 61850. Implementation of these standards should be encouraged.

*Gap 4:* Mapping of the IEC 61850 object models to various protocols should be tested and validated. For instance, mappings of IEC 61850 to MMS, web services, and Modbus have already been developed, while mapping to DNP3 and OPC/UA are underway. Future mappings to SEPv2 are expected when that protocol is defined.

Recommendation:

- While the MMS mapping has been well tested in ICCP and substation automation, the other mappings must undergo rigorous conformance testing and validation. In particular, given the expectation of significant numbers of ES-DER and PEVs within customer sites, the mapping of the existing IEC 61850 models of these devices to SEPv2 should be strongly encouraged.

## Cyber Security

Although much publicity has focused on the need for cyber security to prevent nation-state terrorists, rogue terrorists, and even run-of-the-mill hackers, the August 14, 2003 blackout experience indicated that the information infrastructure failures were not due to any terrorist or Internet hacker or virus; these failures were caused by inadvertent events—mistakes, lack of key alarms, and poor design. Consequently, in order to fulfill the primary goal of maintaining or improving the reliability of the power system, inadvertent compromises of these cyber systems must also be addressed. Therefore, a holistic approach needs to be taken, covering deliberate attacks (e.g. disgruntled employees, industrial espionage agents, vandals, cyber hackers, viruses and worms, thieves, and terrorists) and inadvertent situations (e.g. careless users, employees who bypass security, poorly designed systems, unintended consequences of multiple actions, safety system failures, equipment failures, and natural disasters). Additionally, given the increasing importance of customer actions to power system reliability, the issues of customer privacy and confidentiality issues must be addressed.

Cyber security is an enormous topic, but some key gaps and basic recommendations can be made:

*Gap 1:* Lack of guidelines for determining security requirements.

Recommendation:

- Review the NIST Guidelines for Cyber Security Requirements. The first step in determining a good cost/impact balance is to understand the security requirements for all "cyber assets", where these assets can be defined as physical systems/equipment, stored cyber software and information, and the flows of information across interfaces between systems. The NISTIR 7628 provides guidelines for security requirements, and should be used as both a guide and a checklist of possible requirements.

*Gap 2:* Lack of understanding on balancing the true security impacts for the power infrastructure against the threats and vulnerabilities, in order to assess what appropriate security technologies and methodologies must be applied.

Recommendation:

- Cyber security must balance the cost of implementing security measures against the likelihood and impact of any security breaches. This balancing of cost vs. impact must take into account that excessive costs could impact customer rates, but that inadequate security measures could allow unnecessary power outages to those same customers. The cost/impact balancing also must recognize that no single security measure is 100 percent effective in preventing a security breach – and that security breaches will inevitably occur. Therefore, layered security measures must be applied and methods must be developed so that if one security barrier fails, another is there to deter, detect, cope with (intrusion response), or at least create an audit trail for forensic analysis, corrective action, possible legal actions, and future training.

- Undertake continuous cycles of risk assessments to determining the appropriate levels of security for each asset, including physical assets, systems and software applications, and information assets – "The punishment must fit the crime", or in this case "The cost of preventing or coping with security breaches must fit the probable impacts resulting from those security breaches".

*Gap 3:* Lack of focus on the critical role of information in the smart grid.

Recommendation:

- Focus on information flows across interfaces. The security requirements for hardware and software are often easier to determine and to protect than those for the information flows across interfaces. However, access to sensitive information and the ability to tamper with critical data could ultimately cause more damage than blowing up a substation. Therefore the focus of cyber security guidelines is not only on equipment and systems, but predominantly on the interfaces to and between systems.

*Gap 4:* Recognize that power system reliability is a key cyber security objective.

Recommendation:

Recognize that power system "availability" (reliability) is a cyber security goal and has the highest priority for power system operations. In the smart grid, there are two key purposes for cyber security:

- **Power system reliability:** Keep electricity flowing to customers, businesses, and industry. For decades, the power system industry has been developing extensive and sophisticated systems and equipment to avoid or shorten power system outages. In fact, power system operations have been termed the largest and most complex machine in the world. Although there are definitely new areas of cyber security concerns for power system reliability as technology opens new opportunities and challenges, nonetheless, the existing energy management systems and equipment, possibly enhanced and expanded, should remain as key cyber security solutions.
- **Confidentiality and privacy of customers:** As the smart grid reaches into homes and businesses, and as customers increasingly participate in managing their energy, confidentiality and privacy of their information has increasingly become a concern. Unlike power system reliability, customer privacy is a new issue.

Therefore, expanding existing power system management capabilities to cover major security requirements, such as power system reliability, should be a top priority. For instance, power-flow models and other analysis capabilities are crucial as demand response and high penetrations of DER are deployed and the power system becomes even more dynamic.

*Gap 5:* Lack of key management technologies for large numbers of field devices.

Recommendation:

- Key management technologies for large numbers of devices must be developed. Traditional IT key management procedures cannot function well when large numbers of devices, such as meters, electric vehicles, and consumer products, are involved. New key management procedures must be developed: NIST is developing the new key management requirements, while the IEC is working on key management standards that will meet those requirements. These key management efforts should be recognized and supported.

*Gap 6:* Suspicious events that escalate into incidents must be recognized quickly, and contained in order to minimize adverse impact to the system and recovery of the system can begin.

Smart grid security systems should be designed to automate response by either automatically responding to detected incidents, or by providing recommendations that can be acted on immediately by a human operator to minimize incident impact. Utilities should have mature, well tested and documented incident response capabilities. Incident response capabilities should include the ability to collect, store, correlate, analyze and formulate potential responses to vast numbers of individual events per second in order to alert operators to incidents that require attention along with recommended actions. Utility incident response organizations should combine joint physical and cyber security capabilities for a more complete picture of a developing incident, and respond to such incidents more quickly. Incident responders should be readied for incident response activities through training, procedural development, testing and continuous improvement. Smart grid products made by third parties and utilities' smart grid systems should be designed such that normal system behavior is clearly documented and recognizable by other third party security systems, and anomalous or suspicious behavior is quickly detected without complex signatures or the generation of excessive false positives. The communication of anomalous or suspicious behavior should use a common taxonomy that can be shared between different third party security systems both within a utility, between utilities, and between utilities and governance organizations such as WECC or the Department of Homeland Security.

Recommendation:

- California Incident Response Teams (IRTs) should be coordinated together with CAISO, WECC, federal and state emergency and law enforcement organizations. Common organizational, process, and technological interfaces between these organizations should be planned, agreed upon and implemented. Third parties that plan to produce smart grid products should determine how they will describe normal system behavior to security systems and alert operators to anomalous or suspicious behavior.

Timing of Recommendations

All recommendations under Domain 1 would ideally be pursued starting now or in the very near term.

## Domain 2: Customer Systems

### Demand Response

*Gap 1 (Standards)* – Incomplete demand response information model for dynamic pricing, load curtailment, generation management, and ancillary services.

- Open ADR is one OpenSG activity that is developing a partial, but currently incomplete and limited information model. It does not yet include models for many types of DR, including Peak Time Rebate, DER ancillary services management, multicast capabilities, etc.

- NIST PAPs 3, 4, & 9 are developing different aspects of dynamic pricing and scheduling models for use in DR, and are not yet complete.
- SEP 2.0 is still in the specification phase. It will incorporate the information models from CIM, IEC 61850, BACnet, AHAM, and other sources. At this time, it has only load-related DR object models, while DER modeling is very simplistic. It will need to incorporate the IEC 61850 DER models related to DR.
- None of the DR models includes the ability to request ancillary services.

Recommendations:

- Support continued development of utility DR requirements to meet utility operational needs, including load management, generation management, energy storage management, ancillary services such as voltage management, var management, frequency deviation mitigation, black start, operational reserves, and other functions.
- Continue support of utilities working with the appropriate NIST PAPs and other standards development groups to ensure that the information models meet those requirements, probably using a phased approach.

*Gap 2 (Policy)* – Need for new customer programs and rate structures to enable demand response and customer choice, and need for supporting policy/regulation.

- To enable residential customers and their energy management systems, DER devices, plug-in electric vehicles, and smart appliances to respond appropriately to latest grid and market conditions, new customer programs and rate structures need to be developed and tested.
- These new programs and rate structures are currently prevented by legislation in an environment of conflicting energy policies.
- Retail rates/programs need to be designed against a balanced energy policy that spans environmental sustainability, economic efficiency, and social equity.

Recommendations:

- Support trials of different DR programs and rate structures should be undertaken to refine which ones would be the most effective in achieving the desired objectives from customer responses, while ensuring broad customer acceptance of the programs.
- Identify capabilities and limitations of enabling technology that support DR rate structures (e.g., smart appliances, PEVs, distributed generation, energy storage, and other smart systems).
- DR rate structures should address not only customer responses to energy-related actions, but also to ancillary services actions.

- Support studies to align retail rates/programs for greater customer value capture (e.g., avoided operational costs) when leveraging smart grid capabilities to operate closer to the margin.

*Gap 3 (Policy)* – Need to support the emerging HAN device/appliance market to incentivize the development of equipment able to participate in DR programs.

- Without incentives, vendors are not likely to provide the more expensive, value-added capabilities that their devices/appliances would need to participate in the DR programs.
- Without incentives, customers are less likely to purchase DR-enabled devices and appliances.

Recommendations:

- Support incentive programs (e.g. utility rebates, state tax credits, etc.) to influence the adoption of certified HAN equipment.
- Work with utilities and HAN equipment vendors to develop labeling guidelines for DR capability for different HAN devices (e.g. common comparable statistics, common scoring mechanism, color code, etc.).
- Consider using building codes to influence deployment of HAN-compatible devices (e.g. smart pool pumps, communicating thermostats, etc.).

*Gap 4 (Process)* – Need utility energy management requirements for smart device/appliance responses to DR signals.

- Certain smart devices/appliances could not only shift their energy usage, but also provide ancillary services such as var support, voltage support, operational reserve, black start support, and frequency-deviation mitigation.
- Utility requirements for this emerging HAN device/appliance market are needed to ensure that these new smart devices/appliances are designed to provide the most effective, efficient responses to DR signals.
- Utilities have helped develop var support requirements for inverter-based PV/Storage, and identified additional energy and ancillary services that could/should be supported.

Recommendations:

- Support utility efforts to develop requirements for different types of energy-related responses by smart HAN devices and appliances.
- Develop a database of smart devices/appliances that includes standardized characteristics of their response capabilities, including energy curtailment, voltage support, var support, and other ancillary services.
- Ensure that the SEP 2.0 conformity framework is adequate not only for the interoperability of different HAN-enabled appliances but also DER devices, PEVs, customer EMSs, and other types of systems.

*Gap 5 (Standards)* – Object models need to be developed and/or enhanced for HAN-based devices and appliances used in energy management, so that they can participate in Demand Response programs.

- Fully functional object models are needed for distributed generation devices, energy storage units, plug-in electric vehicles, and electronic appliances such as plasma screens, computers, set top boxes, etc.
- SEP 2.0 will be able to incorporate these object models once both they and SEP 2.0 are implemented.

Recommendations:

- Support efforts of experts in developing the requirements for these object models, including appliance manufacturers, DER manufacturers, and utilities for energy management interactions.
- The actual object models could be standardized to BACnet for appliance-oriented objects, in IEC 61850 for power system devices, and in CIM for application-to-application interactions as an example.

*Gap 6 (Policy)* – Absence of a utility earnings incentive mechanism for demand response resources.

- Without utility shareholder incentives, the costs for implementing DR will be an impediment to wide deployment.
- Need to establish an incentive similar to a shared savings incentive mechanism for energy efficiency.

Recommendations:

- Support a financial incentive mechanism that rewards utility shareholders when customers use energy in a way that reduces costs and maintains or increases reliability.

*Gap 7 (Technology)* – Absence of a workable support model for new customer service needs that are related to the adoption of HAN devices and smart appliances by utility customers.

- Utilities have not previously been in the business of supporting consumer electronics integration into a smart grid/HAN.
- Organizational guidelines are needed for Customer Services departments on how to support customer service inquiries regarding HAN devices/appliances.
- Guidelines are needed on the line of demarcation between device vendors and utility for providing support.
- Guidelines are needed for back office systems and architectures to accommodate device management, etc.

Recommendations:

- Support utility efforts to develop guidelines for Customer Services related to supporting HAN devices and appliances.

- Support CIM development of Customer Services models (see IEC 61968-8).

*Gap 8 (Policy)* – Need jurisdictional clarifications regarding the use/control of demand response resources.

- Jurisdiction over demand response resources is not always clear, with potential overlaps in control jurisdiction existing across ISOs, utility grid operators, utility power procurement and 3rd party energy service providers/aggregators.
- Individual resources should not be allowed to provide mutually exclusive energy services to multiple parties at the same time.
- The same resources should not use incentives from, or provide benefits to, multiple programs for the same services at the same time.

Recommendations:

- Facilitate the clarification of use/control of demand response resources and the allocation of benefits across mutually exclusive users: e.g. ISO for grid support, ISO for market operations, utility power procurement, utility grid operations, and 3rd party energy services aggregators.

## Electric Transportation

*Gap 1 (Technology)* – No standardized HAN communication protocol for electric vehicle charging.

- 5 PLC-based candidates from SAE currently are under consideration between the charger and the battery.
- Smart Energy 2.0 has not identified the PEV messages needed to support advanced charging.

Recommendations:

- Support utility efforts to work with SAE to pick 1-2 PLC based protocols for PEV charging to minimize fragmentation of the market; selection criteria should be based on their rankings to support the relevant SAE adopted use cases for PEV charging and the SEP 2.0 standard for HAN energy management.
- Support the development of IEC 61850 standards, started recently, for interactions between the HAN environment and the PEV charger.

*Gap 2 (Technology/Policy)* – No established financial model of billing for electric vehicle charging in different service territories.

- Many financial models are possible, with varying impacts on utility costs for billing.
- One financial model is that the home-utility rate would apply regardless of where the PEV owner charges the PEV—the telecommunications model.
- Another financial model is that drivers would pay the price where they are charging, rather than having a home-utility special rate—the “gas station” model.

- Variations on these models reflect issues such as whether reselling of electricity would be permitted, whether prepaid "utility smart cards" would be available, or whether a national bill processing capability is developed, etc.

Recommendations:

- Let the market develop to determine the most effective models.

*Gap 3 (Technology)* – Traditionally electric utilities own and self certify the metrology required for capturing revenue grade energy billing data. Furthermore, when special rates are offered for specific equipment such as PEV charging, many utilities will require a second independent meter to measure consumed energy. Currently, the industry at large is exploring methods of leveraging advanced technology such as Home Area Networks (HAN) to facilitate energy measurement of PEV charging without the complexities of second independent meters. Such measurement is needed to support not only the metering of PEV-specific rates, but future requirements for carbon measurement (e.g., Low Carbon Fuel Standards) and or potential road taxes. Two methods of metering PEV loads are operational today: whole house TOU and separately metered (i.e., in parallel with building or house loads) PEV loads. Under consideration, but not available today is a "sub-metering" alternative. This is a method for capturing PEV charging data using a meter in-line (i.e., in series) with the main building and requires utilities to subtract or reconcile the two data tables in order to bill the customer separately for the PEV usage. This metering approach will require additional "back office" billing, programming and customer service support. This is a new area under review in the CPUC's Alternative Fueled Vehicle Order to Institute Rulemaking ("AFV OIR"), currently underway, in the context of other metering technology and with an interest in the integration of the sub-meter metrology with charging equipment. The traditional line between customer and utility owned equipment begin to merge and questions of ownership and certification under review in the AFV OIR:

- Who and how can PEV metrology be certified when it potentially can be installed on-board the vehicle, in the charger, separate parallel meters or sub-meters in the home and non-home settings.
- Other issues are under review in the AFV OIR:
    - Metering ownership & provision of metering services.
    - PEV usage data access.
    - Role of the various entities in the PEV market space.
    - Standards for integration of charging systems with the utility grid.
    - Meter certification, security and calibration.
    - Rate design and cost allocation.
    - Back office support.
    - PEV metering RD&D.

Recommendations:

- Support a multi-lateral evaluation of the pros and cons for the PEV load metering alternatives (e.g. on-board, off-board, unique meter, sub meter, etc.) in terms of the requirements of the customer and the utility, and other entities.
- Work with regulators regarding data transfer and format standardization.

*Gap 4 (Technology)* – Although initially most automakers will be deploying plug-in vehicles with on-board charging capabilities (AC Charging), many automakers are beginning to explore the need for off-board charging (DC Charging). This is mainly attributed to the fact that conventional on-board charging designs are power (kW) limited. Off-board charging gives automakers the freedom to increase power content and hence decrease the charge time. It is still uncertain what power levels will be required to support a massive deployment of vehicles and how the general public will utilize such assets. Furthermore, SAE among other standards organizations is still trying to develop a connector to support DC charging.

- In early deployments it is almost certain that automakers deploying DC chargers will use non-standard connectors and hence run the risk of future stranded assets or instituting a de-facto standard that may not properly meet the best interests of the industry in general.

Recommendations:

- Support the standardization of DC charging levels and connectors.
- Study the charging behavior of early adopters to justify the need and deployment of high powered DC charging.

*Gap 5 (Technology)* – Leveraging advanced smart grid communications for PEV applications such as energy metering and demand response programs can support the national effort of integrating electric transportation with the electric grid. Currently NIST under mandate by congress is leading an effort to reconcile smart grid standards among them the development of a national plan for the standardization of smart grid communications.

- Need to determine the communications infrastructure functional and non-functional requirements to support advanced grid-integrated electric transportation applications including metering and demand response programs.

Recommendations:

- Study communications needs (speed/performance, latency, bandwidth) required to support smart charging capabilities.
- Support the standardization of smart grid communications.

## Security

*Gap 1 (Policy)* – Customer privacy issues need to be addressed.

- What customer data can/should be shared with 3rd party companies like Google & Microsoft (with customer permission)?
- How can privacy concerns be addressed?

Recommendations:

- Utilize the NIST NISTIR 7628 (final) to provide privacy guidelines for the smart grid.
- Business models like Onstar and Medic Alert should be studied to see their approach to the customer privacy issue while collecting personal data on their customers.
- Leverage the existing legal statutes on customer privacy to support development of a workable model.
- Let the smart grid and alternative fuel vehicle OIRs take their course.

## Domain 3: Grid Operations and Control

### Wide Area Situational Awareness and Control

*Gap 1 (Standards)* – Synchrophasor standards incomplete; or standards in need for harmonization.

- Lack of consistency of sampling rates, filtering techniques and compression practices used by different PMU vendors.
- PMU timestamps requirements are not specifically covered in standards.
- Differences among calculation algorithms used by PMU vendors (e.g. phase angle calculations) which may lead to substantial difference in phase angle calculations.
- No standards exist for calibration of PMUs, and lack of uniformity in on-line correction of errors (introduced by instrument transformers, signal transducers, input circuits, data concentrators, multiplexers, etc.) used by the different PMU vendors.
- Lack of solutions for measurement-error for combined traditional telemetry and PMUs for state-estimation.

Recommendations:

Support research and activities aiming at:

- Accelerating standards harmonization.
- Developing standard testing criteria and comparison techniques for wide-area measurement and control devices.
- Developing calibration rules for PMUs and amount of error in PMUs that is acceptable.
- Procedures to compute and report (along with the time stamp) the quality (expected error or accuracy) of phasor measurement.

*Gap 2 (Technology)* – Lack of PMUs that can perform reliably at 120 samples per second (or better). Higher sampling rates will provide a more accurate picture of the measured electrical quantities during a power system event.

Recommendation:

- Support research and activities towards achieving commercial-grade PMUs that have enhanced sampling rates.

*Gap 4 (Technology)* – Lack of a secure, dedicated communications system to support interconnection-wide monitoring, analysis and automated controls. Lack of dedicated communication links for wide-area power system stabilizer action needed for better system damping by feeding multi-input PSS with wide-area signals.

Recommendations:

- Support research and activities to develop performance criteria based on applications and measure existing and new (i.e. WISP) communication systems against criteria. Determine what is required from the CIP perspective.

*Gap 5 (Technology)* – Incomplete system studies for application of PMUs.

Recommendation:

- Identify method of incorporating PMU application and performance requirements into the operational tasks (and traditional planning methodologies) utilized by the CAISO and California IOUs.

*Gap 6 (Policy)* – Sharing of data between different entities may still be lacking even with the NERC Synchrophasor NDA.

Recommendation:

- The CA IOUs utilities need to assess the NERC Synchrophasor NDA and determine what else may be needed over above that in order to effectively manage the CA grid, and establish additional protocols for data-sharing between them.

*Gap 7 (Technology)* – Production-grade PMUs are scarce or not readily available, hindering larger deployments.

Recommendations:

- Support activities to collect, and act on, lessons learned from existing projects in the USA and elsewhere to expedite the realization of production-quality real-time phasor-based tools.

*Gap 8 (Deployment)* – Not enough PMUs deployed across California for self-healing applications.

Recommendations:

- Support activities to add more PMUs across California and conduct the required associated studies for self-healing grid applications.

### Distribution Line and System Management.

*Gap 1 (Standards)* – Distribution system communication/automation standards incomplete; or standards in need for harmonization.

Recommendation:

- Support research and activities aiming at accelerating distribution system communication/automation standards harmonization.

*Gap 3 (Technology)* – Penetration of SCADA in the distribution systems is still not optimum.

Recommendation:

- Support proliferation of SCADA into more substations in California, including down to the distribution system level. This should be done following realistic and manageable targets for completed installations each year.

*Gap 4 (Technology)* – Deficiencies still exist in GIS, applications and circuits maps to support successful DMS.

- Lack of standardized GIS format for DMS operations.
- Lack of complete digitized circuit maps and GIS database for successful deployment of DMS.

Recommendations:

- CA IOU's should address customer connectivity errors (such as in the existing Electric Distribution System Analysis, and incorporate into GIS database in order to fully utilize the benefits of distribution management systems (DMS).
- Accelerate the work of developing the Common Information Model (CIM) for distribution systems applications.

*Gap 5 (Technology)* – Lack of key protective relaying needs for self-healing grid.

- Lack of field experience in adaptive for relaying for use in self-healing grid applications.
- Lack of automated verification of the different settings of relay (and other field component management functions) needed for restoring distribution systems.

Recommendations:

Support activities aiming at accelerating work done within IEEE PSRC, (Working group H5a: Common format for IED configuration data).

- Energy Commission should consider sponsoring field demonstration of adaptive relaying for self-healing grid applications.

### Supporting PEV, Renewables, and Energy Storage Integration

*Gap 1 (Standards)* – Standards for distributed resource integration incomplete; or standards in need for harmonization.

- Gaps around standards harmonization and standards extensions (e.g., IEC 61968 IEC 61850, and IEEE 1547).
- Gaps in the present IEEE 1547 in covering islanding with DER.
- The present IEC 61850-6 System Configuration description Language (SCL) is lacking.

Recommendations:

Support research and activities aiming at:

- Accelerating standard harmonization in the area of distributed resource and renewables integration.
- Accelerating the adoption of new ballots supporting the requirements of the smart grid (e.g., DER including energy storage technologies integration into the grid, microgrids, planned islands, voltage & VAR control, active participation, etc.).
- Enhancing IEC 61850-6 SCL by appropriate add-ons for DER.
- Extending IEC 61850 standard from substation to control centers using the same information model.

*Gap 2 (Technology)* – At the present time, there is minimal deployment of DER and storage in California; hence, there is limited long-term operating experience of accommodating two-way power flow.

- Lack of adequate field monitoring and control of the large number of diverse geographically dispersed DR, PV, PEV and storage.
- Lack of near real-time sensors that can identify faulted conditions and direction of power flow such as sustained, momentary, high impedance. This class of sensors can detect faults near real-time with high penetration of DG on line. These sensors will utilize enterprise communication network installed for smart meter and other DA applications.

Recommendations:

- Sponsor field demonstration of maximum deployment of DG and storage on distribution circuits to gain experience. Develop long term modeling techniques to evaluate impact.

*Gap 3 (Policy)* – Lack of policy guidance for managing renewable variability and other operational challenges.

Recommendations:

- Implement policy changes to address the use of energy storage for balancing the variable output of renewable generation (either on the grid level or for use by renewable operators to account for characteristics of individual resources).
- Potentially impose requirements on renewables to mitigate their effects on grid operations (e.g., ramp rate limits, better short-term forecasting).

# Domain 4: Renewables and DER Integration

## Bulk Renewable Integration

*Gap 1 (Technology)* **–** Marginal grid reliability decreases as the intermittent renewable penetration rate rises under today's operating environment, i.e., without smart grid technology.

Recommendations:

- Examine geographic and temporal diversity of renewables. Understand the statistical behavior and extremes in renewable resource volatility and ramping.
- Ascertain how High Voltage Direct Current (HVDC), Flexible Alternating Current Transmission Systems (FACTS), storage and synchrophasor technologies could help integrate bulk renewable resource farms into the grid and manage the intermittent nature of renewable resources.

*Gap 2 (Technology)* **–** The industry has an incomplete understanding of transient dynamic power behavior with high penetration of renewables and DER. Both at the sub-cycle level and the distribution system level (e.g., islanding when a fault occurs on a feeder).

Recommendations:

- Support research on developing transient dynamics models and exercising the models to fully understand what the impacts are and which advanced technologies could be used to remedy any adverse sub-cycle dynamics.
- Continue to support the investigation and deployment of energy storage applications that are specifically designed and located to support the integration of intermittent or variable bulk renewables.

*Gap 3 (Technology)* **–** Need to be able to accurately predict the renewable resource generation to allow for the proper integrated dispatch of storage and renewable resources. Specifically, there is a lack of microclimate forecasting for localized renewable resources.

Recommendations:

- Support the development and implementation of microclimate forecasting technologies to accurately forecast weather in dimensions of 2-20km and times of 3-30 minutes (i.e., Meso Gamma or very small-scale models).
- Investigate the interaction of renewable energy forecasting and scheduling with generation scheduling to understand the impact on ramping requirements of conventional generation/electricity storage due to the forecast errors.
- Support the development of operations scheduling software to dispatch the integrated storage and renewable resources for the CAISO ancillary services market.
- Develop predictive models for representing bulk wind and solar PV farms and their interactions with the distribution/transmission system.
- Develop models for the inverters and validate them with resource models.

- Develop dynamic concentrated solar generation model to better understand its transient behavior.

*Gap 4 (Technology)* **–** There is a need for improved Automatic Generation Control (AGC) to support fast large-scale storage, intermittency of renewable generation and traditional resources (gas turbines).

Recommendations:

- Support enhanced capabilities of AGC to accommodate the intermittency of bulk renewable in the presence of fast electric storage systems and conventional generation at high renewable levels.
- Promote integration of demand response and market-based products to act as virtual storage.

*Gap 5 (Technology)* **–** The current transmission infrastructure is insufficient to deliver renewable resources from afar.

Recommendation:

- Accelerate the development of transmission infrastructure to match the availability of remote renewable resources.

*Gap 6 (Standards)* **–** Certification standards are based on single inverter operations, not on a multitude of inverters operating in parallel. Inverters working independently can create an environment of instability because inverters are designed to operate on local conditions, not system conditions and can compete against one another during transients.

Recommendation:

- Standardize the design of inverters and associated communications as part of the industry's goal for interoperability. Coordinate with the IEEE 1547, IEEE P2030 project, and SGIP of NIST effort.

### Bulk Storage Integration

*Gap 1 (Technology)* **–** Need power electronics advancements to support the integration of bulk energy storage systems and solar photovoltaic farms via standardized inverters to gain power quality benefits.

Recommendation:

- Research, develop, and demonstrate energy storage and PV inverter applications that support their integration and provide power quality benefits leveraging advancements in power electronics.

*Gap 2 (Technology)* **–** The high cost of bulk energy storage systems and their environmental impacts are preventing their deployment.

Recommendations:

- Support research, development, and demonstration of bulk energy storage technologies to advance activities that reduce storage economics.

- Foster a framework by which the environmental impacts can be internalized into business case studies for integrating bulk storage and renewables into the grid.

*Gap 3 (Technology)* **–** Bulk energy storage locations and capacities are not necessarily aligned to maximize value.

Recommendation:

- Support analysis of grid needs to assess the most valued location and size of bulk energy storage to support reliability, ancillary services, peak shaving, and renewable integration.

*Gap 4 (Policy/Regulatory)* **–** Uncertainty on how to integrate bulk energy storage into the CAISO market.

Recommendations:

- Perform a benefit assessment by identifying the value of using bulk energy storage for energy market products and communicate the results to the industry and regulators.
- Validate ancillary service protocols for electricity storage.

*Gap 5 (Technology)* **–** Lack of system operations and planning software to support the dispatch of intermittent renewable resources and the charging and discharging of bulk energy storage systems in response to the varying loads.

Recommendations:

- Investigate how bulk energy storage systems should be integrated into grid planning in the presence of demand response and electric vehicles.
- Monitor resources and loads on a real-time basis to feed into optimal generator-bulk energy storage dispatch applications, both for real-time operations and to build historical profiles for a longer time horizon basis.

*Gap 6 (Education/Awareness)* **–** Lack of information and understanding of the advanced uses of bulk energy storage.

Recommendations:

- Continue research projects on using bulk energy storage in the areas of dynamic response and peak shifting storage.
- Continue to participate and monitor the research and development of bulk energy storage technologies.

### DER Integration

*Gap 1 (Technology)* **–** Understand the impacts of high concentrations of DER on common distribution circuits. The distribution system was originally designed to serve customer load, not to accommodate customer generation. System protection issues can occur as power flow becomes bidirectional when DER generation exceeds feeder load.

Recommendations:

- Support development immediately, especially given the high DER penetration already being seen on the California distribution system, to develop benchmarks on the bidirectional power flow resulting in adverse system protection conditions and recommended combinations and levels of DER on individual and groups of feeders or methods of mitigation.
- Identify requirements (i.e. use cases) that support the operational functions related to monitoring and communications system architecture to monitor and control the integrated DER and storage systems.
- Support analysis of feeder and substation reliability implications with a high penetration of DER. Also, establish Distribution Management System (DMS) requirements to effectively manage DER to maximizing benefits and preventing adverse effects on reliability.

*Gap 2 (Technology)* **–** Lack of development of DMS applications for advanced functions for DER (ex. Volt/Var support, islanding, isolation, etc.).

Recommendation:

- Accelerate research, development, and demonstrations to support advanced DMS applications software. This will allow DER to be utilized for volt/var support, islanding isolation, and line loss reduction.

*Gap 3 (Education/Awareness)* **–** Lack of information on the effects of customer services or rates on the integration and adoption of DER.

Recommendation:

- Conduct studies to evaluate the effects of tariffs and contracts on influencing the implementation and adoption of DER, and the associated impacts on customer service. Educate stakeholders with the results.

*Gap 4 (Technology)* **–** Lack of information and experience about the use of demand response as an additional ancillary service to facilitate renewable integration and electricity storage.[13]

Recommendation:

- Synthesize existing information about the use of demand response for ancillary services in support of renewable integration and electric storage. Conduct new studies based on identified gaps.

*Gap 5 (Technology)* **–** Little actual experience with high penetrations of DER including large-scale or distributed energy storage devices.

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[13] KEMA, Inc. 2010. Research Evaluation of Wind and Solar Generation, Storage Impact, and Demand Response on the California Grid. Prepared for the California Energy Commission. CEC-500-2010-010.

Recommendation:

- Monitor and participate in national and international research activities that integrate high penetration DER with large scale or distributed energy storage to share benefit from knowledge gained in identifying lessons learned, issues and gaps.

*Gap 6 (Policy/Regulatory)* **–** Operating policy for high concentrations of generation at the distribution level (i.e. large quantities of small-scale PV installations on the distribution system) does not incorporate available smart grid generator technology (e.g., automated voltage regulation).

Recommendation:

- Create working groups with stakeholders (including regulators) to document specific issues related to highly concentrated distributed generation operating policy. Educate stakeholders and regulators on the results that affect the regulatory need for tariffs designed to accommodate high concentrations of distributed renewable generation.

*Gap 7 (Technology)* – IEC 61850-7-420 for DER has not been mapped to SEP 2.0 for use by DER devices within the HAN.

- SEP 2.0 plans to incorporate both CIM and IEC 61850 information models.
- SEP 2.0 requirements have not yet been finalized.
- The appropriate services for monitoring and control of DER generation and storage devices need to be included in SEP 2.0.

Recommendations:

- Map IEC 61850-7-420 object models to SEP 2.0 for DER devices used within the HAN.
- Work with SEP 2.0 process to ensure that the necessary monitoring and control services are also included in SEP 2.0.

## Domain 5: Grid Planning and Asset Efficiency

### Grid Efficiency and Voltage Reduction

*Gap 1 (Process)* **–** Integration of inverters in voltage regulation planning.

Volt/VAR regulation will benefit from data and information collected by the sensors installed on the grid. The use of this information, however, needs to be tailored to specific utilities' equipment uses and the optimization algorithms have to be integrated in DMS. A specific concern is the high penetration of inverters associated with the PV rooftops program; the varied inverters' response to islanding could cause voltage rise, and crew safety and harmonics issues. These types of equipment also need to be part of the voltage regulation schemes. So far some inverters have been tested on the operation side for transient response but the results have not been fully integrated in the system planning processes to support further grid integration.

Recommendation:

- Support research activities to identify, develop and test inverters requirements needed to integrate them in the grid volt/var regulation scheme (data collection, model development). ). The planning tools need to address the transient behavior of voltage to assure the optimal integration of distributed energy resources into the grid. This should be a short-term solution.

*Gap 2 (Technology) –* Integration of advanced equipment.
Advanced equipment such as fault current limiters, superconducting transformers, advanced conductors and power electronics should be commercially available in the coming years. These technologies will expand network flexibility and functionality and also embed information monitoring and recording capabilities to communicate back to the system for more accurate operation. So far, these technologies are being installed for proof of concept testing and the results obtained are very encouraging. To really take advantage of these technologies further developments are needed to accelerate their deployment and provide clear business cases to facilitate the decision making process. In the process, utilities will be able to ascertain the T&D system planning and operational benefits of integrating these technologies, rather a proof of concept type technology studies.

Recommendation:

- Support activities to accelerate the proof testing and validation of advanced equipment for grid applications. This should be a mid-term solution.

*Gap 3 (Policy, Process and Technology) –* Utility processes, procedures, and systems for achieving more energy efficient grid, i.e., reduced line losses.

Grid efficiency can be improved through the implementation of solutions that will lead to the reduction of overall transmission and distribution losses. Such solutions include voltage control, phase balancing or the installation of more efficient equipments. This will require added investment costs that need to be balanced with the benefits of reduced line losses in order to find the optimal trade-off between investment and losses. This is a mid- to long-term gap to overcome.

Recommendation:

- Identify and study integral methods for utilities to optimize system losses by finding the optimal trade-off between investment and losses.

### Asset Management and Performance Optimization

*Gap 4 (Process) –* Assessment of the system impacts of asset management and CBM.
Californian utilities have begun to implement asset condition monitoring and condition-based maintenance (CBM). However, they are not getting the full benefits of asset management and CBM because such implementation is still based on selected critical assets. Moreover, the decision for CBM is usually based on a perspective of an asset in isolation. It does not capture the interactive effects of the performance of that asset in conjunction with other asset in terms of system reliability, customer-minutes of interruption, and lifecycle economics of the asset.

Recommendation:

- Conduct research and development on refining an asset management system that integrates real-time asset condition monitoring with the impact on system reliability and system economics on a real-time online basis. This will be at least for medium time frame.
- Implement a lifecycle cost approach in asset planning in conjunction with regulatory support for this asset management approach. This should be for a short term time frame.

*Gap 5 (Process)* **–** Improved vegetation management through data analytics and business intelligence.

There is a need to realize the true benefit of vegetation management (VM) by tracking the VM practices at different regions and tree species at various times to maximize the return (as measured in system reliability) on investment. The ability to track all these metrics on GIS with VM database and work history, coupled with a data mining engine to develop the business intelligence will benefit the utilities.

Recommendation:

- Conduct activities to track and integrate VM practices and metrics on GIS and support development of statistical treatments to expand the benefits utilities can gather from VM. This should be a short-term activity.

## Planning for Grid Growth

*Gap 6 (Technology – Process)* **–** More complex system planning to include DER
As the grid grows, it is expected to incorporate many of the distributed energy resources (DER) and feeder automation functions to ensure system reliability, sustainability and supply reliability both at transmission and distribution levels. The planning tools and methodology will be much more complicated than the current methodology. The distribution systems will no longer be radial; there will be bidirectional power flows. There will be microgrids. There will be DERs and PEV batteries participating in the CAISO ancillary service market. Customers will demand choices of energy services. California utilities need to be prepared to conduct such transmission and distribution planning. Specific areas of focus include advanced inverters and plug-in electric vehicles – controlling charge and discharge rates on the grid and on zero net energy homes.

Recommendation:

California utilities should participate in R&D to develop a transmission and distribution system planning methodology that incorporates the following:

- Active circuit planning, incorporating DER and feeder automation to provide self-healing features.
- Integration of microgrids, including the dynamic adaptive protective relay systems and islanding.
- Integrated system planning that incorporates capacity and reliability planning in an tightly interwoven framework.

- Analysis of transient behavior of the voltage in the distribution grids in the presence of DER and protection issues associated with bidirectional power flow.
- Integrated transmission and distribution resource planning that considers both supply (e.g., DER, PEV, renewable, etc.) and demand-side resources (e.g., DR, PEV, direct load control, etc.)
- Transmission distribution planning coordination.
- Neighboring transmission planning coordination.
- Accommodation of high levels of variable generation from renewable sources taking advantage of complementary patterns of energy production and advanced control technologies such as storage and flexible power control devices.
- Solutions to inertia issues.
- Cost allocation for transmission planning to integrate smart grid technologies and renewable.

This would fall into the long-term time frame.

*Gap 7 (Technology) –* Assessment of the impact of high penetration levels of distributed renewable generation on system inertia (combined with retirement of local traditional generation).

One of the effects on the system of increased penetration of distributed renewable energy generation (wind and PV) associated with decommission of conventional generation is the reduction of system inertia and frequency regulation. This can significantly affect system reliability following large disturbances.

Recommendation:

- Conduct studies to assess the impact on the California system stability of increased penetration levels of distributed renewable energy generation associated with decommissioning of conventional generation. In particular, such studies should focus on the impact of load following, frequency regulation, operating reserve, spinning reserve, etc. This should be a short-term activity.

## Domain 6: Workforce Effectiveness

### Workforce Management

*Gap 1 (Technology) –* Better systems operations visualization.

Recommendations:

- Support research on how to improve system operator visualization tools to promote situational awareness, smart alarming, drill-down capabilities, real-time and historical data retrieval, event correlation, and multiple application visibility on one display. This would include human factors research on how to make smart grid data available to operators in a more user-friendly, visually enhanced format.

- Support research on improving accuracy of system topology through automatic updates to the hierarchy of system components. System definitions, adjustments and corrections, from distribution substations to the customer meter and beyond would be automatically detected and recorded.

*Gap 2 (Technology)* **–** Advanced mobile workforce automation.

Recommendations:

- Support research that looks at how to integrate the field workforce into the smart grid field area network (FAN). Identify standards and protocols needed to achieve this integration.
- Support research on technology for sensing, monitoring, asset status recognition and augmented reality. An example of this type of technology is the use of RFID tags to maintain and accumulate asset information throughout the lives of assets. Work with manufacturers to design devices (one example being RFID tags) that meet functional and non-functional requirements.
- Support research on next-generation field devices for field workers. These devices should consider the following functionalities: ruggedized wearable equipment (e.g.,. wearable computer), data capture through audio, video and photo, involuntary data capture from field equipment via RFID or beyond RFID technology, GPS tracking of worker location (for optimal dispatch and routing), hands-free wireless (i.e., the ability to control a computer without traditional keyboard and mouse), field access to system for localized devices, noise analysis diagnostics, and wireless field devices to detect overheating assets. (Consider customer privacy issues related to video data capture.)

*Gap 3 (Technology)* **–** Advanced materials technologies.

Recommendation:

- Support research on more modular, plug-and-play construction methods, including standardized pieces and lighter weight, longer lasting materials.

*Gap 4 (Education)* **–** Organizational change preparedness for a 2020 smart grid workforce.

Recommendations:

- Support studies on organizational changes that may become necessary as part of the smart grid deployment and operations. This project should include: (1) organizational alignment, (2) changes to existing functional groups, (3) new skill and capability requirements, (4) new functional groups (i.e. to manage IT/grid technology convergence), (5) workforce readiness (i.e. knowledge base transfer, training, etc.), and (6) new work practices and standards and (7) keep abreast of emerging technologies.
- Perform workforce analysis that involves benchmarking against industries that have undergone or are undergoing workforce changes amidst dramatic advancements in technology.

*Gap 5 (Education)* **–** Lack of power engineering faculty and degree programs at California universities and a historical lack of student interest in power engineering.

Recommendations:

- Target strategic hire(s) or return of intellectual capital (e.g., emeritus faculty) for tenure-track positions in critical areas.
- Industry/private resources contributing to faculty, including lecturer positions, to teach key courses.
- In-kind industry participation through practitioners lecturing at campuses.
- Advertise interesting smart grid challenges through guest lectures that reach diverse audiences.
- Advertise smart grid study opportunities to a broad range of majors with related interests, including diverse engineering specializations, physics, energy, environmental studies, energy economics, energy policy and environmental law.

*Gap 6 (Education)* **–** California is not in a national leadership position with respect to smart grid research capabilities.

Recommendations:

- In coordination with industry structure programs to address critical needs for a skilled workforce, building and strengthening core degree programs to develop base of researchers, qualified to perform cutting edge research and lead in developing innovations where the university is well-suited.
- Strengthen collaboration between universities and industry, leveraging existing industry collaborations to further identify critical research opportunities.
- State, university and industry collaboration to strengthen collective capabilities and effectively execute critical applied research.
- Leverage existing industry collaborations on smart grid projects and programs to inform university research and direct focus to RD&D gaps that are well-suited to be addressed by universities.

*Gap 7 (Education)* **–** Integrative curriculum addressing critical aspects of smart grid knowledge: (a) Information and communication systems, (b) Practical aspects of operations, (c) Human factors, (d) Passive safety engineering, (e) Complex systems theory, (f) Energy economics, and (g) Cross-disciplinary exchange and interdisciplinary research.

Recommendations:

- Recruit practicing professionals from the electric power industry to teach on campuses, contributing relevant expertise and practical knowledge. Recruitment can range from an invitation to speak to students at one lecture, to participation in a formal adjunct program that recognizes longer-term commitments and ongoing contributions of industry professionals.
- Organize field trips for university students to visit generation, transmission and distribution facilities, including opportunities to learn from diverse professionals (engineers, operators, maintenance crews, administrators) on location.

- Sponsor cross-listed courses with other university departments that expose power engineers and other majors to smart grid applications in computer science, communications technology, complex systems, energy economics and other relevant fields.
- Support faculty efforts on smart grid curriculum development, including collaboration with industry practitioners.
- Develop media for faculty to share teaching materials (syllabi, readings, assignments) to leverage course development efforts.
- Where appropriate, develop online curricula to maximize student access to courses.
- Partner with local Power Systems Engineering Societies (like local chapters of IEEE PES and IAB) to identify and organize talks and tours of mutual interest that students may be invited to attend.
- Solicit input from related industries such as telecommunications, information technology, and smart grid vendors.

*Gap 8 (Education) –* Broad, vibrant interaction on smart grid topics within academic community and between academe and practicing professionals is needed.

Recommendations:

- Develop media for knowledge capture and sharing, including online media (e.g. wikis).
- With the help of web professionals and librarians, develop a well-organized, cross-referenced repository of information.
- Sponsor interdisciplinary colloquia and on-campus workshops on smart grid topics, attended by faculty, students and industry experts.
- Support faculty and students attending topical meetings and workshops organized by industry.
- Develop expert support networks and technical advisory committees that include university faculty.
- Include outreach and communications efforts such as guest presentations and the production of easily accessible publications as tasks in smart grid research projects to provide maximal exposure of broad audiences to smart grid topics.

*Gap 9 (Education) –* A lack of (a) industry acceptance of use of dynamic models empowered by PMUs for real-time assessment of transmission lines thermal limits, (b) acceptance of adaptive, or dynamic settings for protection based on prevailing system conditions, (c) universal operator acceptance of the benefit and use of PMU systems and incorporation in the operating rules, (d) staff adoption of new rules and procedures and PMU-based calculations, (e) simulators based on the use of PMUs under normal and emergency conditions, and (f) operator training for system restoration using PMUs.

Recommendation:

Need uniform requirements and protocols for data collection, communications, and security achieved through guidelines/standards.

- Need for education, training, and process and culture change – Ownership within a utility and how to share benefits among groups
- Engineers need to start thinking in terms of phase angles. Development of operating monograms and other operating actions should incorporate the availability of this data.

## Workforce Safety

*Gap 1 (Technology)* **–** Cost-effective wearable technology solutions to improve safety

Recommendation:

- Support research on technologies such as fall protection gear with accelerometer sensors, wearable personal voltage detection for live line warning, wearable heads-up displays that support automated object recognition, and organic LED field force clothing. This technology could be extended to include monitoring of vital signs and live feeds from wearable cameras. Evaluate safety equipment that other industries (e.g., telecom, transportation, military, first responders) are using in order to identify possible cross-cutting applications.

*Gap 2 (Technology)* **–** Faster, more effective, real-time employee training and skills development

Recommendation:

- Support research and evaluations of computing field equipment and simulation equipment that can provide updated training on procedures and safety information on a just in time basis. Develop a component within the Consolidated Mobile Solution field device capable of providing instructions, training and other materials to workforce personnel for a specific apparatus while en-route to an outage or inspection.

*Gap 3 (Technology)* **–** Enhanced safety through remote automation and field robotics technologies

Recommendation:

- Support the research and evaluation of the potential use of unmanned robotic devices for the purpose of asset and facility inspections. For example, unmanned devices could be housed at substations and then activated by system operators to perform visual inspections of substation equipment. This could reduce the number of unnecessary dispatches of field workers and avoid placing field workers in a potentially dangerous environment. Small unmanned vehicles (air and ground) could also be used to perform inspections from dangerous, obstructed or out of reach vantage points, assuming FAA regulations would allow it. Finally, evaluate remote control equipment that other industries (e.g., oil and gas) are using in order to identify possible cross-cutting applications.

# APPENDIX D: Existing Utility Projects Addressing Utility Needs by Domain

The important gaps associated with each domain are listed in the following tables. These are consolidated from the more detailed gap breakdowns in each domain chapter provided previously. The table for each domain summarizes important activities and demonstrations already under way at each of the IOUs in California. These existing activities provide a basis for ongoing work that is needed to develop the smart grid infrastructure to meet 2020 goals.

Note **–** In these tables, the development gaps identified for Domain 3 (Grid Operations & Control) and Domain 5 (Grid Planning & Asset Efficiency) were combined for coordination and to eliminate overlap.

**Table 32: Summary of Existing Programs and Projects for Research Needs in the Architecture and Communications Infrastructure Domain**

| Gap/Need | Example Projects (SDG&E) | Example Projects (SCE) | Example Projects (PG&E) |
|---|---|---|---|
| 1.1 Architecture for integration of utility back office systems with substations, field equipment, customer interfaces, and customer-side devices | OpenSG; | Smart Grid Information Architecture Development System of Systems Integration | NIST SGAC, OpenSG |
| 1.2 Interface requirements and technologies for integrating substation data (e.g. substation data manager, individual substation devices) with enterprise data management systems (both operational and non-operational) | CBM; OMS/DMS | Backbone Network Development System of Systems Integration | CBM; OMS/DMS |
| 1.3 Interface requirements and data exchange standards (object models) for integrating field devices and sensors with both substation systems and enterprise data management systems (multiple architectures may be employed for this) | CBM; OMS/DMS | Implementation of Distribution Management System (DMS)System of Systems Integration | CBM; OMS/DMS |
| 1.4 Interface requirements and data exchange standards (object models) for integrating customer systems and devices with both substations and enterprise data management systems (for both local applications like microgrids as well as utility and market applications like ancillary services) | OpenSG; SEP development; Borrego Springs Microgrid | System of Systems Integration | OpenSG |
| 1.5 Interface requirements and data exchange standards (object models) for distributed and renewable generation technologies and storage with both substations and enterprise data management systems (local, utility, and market applications) | OpenSG; Borrego Springs Microgrid | System of Systems Integration | OpenSG |
| 1.6 WAN communications technologies and interfaces to support widespread substation integration for real time management, PMU integration, etc. | WECC Synchrophasor Initiative; WAN Rebuild and GridComm projects; | Synchrophasor architecture development WECC Synchrophasor Initiative, PMU Deployment | WECC Synchrophasor Initiative |
| 1.7 Application of wireless technologies for field area network implementation (requirements, capabilities vs. application, security management, etc.) | GridComm project | Field Area Network Technology Development and Deployment | Silver Springs |
| 1.8 HAN Communications technologies options (wired, wireless, PLC) and interoperability with utility interfaces | HAN pilot projects | Home Area Network (HAN) Interface Customer Devices Beyond the Meter | HAN Pilot projects |
| 1.9 Guidelines and technologies for security implementation as a function of risk assessments | Information Security Program | Smart Grid Cyber Security Enhancement | Smart Grid Cyber Security; NIST standards |
| 1.9a Key management technologies for large numbers of field devices | Smart Meter program; PKI | Interoperability and Cyber-Security Standards Development Initiatives | NIST, Smart meter |

**Table 33: Summary of Existing Programs and Projects for Research Needs in the Customer Systems Domain**

| Gap/Need | Example Projects (SDG&E) | Example Projects (SCE) | Example Projects (PG&E) |
|---|---|---|---|
| 2.1 Demand Response Information Model that includes dynamic pricing, direct load control, distributed generation for normal conditions, emergency conditions, local conditions, etc. | Enernoc and Comverge programs | Proxy Demand Resource Pilot for Aggregated Air Conditioning and a small Agricultural Pumping Demonstration | Auto DR Specification (PG&E) |
| 2.2 Rate structures that can incorporate demand response incentives associated with market conditions and local conditions (dynamic rates) | CPP and PTR implementations | Zero-Net Energy Homes/Commercial Buildings (dynamic pricing research in Home Battery Pilot) | Dynamic Pricing implementation (PG&E) |
| 2.2a Specific rate structures and approaches for integration of smart appliances and enabling participation in ancillary services | | | |
| 2.2b Specific rate structures and approaches for integration of electric vehicle charging and enabling participation in ancillary services (HAN information model, protocols, etc.) | Electric Vehicle TOU rate experiment | Enabling Technology to Encompass HAN & PCT rates and SCE's Plug-In Car Rate Assistance Program<br><br>PEV Readiness Programs | Electric vehicle infrastructure development |
| 2.2c Specific rate structures and approaches for integration of distributed generation and storage (e.g. PV, storage inverters) with the operation of the grid | Schedule DR-SES Domestic TOU rate for households with Solar Energy System | | |
| 2.3 HAN devices that meet requirements associated with architecture, information models, and communication technologies | 2010 & 2011 HAN Pilots | Energy Smart Customer Devices (ARRA project)Home Area Network (HAN) In-Premise Display Field Trial | HAN Pilots |
| 2.4 Infrastructure, information models, protocols for integrated transaction management associated with electric vehicle charging at locations other than home | DOE EV Project | PEV Integration and Metrology Technology Development and Testing PEV Infrastructure Program | Smart chargers |
| 2.5 Utility energy management systems and other enterprise information management systems that incorporate information from customer systems as part of the grid management and asset management functions | OMS/DMS implementation | Customer Product R&D<br><br>EMS Upgrades | |

**Table 34: Summary of Existing Programs and Projects for Research Needs in the Grid Operations and Control Domain (includes grid planning and asset efficiency)**

| Gap/Need | Example Projects (SDG&E) | Example Projects (SCE) | Example Projects (PG&E) |
|---|---|---|---|
| 3.1 Standards for information models, protocols, and communication technology options for integration of widespread phasor measurement units (PMUs) with the operation of the grid, including sharing across systems | | Smart Grid Standards Development | |
| 3.2 Applications for data management and processing that can derive information from vast amounts of data from sensors, IEDs, etc. (substation applications, enterprise applications, visualization applications) | Time-series data capture and analysis | Wide Area Situational Awareness System Program System Operations Visualization Tool Study | SCADA Historian and network historian with applications turn data into actionable information |
| 3.3 Wide area system management applications (EMS, real time state estimation incorporating PMU data, system analysis functions, visualization functions) that work within standard architectures (1.2) | WECC Synchrophasor Initiative, Advanced PMU Apps | PMU-Enabled Voltage and VAR Control Demonstration Advanced PMU Apps, WECC Synchrophasor Initiative | WECC Synchrophasor Initiative, Advanced PMU Apps |
| 3.4 Dynamic protection systems, applications for managing IED settings and coordination with wide area system management applications | Advanced red flag warning implementation with weather stations into operations | Wide Area Controls (WACs) Roadmap Development | Fuse Saving program (storm activation) |
| 3.5 Model-based management and planning of distribution systems that incorporates information from distributed sensors, customer models, distributed resources, etc. - both reliability applications and steady state optimization applications. Coordinates with architecture 1.3. | Expanded Distribution Automation, Microgrids | Enhanced Distribution Management with Load Control Enhanced Outage Management<br><br>DMS/ALCS Project | Expanded Distribution Automation, DMS |
| 3.6 Planning and implementation of voltage optimization at the distribution level incorporating advanced customer models, integration of distributed resources, and integration with system reconfiguration management. | 73.8% of load Conservation Voltage Reduction compliant | Irvine Smart Grid Demonstration (ISGD) - ARRA | Green Circuits, DMS |
| 3.7 Distribution planning and operations to optimize performance with increased electric vehicle, renewable, and storage penetration. | EV Impact studies, assure reliability | PEV Readiness Program | DMS, GIS |
| 3.8 Asset management applications that incorporate information from widespread sensors, equipment diagnostics applications, and risk assessment methods, integrated with system operation. | SDG&E CBM for substations - 2009 | Advanced Dynamic Asset Rating Transformer Dissolved Gas Analysis (DGA) | PG&E CBM Pilot, network historian, DMS |
| 3.9 Improved system maintenance strategies based on conditions, widespread sensors, etc. - vegetation management, equipment maintenance, etc. | Wide scale deployment of Intellirupter, fire-hardening including wood to steel conversion, operating conditions based upon local weather conditions | Upgraded EMS with Advanced Applications Transformer Dissolved Gas Analysis (DGA) | Network Historian, SCADA Historian |

**Table 35: Summary of Existing Programs and Projects for Research Needs in the Renewables and DER Integration Domain)**

| Gap/Need | Example Projects (SDG&E) | Example Projects (SCE) | Example Projects (PG&E) |
|---|---|---|---|
| 4.1 Reliability assessment methods that take into account smart grid technologies, communications infrastructure, data management requirements and impacts, distributed resources integration and role in operating system, security implementations | Predictive Reliability Assessment Tool | Smart Grid Architecture Program | |
| 4.2 Transmission infrastructure required to integrate increased levels of renewable resources (including effect of technologies like var control, HVDC, demand response integration, etc.) | Integration of renewables T&D study | Ongoing Work at Transmission Interconnection Planning (TIP) | |
| 4.3 Improved modeling and forecasting methods and applications for variable resources (that can be integrated with system operations at all levels) | UCSD microsolar forecasting | Tehachapi Transmission Project/Antelope-Bailey Wind Generation System RTDS Model | |
| 4.4 Characterize new technologies and costs that are required to manage higher penetration levels of variable resources - grid level (HVDC, var control, capacity requirements, ramping requirements, etc.) | Internal T&D project teams assessing impact of renewables and solutions | PMU-Enabled Voltage and VAR Control Demonstration | CAES Energy Storage |
| 4.5 Characterize new technologies and costs that are required to manage higher penetration levels of variable resources - distribution level (storage, demand response, smart transformers, inverter controls, var control, voltage control, protection, system reconfiguration, etc.) | Community Energy Storage | A123 GSS Program<br>Home Battery Pilot Program | CAES Energy Storage |
| 4.6 Advanced applications for distribution protection and management that allow dynamic protection for DG integration, system reconfiguration, and microgrids. | Widescale Deployment of S&C Intellirupter, microgrid master controller | Irvine Smart Grid Demonstration (ISGD) - ARRA | |
| 4.7 Power electronics technologies for advanced inverters with lower cost, reduced losses, and integration of technologies (transformer, storage, PV, electric vehicle charging) | Investigation of advanced inverter designs | SCE Smart Inverter Development and Testing, Solar PV Readiness Studies | |
| 4.8 Ancillary service infrastructure for integrating distributed storage, demand response, etc. so that these resources can help facilitate increased levels of renewables on the grid | CAISODR pilot participation | DR Programs | Demand response tests |
| 4.9 Improved planning tools and methods that integrate demand response, customer systems, distributed storage, renewable characteristics, and advanced load projection approaches (T&D) | Incorporation of DG into the planning process. | DMS/ALCS | CYME Planning Tool, Green Circuits |

**Table 36: Summary of Existing Programs and Projects for Research Needs in the Workforce Management and Effectiveness Domain**

| Gap/Need | Example Projects (SDG&E) | Example Projects (SCE) | Example Projects (PG&E) |
|---|---|---|---|
| 5.1 Improved operator tools to manage the grid (T&D) - integration of information from sensors, analysis to identify problem conditions, visualization and notification approaches, etc. | OMS/DMS - 2011 | Wide Area Situational Awareness System Program<br><br>Advanced Mobile Workforce Automation Program EMS Upgrades, WAMS for Operations | OMS/DMS |
| 5.2 Advanced mobile workforce automation - integration with real-time model based management of the grid, GIS, OMS, fault location, asset management systems (e.g. sensors and RFID tags), advanced systems for dispatching and tracking crews, standards for contracting work crews | SDG&E workforce management integration with OMS/DMS/GIS - 2011, CBM 2009 | Advanced Mobile Workforce Automation Program | PG&E MobileConnect |
| 5.3 Improved training and information resource tools - on line training, guidelines available to mobile crews, integration with mobile devices (mobile phones, etc) | Standards and other resources available on mobile data terminals | Irvine Smart Grid Demonstration (ISGD) - ARRA | Standards |
| 5.4 Application of smart grid technologies to improve workforce safety - advanced protection systems, awareness of conditions, improved models linked to worker safety requirements (e.g. arc flash), warning systems for live lines, arcing, etc. | CBM - 2009, Field Force M&I - 2010 | Technology Evaluation of Safety Equipment Investigating Robotics/Remotely Piloted Vehicles for Remote Inspections | CBM - 2009 |
| 5.5 Organizational structures to facilitate smart grid - skills and capabilities matrix updates, role of IT and communications across organization, advanced maintenance and asset management integrated with operations, integrated planning, crew skills and training, etc. | CBM 2009 (new workforce skills) | Wires Investment Strategy Efficiency Review (WISER)<br><br>"Innovation Lab" to Address Next Generation Workforce | CBM - 2009 |
| 5.6 Educational infrastructure linked to smart grid skills requirements and resource needs | | "Innovation Lab" to Address Next Generation Workforce Full EMS Simulator for Operator Training | |

# APPENDIX E: Perspectives on the Role of Natural Gas

## Approach

The majority of the project team's effort focused on the electric power grid rather than the natural gas delivery network. However, the perspective of natural gas industry representatives was also sought and incorporated into the vision and roadmap. As a point of entry for incorporating the natural gas industry perspective, the project team sought to identify "the role of natural gas in supporting the electric smart grid."

The project team first performed secondary research, gathering and reviewing documents from the American Gas Association, Southern California Gas Company, and PG&E to identify supports for the electric smart grid and benefits along the gas value chain. The team then engaged in primary research to directly obtain the shared perspectives of natural gas industry expert advisors. Building on this information the project team developed a natural gas technology framework and established priority areas to define a consensus perspective on natural gas supports for the electric smart grid vision. The perspective encompassed natural gas supports for existing energy policies and other drivers, including GHG reduction, renewables portfolio standards, energy efficiency, demand response, reliability and power system improvements. The team also identified gas supports for benefits, along with assumptions driving the timing for achieving the smart grid vision.

## Background on the Natural Gas Industry

The natural gas production and delivery infrastructure is in many respects analogous to that of the electric power industry, in terms of the functions served by generation, high-voltage transmission lines, substations, and lower-voltage distribution lines. Natural gas is produced at numerous, geographically dispersed wellheads and transported over long distances via high-pressure transmission pipelines and then through lower pressure distribution pipelines to end users. Unlike the electricity industry, however, the natural gas industry has never been vertically integrated. Rather, the industry consists of three largely independent sectors—a production sector, an inter- and intra-state transmission sector, and a distribution sector. This differs from the electric industry, which before deregulation was fully integrated and then divided into generation, transmission and distribution sectors. In California, gas utilities own both intra-state transmission lines and distribution systems.

The natural gas and electric industries are both continuously evolving and improving their energy infrastructures, including the enhancement of data collection to support informed decision making across traditional boundaries. Both the electricity and natural gas industries are evolving toward a future with greater penetration of renewable resources, clean transportation, and expanded roles for advanced sensors, data integration and smart metering. One difference that will remain is that the electric industry is moving further to enable greater bidirectional energy flows between electric consumers and the electric grid. Similar applications and opportunities don't currently exist in the natural gas industry, since natural gas flows in one direction from the distribution pipeline to gas consumers. Another important difference between the two industries is that natural gas can be economically stored, unlike electricity, thereby presenting opportunities for demand response and electric grid support using distributed energy resources.

**Figure 12: Electric Smart Grid Technologies at Different Levels**

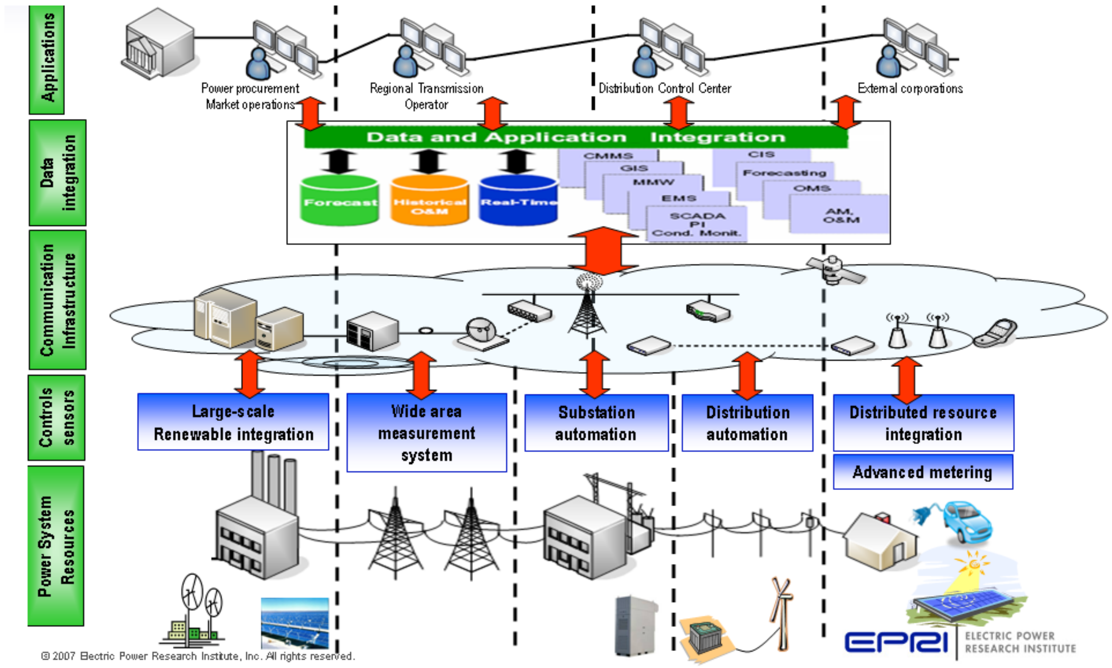


**Figure 13 : Natural Gas Technology Framework**

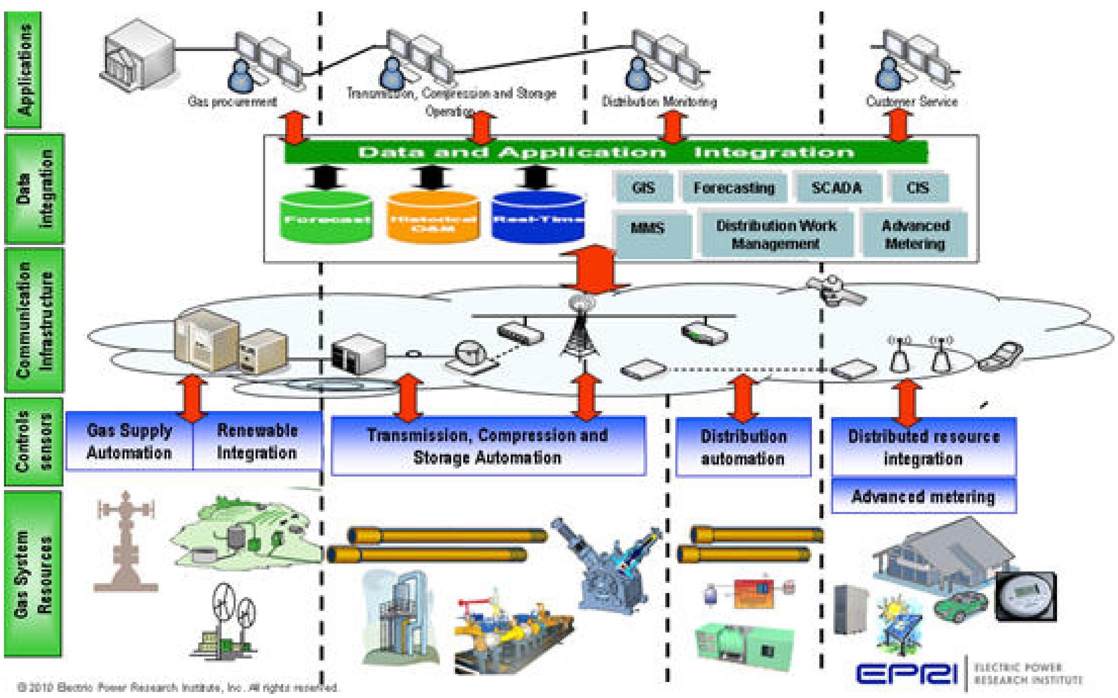


Figure 12 illustrates technologies at different levels of the electric smart grid. The smart grid enables more intelligent use of information across traditional boundaries. Boundaries that exist are indicated in the figure horizontally (by level of technology) and vertically (by organizational boundary).

Figure 13 depicts a natural gas technology framework. The natural gas industry framework includes natural gas specific data integration applications to enable natural gas functions, processes and operations analogous to the electricity industry's framework. This includes natural gas supply automation, renewables integration, transmission and distribution control, monitoring and automation, advanced metering, and natural gas-fueled vehicles (e.g., clean transportation).

## Priority Areas

The team identified four priority areas for considering the role of natural gas (e.g., technologies and infrastructure) in supporting the California Smart Grid vision. The four natural gas priority areas and the supports identified are summarized below.

DERs play an essential role in the electric smart grid. Natural gas is an important fuel for DERs. Typical natural gas-fueled DERs include: (a) individual reciprocating engines, (b) small aeroderivative gas turbines and microturbines, (c) combined heat and power (CHP) configurations utilizing either engines or turbines, and (d) fuel cells. Nature gas-fueled DER has the following advantages.

1. Natural gas is viewed as the least polluting, lowest carbon fossil fuel and an economic and plentiful domestic fuel for supporting strategically located DER.
2. Natural gas-fueled DER can be either deployed across a region or at specific locations as dispatchable DER. In this case, natural gas-fueled DER can enhance the electric grid's reliability, resilience, security, and efficiency.
3. Most natural gas-fueled DERs behave similarly to typical generators and do not present the complications introduced by inverters. Inverter-based DER, such as PV, may cause power quality or grid operation difficulties.

**Natural Gas-Fired Electric Generation as Backup for Renewable Electric Generation**

Natural gas-fired electric generation can serve as a backup for intermittent renewable electric generation. Typical natural gas-fueled flexible energy resources include (a) combined cycles (particularly those with enhanced flexibility via design adaptations), (b) large aeroderivative gas turbines, and quick-start frame gas turbines, and (c) large-scale projects with multiple (20-30) reciprocating engines. Natural gas-fired electric generation has the following advantages.

1. Natural gas is viewed as the least polluting, lowest carbon fossil fuel and an economic and plentiful domestic fuel for supporting bulk generation. The natural gas technologies can facilitate the renewable generation integration and effectively counter-balance intermittent renewable generation.
2. Natural gas-fueled generation sources that can be sited strategically to address locational electric needs, provide operational flexibility, and increase grid efficiency.

**Advanced Metering of Natural Gas Consumption in Homes and Small Businesses**

AMI for direct uses of natural gas may expand open markets by allowing consumers better monitor their natural gas usage. This improved understanding of usage may result in increased customer conservation and efficiency. Natural gas utilities will also utilize the additional data to enhance the planning and operations of their systems, which will benefit DER and generators backing up renewable resources.

In the future, with an effective information integration of electric and gas AMI, consumers can monitor their natural gas and electric consumption via AMI to make better informed decisions regarding energy use. Residential and commercial end-use customers can engage in arbitrage between natural gas and electric uses. Such actions by consumers can lower the demand for electricity at peak times through direct natural gas use to lower overall energy costs.

**Natural Gas-fueled Vehicles (NGVs)**

The natural gas industry has provided NGV technology and fueling infrastructure to commercial and passenger vehicles for many years. The renewed focus on reducing the nation's dependence on foreign oil and reducing vehicle emissions may lead to an increase in the sales of NGVs to smaller sized fleets and individual consumers. When significant market penetration of NGV is achieved at the individual consumer level, electric utilities may need to begin monitoring the power consumption of home compressors used for refueling individual vehicles. In essence, given significant penetration, electric-powered compressors for refueling become a load to be managed by utilities and a demand response opportunity for customers.

## Natural Gas Supports for Energy Policy Drivers

In addition to supporting the smart grid vision, natural gas-fueled technologies, delivery system, etc. also support key energy policies and other drivers.

**Greenhouse Gas**

Reducing greenhouse gas emissions, particularly $CO_2$, requires an energy industry that is more fuel efficient, uses less carbon-intensive fuels, and increases the utilization of renewable resources. Natural gas can support each of these objectives. Natural gas fired generators can become effective "peakers" when managing renewable integration. With the increase in bulk renewables, demand is created for flexible natural gas fired generation to respond when, for minutes, hours, or days, electricity from wind and solar resources is unavailable. Natural gas-fueled vehicles open the possibility to more carbon-efficient transportation.

**Renewables Portfolio Standards**

With increased levels of intermittent renewable generation, the problem of managing grid congestion is made more complex. However, decentralized natural gas-fired DER that provide electricity at the point of consumption may ameliorate the grid congestion problem and ensure voltage stability. Further, for the majority of the electric load that still depends on the grid for power, grid-based natural gas fired electric generation will support the additional variation in "net load" created by more bulk renewable capacity.

**Demand Response**

DR participating customers who agree to be curtailed from the grid may own their own natural gas-fired distributed energy resource, and would be able to essentially maintain independence from the grid, thus potentially providing a reliability service. Advanced metering of natural gas consumption, particularly in small businesses that own CHP, can enhance the timely delivery of natural gas fuel at such critical times, assuming the advanced metering has adequate usage resolution and near real-time availability of usage.

**Energy Efficiency**

The increased utilization of natural gas-fired CHP capacity, a DER, can help increase overall customer energy system efficiency and reliability. Heat recovered from CHP systems can be used for direct heating, or a heat-driven absorption chilling process.

**Reliability**

DERs diminish the load on the grid, and as discussed above, assist the grid operator in managing congestion and providing reliable delivery of power. Though CHP DERs that can adjust electric and thermal output on a short-term basis may provide much of this benefit, another significant portion will come from the "peaking" DER category.

## Natural Gas Support for Capture of Benefits

In addition to supports for smart grid vision and for policy objectives, natural gas provides supports for capturing a wide range of benefits. The discussion below expands on some supports by category of benefit impact.

**Utility Technical Efficiency**

Gas priority areas such as natural gas-fired DERs and bulk electric generation resources and advanced metering of natural gas consumption contribute to overall utility operational efficiency by providing more alternatives to meet energy demand, and more information with which to guide particular decisions. This improves asset utilization and helps optimize decision making regarding on infrastructure improvements.

**KWh and KW Reductions**

CHP and other types of DER can support the grid by achieving kWh and kW reductions, while potentially lowering overall customer energy costs. A decrease in the peak load experienced by the grid may diminish reliance on natural gas fired bulk electric generation. Additionally, assuming current gas usage resolution and frequency issues are addressed, advanced metering of natural gas consumption enhances the potential for consumers possessing both gas and electric equipment to arbitrage between electricity and gas.

**Environmental Improvements**

Natural gas-fired bulk generation is viewed as an important enabler of increased renewable generation, lowering the overall emissions of the energy sector, and diminishing the effects of production of fossil fuels. Advanced metering will drive ever more economically efficient consumption of natural gas fuel, lowering emissions associated with natural gas. Natural gas vehicles can also lower the overall carbon intensity of the transportation sector, compared to gasoline fueled vehicles.

**Power Quality**

Power quality is associated with reduced harmonic distortion and reactive power. It is frequently managed in terms of maintaining voltage and frequency levels within certain tolerances, to protect both synchronous-machine and solid-state electric loads, as well as the integrity of the transmission and distribution systems. Excursions in voltage and frequency, if unmanaged, can cause severe damage. Natural gas-fired DERs and bulk generation are typically called on to provide voltage or frequency support to maintain grid operation and power quality within acceptable limits.

**Service Reliability**

DERs diminish the load on the grid and assist the grid operator in managing congestion and providing reliable delivery of power. Though CHP DERs that have the capability of adjusting electric and thermal output on a short term basis may be expected to provide much of this benefit, another significant portion will from the "peaking" DER category, consisting of turbines and engines that rarely run, but can be called upon to run on short notice as necessary. Further, natural gas-fired bulk generation of the "peaking" type is installed at areas throughout the grid to assist in congestion management during peak periods. Both types of natural gas-fired DERs support the reliability of the grid, with shorter and less frequent loss of service. Advanced metering of natural gas can also improve service reliability from the customer perspective, by providing enhanced and timely information on major natural gas users during temporary periods of gas supply scarcity, as well as expedited recovery of the gas supply infrastructure during service interruptions or unforeseen events.

**National Security**

The United States is a significant energy importer, particularly of petroleum. Increased development and deployment of natural gas vehicles would provide immediate opportunities to reduce the nation's dependence on imported oil, with substantial ramifications for U.S. foreign policy responses to the energy security issue.

Domestic natural gas supplies in the near, mid and long-term are generally assumed to be plentiful. It is also assumed that imported Liquefied Natural Gas (LNG) fuel will gradually be integrated into domestic supply resources, serving mostly large, Combined Cycle Power Plants and perhaps transportation applications. Natural gas-fired CHP DERs will enhance the efficient utilization of natural gas fuel. Bulk natural gas-fired generation used to integrate renewable power resources will allow for a net reduction in natural gas use. Advanced metering of natural gas consumption will also tend to lower the use of natural gas. In the long term, these will all work in concert to lower the consumption of natural gas, and minimize dependence on imported LNG, which will benefit national security.

**Sustainable Economic Prosperity**

Economic activity, particularly energy-intensive industries, benefits from the long-term, consistent availability of inexpensive power. Indeed, low-cost, long-term power is a precondition for manufacturing and raw-material processing economic activities that create job and economic output. Hydroelectric energy is a good example of this type of power. Though somewhat intermittent based on weather patterns and larger watershed management issues, hydro is an inexpensive source of power that has reliability supplied high-usage areas and activities. But significant load also exists in areas without ready access to hydropower resources. Other renewable resources, such as wind and solar, are sufficiently intermittent to raise reliability and grid operational issues. Efficient natural gas-fired bulk electric generation helps resolve this issue, by being available to run during periods when intermittent renewables are not generating, thereby facilitating the long-term utilization of intermittent renewable energy sources. This lowers overall production costs in the long term, providing room for new industries and expansions of existing ones, and the accompanying new jobs.

## Assumptions

The project team examined various types of uncertainties that may influence the timing of achieving the smart grid vision, and made assumptions about those uncertainties. Assumptions comprise a particular scenario in an analysis that explores alternative pathways for achieving the smart grid vision. By examining alternative configurations of internally-consistent assumptions, a range of pathways and time frames for achieving the California Smart Grid vision may be determined.

Key types of uncertainties that influence the timing of achieving the smart grid vision include regulatory policy, technology innovations, commodity prices, customer acceptance, etc. The project team's assumptions about such uncertainties are summarized next. Rather than a prediction of the future, the roadmap presented in this chapter represents a sample pathway for achieving the described vision, taking into consideration the assumptions identified below.

### Drivers for a Smart Grid Remain Strong

In general, regulatory policy is the primary driver for deploying smart grid in California. California is leading the nation with ambitious energy and environmental policies that are driving the development of a smarter, more robust, and more efficient electricity infrastructure. The California Smart Grid is to support achievement of multiple energy and environmental policy goals, as described in Chapter 3, including:

- Renewables portfolio standards.
- Greenhouse gas reduction.
- Energy efficiency standards.
- Demand response.
- Distributed energy resources.
- System reliability.
- Transportation electrification through adoption of plug-in electric vehicles.
- Security and Privacy.

These types of regulatory policies serve as drivers for smart grid deployment in the state. For roadmap development, such drivers are assumed to remain consistently strong. That is, regulatory policies are assumed to continue to support focused and concerted efforts to deploy the California Smart Grid.

## Basic Project Assumptions Are Not Violated

The following assumptions were identified early on during the first stage of the project to guide domain team efforts. Domain teams were directed to develop project findings that did not conflict with any of the identified assumptions below, which also comprise roadmap assumptions.

1. Existing California Energy Policy Targets for Year 2020 are met by Year 2020.
2. Uncertainties affecting grid and market operations are handled logically.
3. Rates and programs encourage behavior that is in alignment with energy policy goals.
4. The smart grid accommodates market enablement and customer-driven choices.
5. The smart grid accommodates the integration of alternative resources.

## Reasonable Outcomes Are Assumed

In an effort to define a pathway to achieve the 2020 vision, reasonable outcomes were assumed, beyond the continuation of strong policy goals driving smart grid deployment. The team identified five types of critical assumptions, some of which are related to developments in the natural gas industry, which will have bearing on the actual timing for achieving the electric smart grid vision. They are:

1. *Regulatory Support for Smart Grid Deployment.* Regulatory decisions are often informed by cost effectiveness analyses of particular proposals conducted from several different perspectives: the customer or ratepayer, the utility, and overall society. For example, if a utility proposes a capital expenditure on natural gas infrastructure that would complement or support the smart grid vision, it must articulate the costs and benefits in terms of methodology based on consideration from the three alternative perspectives. In addition to being informed by the results of such cost-benefit analysis, a number of factors may also influence the development of the regulator authority's decision to support infrastructure programs like smart grid deployment. Depending on diverse factors taken as a whole, regulatory decisions may or may not support a given infrastructure program. Furthermore, climate control policy governing emissions control or imposing a carbon tax can significantly impact the cost of carbon, and the resulting generation mix.
2. *Technology Innovation.* Gas turbine-based natural gas-fired generating technologies have, over the last 10 to 15 years, increasingly become the marginal cost generator. This has driven continued industry focus in advancing technical development of gas-fired technologies, including simple cycle (gas turbine only) or combined cycle technologies (i.e., a gas turbine with its exhaust heat directed towards powering a steam cycle). Much technical innovation thus far has been concerned with increasing efficiency, particularly among combined cycle applications. The most significant innovations have been concerned with increasing the gas turbine firing temperature, which is generally dependent on the development of improved materials and turbine cooling designs. Gas turbine flexibility has also been an important focus, since gas turbines increasingly serve as the marginally dispatched resource, and are used for real-time balancing of electricity supply and demand. Designers have responded by incorporating improved controls, steam cycle thermal design adaptations, and even providing for increased flexibility at

the expense of efficiency in some cases. Further, inherently flexible aeroderivative gas turbines based on jet airplane engine technology are being developed for use at the utility scale. Reciprocating engines are also contemplated to have a role in supplying flexible generation needs. Though gas technology innovations have been incremental in nature, unexpected break-through technical developments are possible, as is the case with development of alternative, non-gas fueled technologies. Other new technologies are also beginning to emerge including the next generation of low emission internal combustion engines and fuel cells.

3. *Customer Acceptance.* Customers are the ultimate decision-makers on their adoption of and utilization of technologies. Depending on the customer, there are different interests. For example, a commercial or industrial customer may be concerned with the historical price volatility of natural gas and electricity, comparing costs for energy sources that can severely impact business operating results. Residential customers, on the other hand, may be more concerned with monthly energy bills. They may also value cleaner energy sources. Natural gas, for example, is a cleaner hydrocarbon choice compared to other fossil fuel alternatives, and customers may view this as a positive factor in their energy decisions. There is a threshold of environmental acceptance that any energy source must meet before widespread use, and natural gas has so far been viewed as more environmentally friendly than coal, for example. These and other factors collectively determine customer acceptance.

4. *Natural Gas and Other Infrastructure Costs.* Within the priority areas are implicit assumptions about the need for additional gas and communications infrastructure. Much of the natural gas infrastructure would only be "more of the same" types of distribution piping and metering currently in use, necessary to support distributed energy resources. However, there will also be new infrastructure elements. For example, natural gas vehicles would also add infrastructure-related costs in terms of special in-home fueling stations and fitting, as well as small 2-3kW compressors needed to fuel a compressed-natural gas (CNG) natural gas vehicle. Further, advanced metering capabilities will involve costs not only for the meters but also for the sizable communications infrastructure needed to support them. The costs of each of these infrastructure elements will in turn depend on the aggregate supply and demand, as well as innovation and competition to supply them. Depending on the materials and technical sophistication of each element, there is expected to be a range of costs associated with natural gas infrastructure.

5. *Natural Gas Commodity Costs.* Natural gas price volatility is a primary determinant for the average cost of natural gas commodity itself. Fundamental analysis of future natural gas prices depends on supply and demand assumptions found in all commodity markets, plus specialized elements found in the natural gas industry. For example, the finding and development costs associated with a given natural gas field may be more or less well known. Recent experience with the development and production from shale formations suggests that these costs are becoming more well-known, though there is an unresolved potential environmental/regulatory issue regarding the use of water and specialized chemicals associated with the hydrofracturing needed to produce natural gas from such formations.

The extent of future LNG import capacity is another factor affecting the price of natural gas. The import capacity links the domestic North American gas market with the world LNG market, potentially affecting the price of gas.

Another important concern effecting commodity cost is greenhouse gas emissions control policy. Such policy could induce the economic preference for natural gas over coal, increasing gas demand but also pushing the source of marginal production to a higher cost level and possibly a more uncertain one as well.

For each type of assumption above, the project team identified reasonable outcomes, as follows. The assumptions below form the basis of an "expected case" of the roadmap effort. Each case or scenario in turn influences the timing of achieving the smart grid vision.

- *Supportive regulatory policy for smart grid continues based on cost effectiveness.* Cost-benefit analysis of proposals for smart grid related deployment favors implementation on an objective basis, and there is broad support on the basis of subjective considerations of stakeholder interests. Implicit in this assumption is that the regulatory authorities arrive at a satisfactory allocation of authorized expenditure. Considerations are made of costs associated with both the electric smart grid and investments required to fully enable gas support of the smart grid vision. In the instances where infrastructure is required to support providing natural gas to a generating project, it is typical for the natural gas infrastructure alterations and additions to be paid for by the generator (developer) and not other gas utility customers.
- *Existing natural gas and competing technologies make incremental improvements.* Natural gas fired technologies and their alternatives continue to make modest improvements, and maintain their relative positions with respect to overall cost-effectiveness.
- *Customer acceptance of smart grid technologies is based on economics and environmental drivers.* Customers generally accept an increased role for technologies in support of the smart grid vision on the basis of favorable economics, and a perception of enabling a cleaner energy future. There is modest support for bulk and distributed renewable technology, due to high costs. There is positive customer perception of smart grid technologies to remedy safety-related concerns.
- *Natural gas and other infrastructure costs remain within historical norms.* The cost of natural gas piping, metering, and the underlying labor and technology costs remain stable and are consistent with recent history. There are no major surprises in advanced metering infrastructure costs, including for the communications infrastructure needed to support advanced metering.
- *Natural gas commodity costs are in the range of $4 to $10/MMbtu.* This range is considered "business as usual" for natural gas commodity costs. It considers that natural gas prices in 2008 were anomalous, and confines gas price assumptions to a generally-accepted range of natural gas prices. This view is supported by the related assumption of shale gas availability at reasonable prices.

## Extreme Outcomes Are Not Assumed

Assumptions surrounding natural gas commodity costs and other types of uncertainties, as described above, are important to consider in any roadmapping effort. Balanced consideration is important in the midst of industry uncertainties and complexities, all of which influence the timing of achieving the smart grid vision. For example, though current prices may be relatively low, allowance can be made for the possibility of gas prices becoming very high in an "extreme case" or scenario.

The team also identified extreme outcomes for key uncertainties. Together the outcomes below define an "extreme case" for each type of uncertainty, as follows:

- *Denial of cost recovery for natural gas related smart grid programs and infrastructure.* Due to an overall reluctance to burden ratepayers with additional costs of any sort, or the potential disproportionate allocation to the electric industry, regulatory authorities choose not to approve smart grid activities and infrastructure improvements needed to fully support achieving the smart grid vision.

- *The emergence of a breakthrough technology undercuts smart grid related technology.* A technical development allows for economic, rapid deployment of alternative energy sources outside of existing energy policy targets, such as nuclear power including distributed nuclear power or cost-effective electric storage devices. Alternative dispatchable technology breakthroughs could cause natural gas use to become increasingly marginal in the power generating sector, and generally confined to direct use (combustion) among most customer classes.

- *Safety concerns blunt customer acceptance.* Public concerns about public health and safety (e.g., physical and cyber attacks or pipeline incidents) make it difficult for customer adoption of distributed resource and demand response enabling technologies.

- *High natural gas or other infrastructure costs.* High costs, possibly due to cost overruns related to advanced metering equipment installation, maintenance and communications/computer infrastructure, discourage customer acceptance and dissuade regulators from approving expansion of supporting infrastructure.

- *High natural gas commodity costs ($14-20/MMBtu).* High and/or volatile natural gas prices preclude stable economic utilization of natural gas. Potential causes may include increased costs associated with mitigation of environmental issues (e.g., related to shale gas development or GHG emission controls), combined with limits on areas in which gas exploration are permitted. If prices in this range were realized, high gas prices would increase the requirement for a Smart Electric Grid, since the increase in renewable generation would be substantial, including the intermittency that goes with it. Storage would also appear more economically feasible.

The 2020 vision and roadmap were defined assuming reasonable assumptions (e.g., supportive regulatory policy, only incremental improvements in technology, costs remain within historical norms). Any of the extreme outcomes (e.g., high infrastructure and commodity costs, emergence of a breakthrough technology that undercuts natural gas, etc.) creates a different scenario that could significantly alter timing for achieving the 2020 vision and roadmap.