ADVANCED TECHNOLOGY

Transmission & Distribution Business Unit





Southern California Edison Smart Grid Strategy & Roadmap

SOUTHERN CALIFORNIA EDISON®

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In 2007, Southern California Edison developed its first comprehensive Smart Grid Roadmap spanning transmission, distribution and customer facing technologies. Since that time, national and state policy regarding smart grid development has significantly grown including the passage of the landmark Energy Independence and Security Act of 2007 (EISA). In 2009, California passed its version in Senate Bill 17.

The purpose of this updated Smart Grid Strategy and Roadmap is to summarize SCE's activities and plans for development and implementation of a smarter grid as well as explain the organizing principles, decision framework and methods used to manage the adoption and adaptation of new technologies into our operation. While we hope that the document proves useful for all readers, it is intended primarily to convey SCE's perspectives on the smart grid for policy makers, the electric utility industry, and technology providers which serve our industry.

SCE is grateful for the supporting contributions by IBM, Enernex, Cisco, Quanta and EPRI to the development of this document that began with expanding the set of Use Cases to encompass the breadth of the smart grid. We also appreciate the earlier support by Bridge on the development of the 2007 roadmap that was the foundation for this effort. Finally, we appreciate the reviews provided by our Technology Advisory Board, PG&E and SDG&E, and Jesse Berst.

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1. Introduction

1.1. Why do we need a smarter grid?

The United States has arrived at a critical juncture in its energy future. The stakes for addressing climate change, energy independence and infrastructure security could not be higher. Federal and state policymakers alike have recognized the need for a smarter, more robust electricity infrastructure if we as a country are to rely on greater amounts of renewable generation, use electricity as a fuel for vehicles, enable consumers to become active participants in the energy supply chain, and ensure the continued reliability and vitality of our nation's energy economy. Southern California Edison (SCE) must meet these challenges while continuing to operate the grid in a safe and reliable manner. SCE has served as a leader in fostering the development of advanced grid technologies and the adoption of technology to create a smarter grid.

SCE recognized the need for the development of a smarter grid more than a decade ago. This need was heightened with the wide range of climate and energy policy objectives introduced earlier in the last decade after the 2001 California Energy Crisis. Also, post dot-com venture investment in clean technology has yielded several emergent technologies that have made certain aspects of a smart grid more viable. In 2007, SCE developed a detailed smart grid technology roadmap across five themes described in our Smart Grid Vision in section 1.2. Many elements of this earlier roadmap are valid and continue to be pursued. However, over the past three years a number of additional policy targets have been introduced to create a very aggressive set of goals that have implications for development of a smarter grid. It is important to note that it is not entirely clear that all these policy targets are viable given the technology development and deployment timelines and customer rate impacts. Figure 1 below summarizes the current California policies affecting smart grid development.

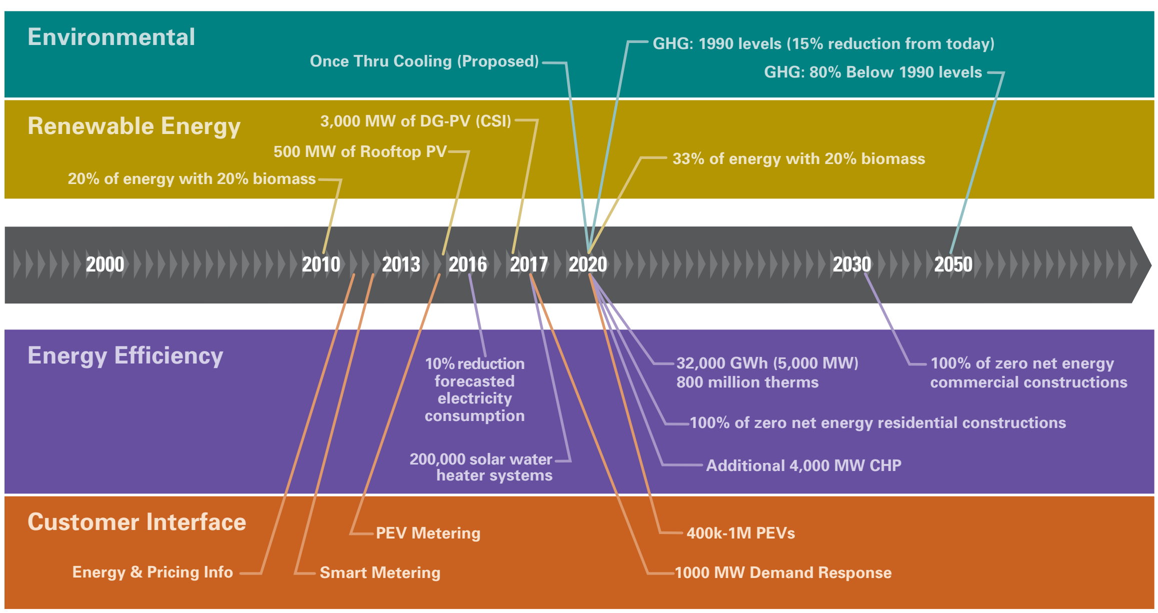


Figure 1 - California Smart Grid Policy Timeline

The breadth of the change required for modernizing the nation's electricity grid is highlighted by the policy objectives defined in the federal Energy Independence and Security Act of 2007 (EISA). This law identifies the following specific capabilities that should be enabled by a smart grid:

2007 EISA Smart Grid Policy
1. Increased use of digital information and controls technology to improve reliability, security and efficiency of the electric grid.
2. Dynamic optimization of grid operations and resources, with full cyber-security.
3. Deployment and integration of distributed resources and generation, including renewable resources
4. Development and incorporation of demand response, demand-side resources and energy-efficiency resources.
5. Deployment of smart (real-time, automated, interactive) technologies that optimize the physical operation of appliances and consumer devices for metering, communications concerning grid operations and status, and distribution automation.
6. Integration of smart appliances and consumer devices.
7. Deployment and integration of advanced electricity storage and peak-shaving technologies including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning.
8. Consumer access to timely information and control options.
9. Development of standards for communication and interoperability of appliances and equipment connected to the electric grid including the infrastructure serving the grid.
10. Identification and reduction of unreasonable or unnecessary barriers to the adoption of smart grid technologies, practices and services.

Table 1 - 2007 EISA Smart Grid Policy

These same objectives were incorporated into a recent California law, Senate Bill (SB) 17, which was enacted in October, 2009. The law recognizes the need for a smarter grid to support California's ambitious energy and environmental policies such as the Renewables Portfolio Standard[1], greenhouse gas reduction law[2], energy efficiency standards including requirements for Zero-Net Energy Homes, distributed resource goals like the California Solar Initiative, demand response objectives and support for widespread consumer adoption of plug-in electric vehicles (PEV). In this context, SCE believes that many aspects of its smart grid vision would need to be operational by the year 2020 to enable a number of California's ambitious policy goals. In recognition of this challenge, SB 17 requires investor owned utilities to prepare a 2020 smart grid development plan and file it with the CPUC by July 1, 2011. The parameters of this development plan will be identified in the Smart Grid OIR in the summer of 2010.

While many details regarding development of a smart grid need to be resolved, including scope, standards, benefits, cost and timing, one thing is clear: We as an industry need to modernize our electric grid in order to support an increasing reliance on electricity to fuel the nation's economy.

"…we'll also do more to retrofit America for the global economy. That means updating the way we get our electricity by starting to build a new smart grid that will save us money, protect our power sources from blackout or attack, and deliver clean, alternative forms of energy to every corner of our nation."

– President Barack Obama, January 2009

1 California's Renewables Portfolio Standard (RPS) requires that 20% of electricity sales be from renewable sources by 2010. In September 2009, Governor Schwarzenegger signed an Executive Order raising the RPS target to 33% by 2020. SCE supports development of cleaner energy resources and currently has the largest RPS portfolio in the nation, however we do not believe that a 33% RPS target is achievable by 2020.

2 California Assembly Bill 32 requires that carbon emissions be reduced to 1990 levels by 2020, and to 80% below 1990 levels by 2050.

1.2. The SCE Smart Grid Vision

"SCE's vision of a smart grid is to develop and deploy a more reliable, secure, economic, efficient, safe and environmentally-friendly electric system."

SCE's vision of a smart grid is to develop and deploy a more reliable, secure, economic, efficient, safe and environmentally-friendly electric system. This vision covers all facets of energy from its production to transmission, distribution, and finally its efficient use in homes, businesses and vehicles. This smart grid will incorporate high-tech digital devices throughout the transmission, substation and distribution systems and integrate advanced intelligence to provide the information necessary to both optimize electric service and empower customers to make informed energy decisions.

Consistent with the 2007 EISA and the U.S. Department of Energy's and National Energy Technology Laboratory's Vision for the Modern Grid, SCE's smart grid will enable increased levels of intermittent and renewable resources (such as wind and solar power) and lead to greater use of Plug-in Electric Vehicles (PEV). To achieve these goals and the complete smart grid vision, the SCE smart grid will increase system flexibility; reduce greenhouse gas emissions; avoid the economic losses associated with catastrophic failures and wide-area blackouts; foster energy conservation, energy efficiency and demand response capabilities by providing customers with better energy use information and choices; reduce operating costs and improve reliability and safety by providing real-time information for system monitoring and system automation; improve maintenance and operations practices on the electrical grid; and facilitate the development of a "Clean Tech" economy, which is expected to include the creation of new jobs. We believe a true smart grid can help America achieve meaningful greenhouse gas reductions and a more secure energy future.

Figure 2 - SCE Smart Grid Vision Themes

The five key smart grid strategic themes, as depicted in Figure 2 on the previous page, serve as the basis for SCE's smart grid vision:

- ***Empower Customers*** to manage energy use and reduce their carbon footprint through the use of smart energy devices, PEV and distributed energy resources at customers' premises.
- ***Improve Workforce Safety and Productivity*** through smarter tools, advanced robotics, remote controlled devices, protective equipment and workforce mobility applications.
- ***Integrate Renewable and Distributed Energy Resources*** through new engineering designs for resource integration, protection schemes and circuits, storage technologies, power electronics and technology to provide system stability.
- ***Improve Grid Efficiency & Resiliency*** through innovative real-time power system measurement, controls, analytics and grid technologies including the application of high temperature superconducting materials.
- ***Provide Information and Connectivity*** through the development of an open standards-based, secure, resilient and extensible information and communications technology (ICT) infrastructure.

Several aspects of SCE's smart grid vision must be developed by 2020 in order to comply with ambitious state and federal policy goals related to climate change, clean energy and infrastructure security. However, it is impractical to think that all aspects of this Vision can be developed and implemented within 10 years given the nascent stage of many technologies and the ratepayer costs. As such, deployment of a smarter grid is a journey that will extend well beyond 2020. The remainder of this document describes the customer and societal value of the SCE smart grid, provides further definition around each of the SCE smart grid themes depicted in Figure 2, articulates strategies and methods which will be followed to help ensure success, and provides a roadmap describing the pathway and evolution of the SCE smart grid.

1.3. Smart Grid Value Proposition

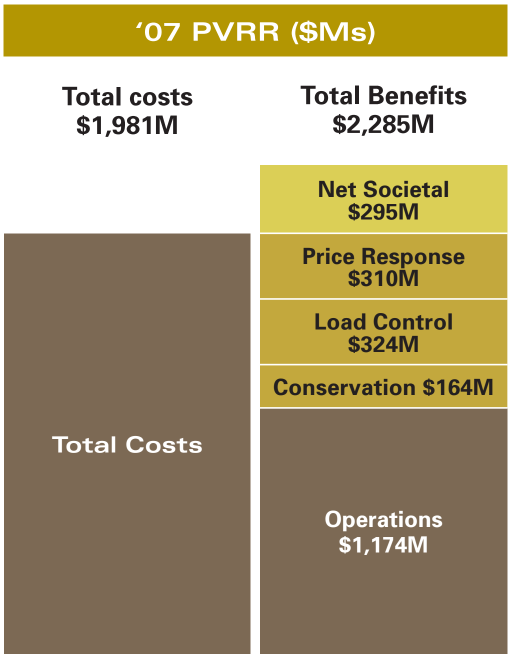
Key objectives of SCE's smart grid development strategy include pursuit of technologies that provide significant customer value that exceeds the cost of implementation, as well as identifying best fit solutions to meet policy objectives that may not have direct operational benefits. Smart grid technology projects will likely involve a mix of both incremental and replacement investments that not only expand existing capabilities, but also build new capabilities.

Although SCE believes in taking a cost-effective approach to the deployment of smart grid technologies and systems, traditional cost/benefit models may not account for all of the value to be derived from smart grid investment decisions. A substantial portion of smart grid benefits are societal in nature and include achieving national and state priorities such as energy independence, reducing greenhouse gas emissions and increasing grid security, safety and reliability. These benefits are often difficult to quantify, may vary widely in their justification of various smart grid technologies, and are multi-faceted in terms of who receives benefits from them. Benefits may not only accrue to SCE customers, but also to California residents or our broader society. In addition, these benefits need to be considered within the context of the portfolio of smart grid technologies to be deployed at different times over the next twenty years and beyond.

SCE has identified 10 broad smart grid benefits categories. Accordingly, the smart grid has the potential to:

1. ***Provide Customer Benefits*** by improving grid reliability, enhancing customer communications, and by empowering customers to better manage their energy usage and costs.
2. ***Reduce Peak Demand*** through demand management programs and services.
3. ***Increase Energy Conservation & Efficiency*** by enabling integration of customer energy management systems and grid energy management systems; this integration can reduce system losses.
4. ***Reduce Operating Expenses*** by lowering the cost of planning and support functions, operating costs and energy costs.
5. ***Avoid, Reduce or Defer Capital Investments*** by increasing capacity utilization, extending the useful lives of grid assets, optimizing energy procurement practices, and investigating new technologies.
6. ***Increase Utility Worker Safety*** by providing tools and information that allow them to perform their work in a safer manner.
7. ***Improve Grid Resiliency and Reliability*** by reducing the frequency and duration of outages and service interruptions, and by improving power quality, accommodating greater diversity of energy resources, and increasing grid security.
8. ***Reduce Greenhouse Gas Emissions*** by integrating renewable energy resources with the electric delivery system, and promoting the adoption of electric vehicles.
9. ***Promote Energy Independence*** by facilitating electricity-based transportation.
10. ***Promote Economic Growth & Productivity*** by fostering the development of California's clean technology economy, and associated job growth.

SCE is already on a trajectory to significantly increase energy conservation, enable advanced demand response programs, reduce greenhouse gas emissions, and enable customer energy management through a combination of Edison SmartConnect™ (smart metering), demand response and energy efficiency initiatives[3]. Figure 3 below illustrates the 20 year NPV of the Edison SmartConnect™ residential and small commercial smart metering program.



	($Millions)	
Costs	**Nominal**	**'07 PVRR**
Phase II Pre-Deployment	$ (45)	
Acquisition of Meters & Comm Network	(726)	
Installation of Meters & Comm Network	(285)	
Back Office Systems	(251)	
Customer Tariffs, Programs & Services	(117)	
Customer Service Operations	(82)	
Overall Program Management	(45)	
Contingency	(130)	
Post-Deployment	(1,582)	
Total Costs	**$ (3,263)**	**$ (1,981)**
Benefits		
Meter Services	$ 3,909	
Billing Operations	187	
Call Center	96	
Transmission & Distribution Operations	92	
Demand Response - Price Response	1,044	
Demand Response - Load Control	1,242	
Conservation Effect	828	
Other	39	
Total Benefits	**$ 7,437**	**$ 1,990**
Net Benefits Excluding Societal	**$ 4,174**	**$ 9**
Societal Benefits		**295**
Net PVRR		**$ 304**

Figure 3 - Edison SmartConnect™ Cost Benefit Information

Other aspects of a smart grid are in the development phase, but it is clear that their future implementation will play a crucial role in enabling SCE to meet renewable energy goals, further reduce greenhouse gas emissions, and improve system reliability and safety.

3 California Public Utilities Commission (CPUC) Proceedings: D.08-09-039; A.08-06-001; A.08-07-021.

1.4. Smart Grid Definition

SCE defines the smart grid as an increasingly intelligent and highly automated electric power system that utilizes technology advancements in telecommunications, information, computing, sensing, controls, materials, in addition to other grid technologies. The smart grid will be able to better meet customers' energy demands, while also seamlessly integrating new sources of energy and delivering power over a network that is increasingly interoperable, efficient and resilient.

The smart grid of 2020 will comprise an expansive network of grid components. Millions of intelligent digital devices will continuously generate increasingly large amounts of data about the system's state. This data will ultimately yield visual and actionable information that can be used to optimize control of the electric system and empower customers to make informed energy decisions. In addition, a smart grid will enable customers to utilize electric power as a fuel source for their transportation needs.

The SCE smart grid will leverage emerging technologies such as transformers that utilize superconducting materials, new energy storage devices, advanced sensors and controls, 4G broad-band wireless telecommunications, and decision-support software. Implementing these technologies will lead to an SCE smart grid that continuously examines the electric system's status and iteratively simulates grid conditions while calculating contingencies. The smart grid system will be able to determine the most optimal set of coordinated control actions to mitigate abnormal system conditions, increase capacity utilization and improve power quality. In addition, the SCE smart grid will be able to assess the health of critical assets such as bulk power transformers. If a critical failure occurs, putting the stability of the system at risk, the network would automatically transfer load from the relevant transformer banks through automated reconfiguration of switches and transformer banks to prevent failure and maintain electric service.

The SCE smart grid vision is made possible by the five key strategic themes depicted in Figure 2 and portrayed as five overlapping rings. Each of these theme areas can be broken down into supporting objectives. In the following sections, we drill one level deeper in order to define these theme-specific objectives.

1.4.1. Customer Empowerment: Energy Smart Customer Solutions & Advanced Electric Transportation

Energy Smart Customer Solutions

Definition: Empower customers to become active participants in the energy supply chain by providing them with information and new customer service options that enable management of their own energy consumption and reduction in carbon emissions

The Edison SmartConnect™ advanced metering infrastructure program involves the planned installation of over 5 million advanced meters by 2012.

California policy over the past decade has clearly recognized the benefits of enabling customer participation in the energy supply chain through the preferred loading order for energy efficiency and demand response, and through several regulatory policies that have led to smart metering, dynamic rate options and demand response programs for all customers. The foundational technology currently being deployed through Edison SmartConnect™ will provide a platform that can be utilized to leverage future customer technology. To take advantage of this platform, SCE continues to support the development of industry standards at the customer level and encourage third-party product development. We also identify opportunities for SCE technology adoption that further enables customers to manage their energy usage and monthly bills. Moreover, SCE is pursuing opportunities to leverage our smart metering infrastructure to improve utility operations and customer service.

Theme Objectives	
Customer Situational Awareness	Develop capabilities to dynamically provide customers with information about relevant grid conditions (e.g. outages, grid events, power quality, etc.).
Customer Energy Management	Provide customers with pricing and usage information necessary to help them manage consumption and production of energy at their residences or places of business.
Customer Energy Storage	Evaluate customer energy storage applications such as enabling Zero Net Energy homes and buildings and improving DER effectiveness.
Customer Technology Advocacy	Represent the customers' interests in engaging technology providers to develop effective and interoperable new smart grid technologies and services. Actively support interoperability standards development and adoption to promote increased speed to market and broad compatibility of customer technology.

Advanced Electric Transportation

Definition: Provide support and infrastructure solutions for port and rail electrification, SCE fleet electrification, and electric vehicle charging.

SCE possesses the largest private electric vehicle fleet and is involved in partnerships with EPRI, Ford and GM in developing Plug-In Electric Vehicles which can be integrated with the smart grid.

The largest contributors to greenhouse gas emissions in Southern California are the Ports of Los Angeles and Long Beach, and truck and car traffic occurring on the extensive freeway system in the Los Angeles basin. Efforts are underway at the Port of Long Beach to use electricity rather than diesel-fueled power for ships in port, and to use electric rail or trucks for moving cargo from the port to inland rail hubs and distribution centers. SCE is an active supporter of these port electrification efforts and a contributor to the technology strategy for reducing overall port and related emissions. California approved a high-speed rail bond measure in 2009 that matches federal money to build a system across the state and to Las Vegas. SCE is supporting the engineering analysis for the integration of this new dynamic load. Similarly, a transformation in the passenger vehicle market is expected to be launched in 2010 with the arrival of mass market PEV. SCE has equipment testing in progress at our Electric Vehicle Technology Center that focus on advancing vehicle charging systems to integrate effectively into the grid and potentially market operations. SCE continues to collaboratively develop medium and heavy duty electric trucks to expand the electrification of our utility fleet as part of our broader commitment to the Edison Electric Institute's Electric Transportation pledge. SCE already has the largest electric vehicle fleet in the US utility industry with nearly 300 light duty vehicles that have driven over 18 million miles.

Theme Objectives	
Port Electrification and High Speed Rail	Support California port electrification and high speed rail initiatives and explore other industrial non-road electric transportation applications.
Medium and Heavy Duty Electric Vehicles	Support development of advanced electric vehicle propulsion systems and adopt as appropriate into the SCE medium and heavy duty transportation fleet.
Electric Vehicle Charging Systems	Support development of electric vehicle charging systems for home, workplace, commercial, and public charging locations. Evaluate vehicle monitoring and control systems and adopt as appropriate. Actively support electric vehicle standards development and adoption.

1.4.2. Workforce Safety & Effectiveness

Definition: Evaluate and adopt technologies that maximize workforce productivity, effectiveness and safety through application of enabling tools and technologies.

Smart grid deployment, operations and maintenance at SCE will require new skill sets and a safe and productive workforce.

As SCE deploys smart grid technologies and systems, its work practices and tools must evolve to safely and effectively deploy, operate and maintain the smart grid. SCE anticipates a variety of workforce challenges that include managing an increasingly complex infrastructure, replenishing an aging workforce and leveraging an increasing amount of field data, all while maintaining an unwavering focus on safety. To address these issues, SCE is focusing on improving the productivity, safety and effectiveness of its field and system operator workforce. This will require evaluation of new safety and mobile workforce computing technologies.

Theme Objectives	
Workforce Safety Technologies	Investigate and leverage technologies and revised work processes to further enhance the safety of the SCE workforce. These technologies include robotics applications for inspections and field force personal safety technologies.
Organizational Preparedness	Ensure SCE is organizationally prepared for the deployment and operation of advanced technologies through internal skills development, external education programs, recruiting, knowledge management, and communications.
Workforce Productivity Technologies	Leverage emerging smart grid and communications technologies to enhance productivity of the SCE field workforce and system operators. Promising technologies include advanced work management, scheduling and routing.

1.4.3. Renewable & Distributed Energy Resource Integration

Definition: Utilize intelligent monitoring, protection and control technology, and storage technology to effectively integrate and manage new sources of bulk and distributed renewable energy supply.

In 2009, SCE obtained approval to cover 65 million square feet of unused Southern California commercial rooftops with 250 megawatts of the latest photovoltaic technology – enough generating capacity to meet the needs of approximately 162,000 homes.

In 2009, California's Governor signed an executive order to increase the renewables portfolio standard from 20% to 33% by 2020. This target – one of the most aggressive RPS targets in the world – cannot be achieved without advances in grid technology and resource integration technology such as intelligent inverters and protection and control systems. Today's electric grid was not designed with these technologies and policy goals in mind and a significant effort is underway within SCE and across the industry and academia to address the necessary redesigning of the electric system. At the same time, SCE, like many industry stakeholders, recognizes the potential for various energy storage technologies to help better integrate intermittent resources and address some fundamental changes such as bi-directional power flow on distribution systems. SCE has a twenty-year technology evaluation and testing legacy with battery storage technologies that creates unique opportunities to actively support product development that is occurring at battery technology suppliers.

Theme Objectives	
Renewables and DER Integration	Conduct studies and develop technical solutions that will help SCE accommodate increased RPS targets and distributed energy resource policies in both the transmission and distribution systems.
Dynamic Response Storage	Investigate and deploy dynamic response storage applications that support the integration of intermittent renewable energy resources by mitigating power quality issues and providing grid support.
Energy Shifting Storage	Investigate energy shifting storage applications to assist with the integration of intermittent renewable energy resources by storing surplus power during off-peak periods and supplying power during peak periods or periods of limited renewable resource output.

1.4.4. Grid Efficiency & Resiliency

Definition: Utilize improved asset monitoring, data analytics and advanced materials to operate the existing grid at optimum performance levels that maximize efficiency, and to improve system planning and engineering processes for future grid development.

As part of its efforts to redesign the electric grid for the 21st century, SCE is assessing future requirements for grid efficiency and resiliency, as well as evaluating the technologies that will enable this future grid. SCE views grid efficiency as improving electric system and capital efficiency by using better intelligence and materials technology to optimize system planning and improve grid throughput. Resiliency includes the abilities to automatically monitor, assess and control the grid, to adapt to changing conditions, meet customer reliability and power quality requirements, and prevent catastrophic bulk-power system failures.

SCE's Synchronized Phasor Measurement Systems (SPMS) project, with visualization capabilities for operator use, was awarded the "2007 T&D Automation Project of the Year" by Utility Automation & Engineering T&D Magazine.

Theme Objectives	
Grid Asset Performance	Maximize the efficiency and utilization of grid assets through improved asset monitoring and maintenance processes and technologies.
Enhanced System Planning	Develop advanced system analysis tools to store and compile smart grid data and to identify impacts of evolving technologies and markets on the planning and installation of grid infrastructure.
Grid Efficiency	Develop and apply technologies, such as Volt/Var control, to reduce losses and increase grid efficiency and capacity.
Advanced Grid Materials	Develop and apply technologies that include advanced materials to enhance equipment efficiency, safety, and environmental and performance characteristics.
Enhanced Grid Reliability	Evaluate and adopt smart grid technology which continues to enhance reliability and ensures compliance with National Energy Reliability Corporation (NERC) reliability standards while also allowing for increasing operational coordination across the entire grid.
High Impact Event Mitigation and Preparedness	Ensure that proper measures are being undertaken and technologies deployed to protect against and recover from low probability, high impact risks (e.g. electromagnetic pulse threats, cyber-terrorism, natural disasters, etc.).

1.4.5. Information and Connectivity

Definition: Evaluate and adopt information and telecommunications technologies which provide scalability, flexibility and interoperability for data and information exchange across the entire grid supply chain from generation to customer. These technologies will be able to be easily integrated into a resilient and secure smart grid architecture which supports electric system operations.

SCE currently has one of the most comprehensive telecommunications portfolios in the industry. It is comprised of 5,250 circuit miles of fiber optic communications, over 30,000 Netcomm radios, and a proprietary satellite communications system to monitor and control the electric system.

Creating a 21st century electric grid requires significant investment in new information and telecommunication technologies. While several fundamental technologies exist in commercial form, many require adaptation from their present use in other industries or in military applications. SCE has an extensive ongoing effort to evaluate information and telecommunication technologies for electric system adoption. SCE is also designing a smart grid telecommunications network that will provide connectivity, security and intelligent processing through a "network-of-networks" consisting of inter-utility, intra-utility and field area networks. This integrated set of networks will facilitate data exchange and communications among customer devices, utility field devices, the field workforce, grid operators, utility computing systems and external parties such as the California Independent System Operator (CAISO).

A smarter grid will generate exponentially larger amounts of data. To meet this challenge, SCE is also designing an integrated, resilient, adaptive, and interoperable information "system-of-systems" to collect, interpret, and rapidly respond to this data. To ensure system survival in light of potential cyber-security threats, SCE is taking measures to provide comprehensive end-to-end security coverage. These measures address security concerns at a holistic, system-wide level and identify the impacts of any given vulnerability or threat to the entire system. SCE's cyber-security efforts involve external engagement with technology suppliers, standards organizations and policy makers, and internal engagement to address the security requirements of SCE systems.

Theme Objectives	
Information and Communications Architecture and Engineering	Develop and implement a unified architecture that defines functional requirements and provides required availability, reliability, resiliency, interoperability, and security (ARRIS).
High Speed Backbone Telecommunications	Evaluate and deploy high speed telecommunications technology to interconnect substations and link to field area communications that will support utility and customer communications needs, and will enable the grid telecommunication systems to operate as an integrated network of networks.
Advanced Field Telecommunications	Evaluate and adopt telecommunications technologies to improve field area networks and link backhaul field area information, including customer information, to substations and utility operations.
Information Systems	Develop and implement highly reliable, secure and scalable information systems to meet future needs for data management, analytics and complex automation and control systems.
Cyber-security	Develop and implement common security services to resist attacks and dynamically respond to threats.

2. Smart Grid Development Methodology

Much of SCE's smart grid vision and strategy needs to be realized over the next decade in order to meet state and federal policy initiatives and to accomplish company objectives. In order to execute on the broad smart grid vision outlined above, SCE has employed several methods that involve careful and customer-focused technology planning, internal and external alignment of resources, disciplined processes for technology evaluation, and an open standards-based approach to technology innovation. The following methods have been in use at SCE over the past five years and have resulted in our successful smart metering and synchrophasor deployment programs:

1. ***Customer-Focused Systems Engineering***
2. ***Open Innovation***
3. ***Technology Development Scenario Planning***
4. ***Proactive Standards Development***
5. ***Rigorous Technology Evaluation***

2.1. Customer-Focused Systems Engineering

"Creates a structured framework in order to balance cost, schedule and technical constraints of smart grid deployment"

An important aspect of smart grid deployment is the ability to balance cost, schedule and technical constraints with a thorough understanding of customer needs, business goals, and the maturity level of technologies available in the marketplace. SCE's Customer-Focused Systems Engineering approach addresses these complexities by providing a structured framework for understanding the value and risks inherent in deploying a complex "system-of-systems" and "network-of-networks" such as the smart grid.

Design thinking for a smart grid requires the more robust and holistic approach offered by systems engineering. Benefits of this approach include better solution quality, higher value solutions, lower project costs, reduced project risks and shorter project schedules.

SCE was an early implementer of the IntelliGrid methodology to gather smart grid requirements and develop architecture using a disciplined systems engineering approach. This approach was subsequently adopted by several other utilities (e.g., Consumers Energy, Florida Power & Light, Salt River Project, First Energy) and by NIST to develop their standards roadmap. This approach has been codified in IEC standard 62559[4].

4 IEC standard 62559 - http://webstore.iec.ch/preview/info_iecpas62559%7Bed1.0%7Den.pdf

The development of use cases is an important first step in the systems engineering process at SCE (www.sce.com/usecases). Use cases support the generation and documentation of requirement sets for smart grid technologies. The use cases accomplish this by focusing on business scenarios that identify the people, field technologies and information systems that must interact to achieve a business goal. At SCE, concepts from the Customer Focused Technology Planning® (CFTP®) framework have been adapted to help evaluate smart grid requirements resulting from the use case process. CFTP® is a methodology that has been used in a wide variety of industries to help guide technology strategy and evaluation by providing a means to identify and prioritize the deployment of smart grid technologies. It helps to ensure that the needs of customers and other key stakeholders are considered in a way that balances the risks and rewards of implementing new technologies. By incorporating CFTP® concepts into the Systems Engineering processes at SCE, the result is a methodology which we have called Customer-Focused Systems Engineering.

"System engineering is a robust approach to the design, creation, and operation of systems. In simple terms, the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals."

– NASA Systems Engineering Handbook, 1995.

Our smart grid challenge and opportunity is to develop a technology game plan that appropriately balances state and federal policy objectives, our customers' needs, SCE's business objectives, and the adoption of new smart grid technologies. In light of this challenge, before we engage in any new smart grid opportunity, be it for emerging technology evaluation or commercial technology deployment, we first score and rank that opportunity using a standard rating system. This system considers three critical criteria: (1) alignment with business objectives (including customer value, improved grid operations and compliance with state and federal energy policies); (2) risks associated with adopting the technology; and (3) cost effectiveness. In the aggregate, potential smart grid investment opportunities over the next decade and beyond appear to follow a diminishing returns curve. SCE is therefore careful to consider opportunities based not only on their potential value, but also with contemplation of the risks of technology adoption.

As such, SCE's Customer-Focused Systems Engineering approach also includes a structured framework for understanding the value and risks inherent in deploying complex, network-centric systems such as the smart grid. SCE has developed several analytical models, including Technology Capability Maturity (TCM) and early Stage Technology Adoption Risk (eSTAR) models that are used to assist with early stage technology adoption and/or development decisions.

2.2. Open Innovation

SCE has a long history of following an open innovation approach to technology evaluation and adoption. Although Edison is recognized as a global leader in the development and implementation of advanced technologies, it is aware that smart grid deployment is a complex undertaking requiring a collaborative effort by many stakeholders. Therefore, SCE is actively pursuing an open innovation approach that involves working closely with many of the various stakeholder groups. These groups include customers, other utilities, policymakers, technology manufacturers, standards organizations, universities, national labs, and research institutes. This collaborative approach is needed to achieve common understanding on key issues and interests across these diverse groups.

"Allows for the sharing of ideas and concepts across utilities, policy makers, vendors, and research groups to advance technology development and applied research"

Open innovation allows for sharing of ideas and concepts across entities – utilities, policy makers, vendors, and research groups – to drive further applied research and technology development in needed areas, and to better understand the value proposition of smart grid components for our customers, utility operations and society as a whole. This approach builds consensus and critical mass in the industry in order to drive technology development to meet open and interoperable standards and new performance requirements. Notable collaboration efforts with other smart grid stakeholder organizations include the following:

- SCE is actively engaged with the Edison Electric Institute's (EEI) and the Electric Power Research Institute's (EPRI) smart grid initiatives and is the current chair for both EEI's and EPRI's Smart Grid Executive working groups.
- SCE co-chairs the Western Electric Industry Leaders (WEIL) technology collaborative.
- SCE founded the Southern California Energy Research Consortium involving local distinguished international research universities: Caltech, University of Southern California, University of California, Los Angeles, UC Irvine and UC Santa Barbara. SCE also collaborates with Massachusetts Institute of Technology, Stanford, University of Illinois, UC Berkeley, UC Davis and Carnegie Mellon.
- SCE is collaborating with several national research labs, including Lawrence Berkeley National Lab, National Renewable Energy Lab, Idaho National Lab and Pacific Northwest National Lab.
- SCE has technical exchange efforts underway with leading utilities in Asia, Australia, Europe, South America and Canada, in addition to our US utility collaborations.

2.3. Technology Development Scenario Planning

"Ensures that SCE's smart grid strategy remains a viable technology adoption plan as driving forces alter the smart grid landscape"

SCE engages in scenario planning as part of its strategy for ensuring success in achieving its smart grid vision. Over the past year, SCE's scenario planning efforts have resulted in the development of four potential pathways for the pace of technology development and adoption for the smart grid. A key objective of this analysis is to ensure that the SCE's smart grid strategy provides a viable adoption roadmap in any of the four potential pathways. These scenarios were created following a careful analysis of the critical driving forces affecting the smart grid, and after making some assumptions as to the degree of impact (positive or negative) that these forces might have on the pace of technology development and adoption. The following driving forces were considered:

- Economic Growth
- Policy Focus
- Technology Innovation & Adoption
- Energy Markets
- Customer Trends
- Environmental Developments

The goal for developing future scenarios is not to identify the most likely future but to examine how these important external forces may shape smart grid deployment through 2020 and beyond. The characteristics of the resulting scenarios are used by SCE to help prioritize and select smart grid technology projects. Those opportunities which seem to be relevant and viable across multiple future scenarios receive additional consideration, in comparison to those opportunities which might seem promising in a single future scenario but may look irrelevant or risky under other scenarios. In addition, for each future scenario, SCE has developed specific proactive responses based on the implications of that scenario. As evidence develops that the future is trending toward any given scenario, these "contingency plan" responses for the given scenario can be called into action.

SCE's smart grid future scenarios were developed by considering a spectrum of two of the most critical driving forces – Economic Growth and Policy Driven Innovation – placed along two axes as follows:

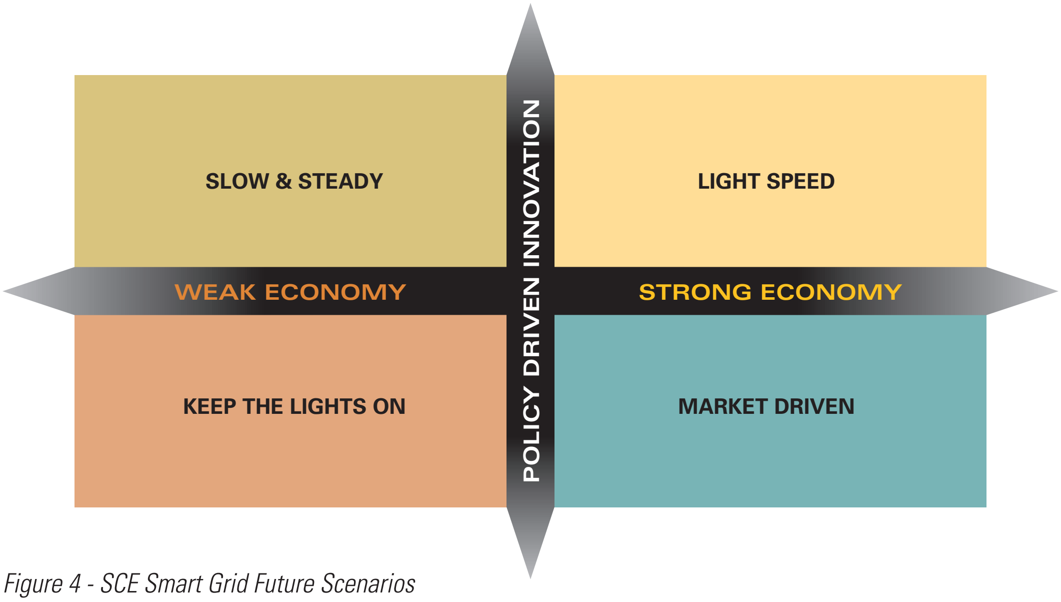


Figure 4 - SCE Smart Grid Future Scenarios

These four scenarios have been defined as follows:

- **Slow and Steady:** Policymakers continue to support utility investment in smart grid development and implementation. Progress towards energy and climate policy goals continues but is slowed by economic forces.
- **Light Speed:** Policymakers issue mandates for utility investment in smart grid deployment and provide financial support for technology innovation. A "clean tech" investment boom spurs technology innovation and development.
- **Market Driven:** Policymakers shift emphasis towards market driven outcomes for technology innovation and infrastructure investment. Strong economic growth and potential new market opportunities encourage new entrants into the energy market.
- **Keep the Lights On:** Continued economic stagnation squeezes consumers and industry, slowing venture and technology industry investment and innovation in smart grid technologies. Lower energy demand and a regulatory focus on rate containment reduce funding available for additional smart grid investment.

Across each of the four scenarios, SCE has identified potential data points as "signposts" which would suggest the extent of progression into one or more of the different pathways over time. Examples of signposts for the smart grid scenarios include, among others:

- The U.S. national unemployment rate (expressed as a percentage)
- Average gasoline prices ($/gal)
- Average natural gas prices (per mmBTU)
- Distributed resource cost effectiveness
- Consumer adoption rates for energy smart devices
- Consumer adoption of electric vehicles
- Customer response to dynamic pricing and usage information
- US economic GDP growth (as a percentage increase or decrease)
- Annual clean technology venture capital investment
- Industry and government investment in related technology R&D

SCE regularly monitors these signposts to determine whether there is movement in the direction of one or more of the developed scenarios, or if entirely new scenarios are emerging. This process will help identify the need for any adjustments to projects included in either of SCE's technology evaluation or deployment portfolios of smart grid projects. Because the smart grid will be developed and deployed over a long period of time (as is discussed in the smart grid development roadmap section that follows), periodic monitoring of these signposts will help SCE to understand if adjustments in the smart grid vision, strategy or development timing are required.

2.4. Proactive Standards Development

"Enables the adoption of standards that encourage interoperability of multiple generations of smart grid technologies"

As the grid evolves and becomes "smarter" and more capable over time, standards must also evolve to support higher degrees of interoperability and to enable more advanced capabilities. When the concept of smart grid evolution is applied in the area of standards adoption, the implication is that at any point in time the industry will be characterized by a mix of old technology (or no technology at all), last-generation smart technology, current-generation smart technology, and "greenfield" technology opportunities, all of which must function together in an integrated manner. Also, given that many smart grid technology lifecycles are much shorter than a typical utility regulatory-to-deployment cycle, it is very likely that the grid will continuously evolve to the degree by which intelligence is both incorporated and leveraged. Smart grid interoperability standards will be critical in helping to bridge the gap between different generations of technologies and in supporting a gradual, multi-step transition to the smart grid vision.

The issue of evolution is particularly important because smart grid investments tend to fall onto a continuum characterized by policy imperatives, system reliability and customer value. Policymakers and utilities must balance these considerations regarding certain smart grid investments before a complete set of standards has been adopted and benefit to customers dictates moving forward. In a number of instances across the nation, utilities and regulators have given much thought to balancing acceleration of customer benefits, project cost-effectiveness, and management of emerging technology risks. Smart grid systems that are planned and structured appropriately should be able to accept updated and new standards as they progress, assuming the following standards evolution principles[5] are recognized:

- Interoperability must be adopted as a design goal, regardless of the current state of standards.
- Interoperability through standards must be viewed as a continuum.
- Successive product generations must incorporate standards to realize the value of interoperability.
- Smart grid technology roadmaps must consider each product's role in the overall system and select standards-compliant commercial products accordingly.
- Standards compliance testing to ensure common interpretation of standards is required.

These principles are being followed by many utilities implementing smart grid systems today by requiring standard capabilities such as remote device upgradeability and support for robust system-wide security. In addition, standard boundaries of interoperability are being identified to allow smart grid investments to evolve in order to satisfy increasingly advanced capabilities.

5 SCE adopted the Gridwise Architecture Council's constitutional principles for interoperability and the several papers that address the integration of interoperability standards over time. These documents can be found at: http://www.gridwiseac.org

Determining what activities to prioritize and which smart grid standards to adopt and implement requires an understanding of the capabilities the standard supports in the context of the overall system. The smart grid is comprised of multiple integrated sub-systems. These include a "utility system" which is composed of many individual systems including transmission, distribution and customer systems within the utility, other entity systems comprised of the many unique customer systems, services and resource provider systems, and overall macro-systems such as a wide-area control system and RTO/ISO systems. As these "utility systems", other entity systems and macro-systems are linked, the result is a "System of Systems", as illustrated in Figure 5 below.

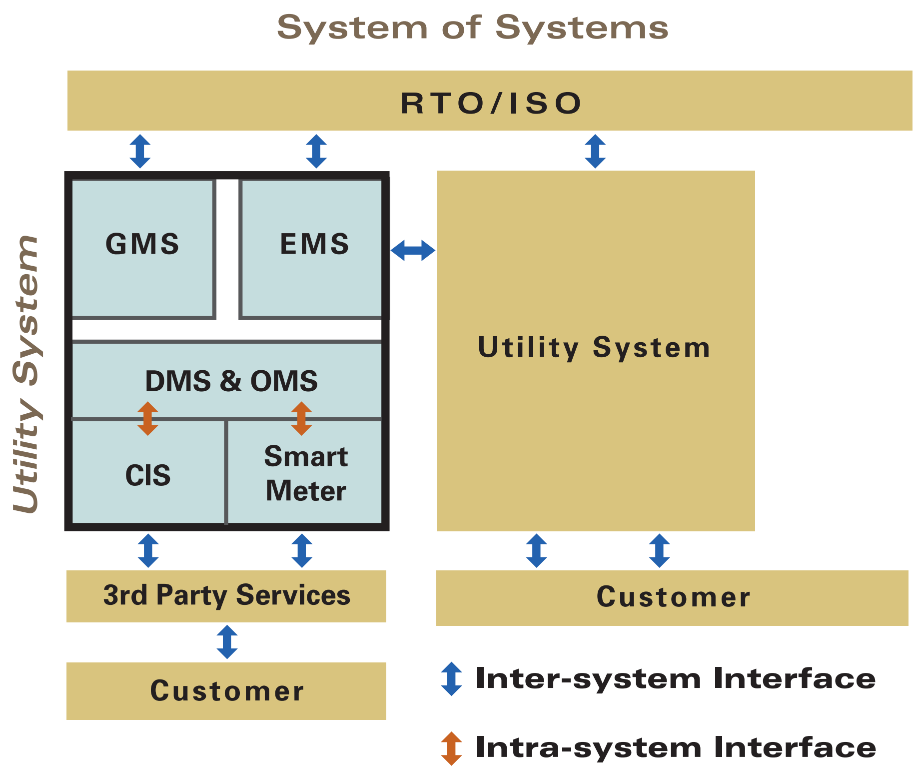


Figure 5 - Smart Grid Systems of Systems

Due to the importance of smart grid standards development, SCE has devoted considerable time and resources to standards efforts over the past ten years. Over the past five years SCE has testified at FERC, CPUC, CEC and the US House of Representatives on the need for standards and has also authored and co-authored several standards development papers in 2009. Furthermore SCE employees serve on a number of working groups and governing boards for National Institute of Standards and Technology (NIST), Institute of Electrical and Electronics Engineers (IEEE), Society of Automotive Engineers (SAE), Utility Communications Architecture International Users Group (UCAIug), Open Smart Grid (OpenSG), North American Synchrophasor Initiative (NASPI) and others. SCE intends to continue contributing to the thought leadership on the development of standards both at the state and national level.

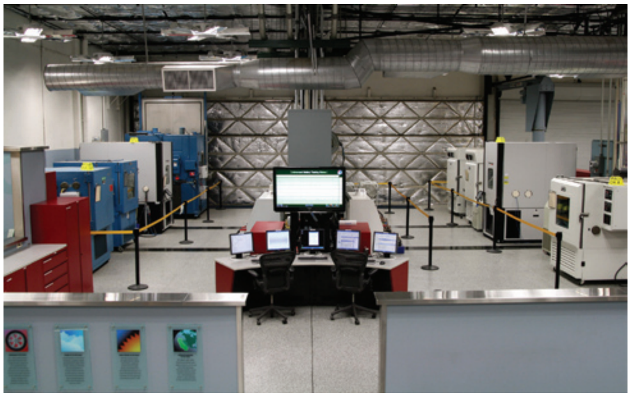
2.5. Rigorous Technology Evaluation

SCE is widely recognized in the electric utility industry as a leader in the evaluation, adoption and implementation of advanced technology. Edison has achieved this leadership position by creating a rigorous and repeatable technology evaluation and testing process. SCE's technology evaluation approach follows industry testing standards developed by, among others, the IEEE and the International Organization for Standards (ISO).

"Defines SCE's approach for testing, evaluating, and deploying emerging smart grid technologies"

This testing and evaluation process is first used to test technology in a laboratory environment against its manufacturer's specifications. Once the technology's performance is verified to be in compliance with specifications, a next step involves additional testing in small scale field trials, typically following the same set of testing process steps as those used in the lab environment. If the technology's performance in the field trial is acceptable, and it is deemed to be commercially viable, the technology then proceeds through a formal "tech transfer" process where it is handed off to the appropriate engineering and operations divisions. SCE's internal engineering standards are then modified to include the new technology, so that the technology can be incorporated in the plans and designs for future grid development. In some cases, where it would be immediately beneficial for our customers, a new deployment project will be initiated to ensure that the given technology is rapidly deployed in locations throughout the SCE transmission and distribution network, as information technology infrastructure or within customer service operations.

SCE's rigorous technology evaluation process has been proven at its Electric Vehicle Technical Center (EVTC) with the testing of various electric vehicle energy storage systems, in the Edison SmartConnect™ program with both advanced metering infrastructure and peripheral HAN devices, and with advanced distribution grid technologies, notably at the Avanti "Circuit of the Future" test bed. Each of these examples utilized both laboratory testing and production-based field tests.



3. Smart Grid Engineering and Architecture

3.1. Smart Grid Electric System Design

"Advanced system design concepts will enable the bi-directional flow of energy and information, integration of new supply and demand resources, and a network of networks between customers and market participants."

Over the past 125 years, electric grid architecture and development was driven by scale economies and the need to reliably connect all of the nation's population to the grid. Scale economies drove monopoly infrastructure and large centralized generation over the past century. Rural electrification legislation extended electric service to the entire country. More recently, in the 1960's, as the federal interstate highway system interconnected our communities, so did the development of the high voltage transmission regional inter-ties. The resulting electric system was recognized by National Academy of Engineering as the greatest engineering achievement of the 20^{th} century. So why does a need exist to redesign the grid?

Over the past 30 years, three key factors have increasingly driven the need to rethink the nation's electric grid design:

- Renewable & Distributed Generation
- Customer Demand/Energy Management
- Information Technology applied to system operations and controls

Each of these factors was introduced around 1980. In the case of renewable and distributed generation, the passage of the Public Utility Regulatory Policy Act (PURPA) in 1978 spurred initial wind, solar and distributed co-generation development. In California, the 1981 regulatory de-coupling of sales and revenues for investor-owned utilities removed a key barrier to the widespread customer energy demand management that has followed. In 1981, the introduction of personal computers corresponded with the introduction of microprocessor based relays and control systems on the electric grid. The subsequent benefits of Moore's law in terms of computational power combined with telecommunications innovation led to advanced measurement and control systems.[6] Each of these three drivers has over time increasingly become a critical factor in driving change to traditional grid architecture.

By 2005, these three factors had converged to enable concepts like micro-grids, aggregated customer participation in wholesale markets and SCE's 500MW large roof-top solar program. These concepts and others require a different electric grid design. This design must i) enable bi-directional flow of information and energy back and forth between generation, the utility, and the customer, ii) operate as a unified network-of-networks between customers and market participants across a region, and iii) enable integration of a wide variety of supply and demand resources. In effect, this revised electric grid models the principles of the conceptual architecture for the internet. Figure 6 below illustrates the evolution of information networks from Bell's telephone to Web 2.0 and electric networks from Thomas Edison's Pearl Street Station to the

6 "Moore's law," Wikipedia, http://en.wikipedia.org/w/index.php?title=Moore%27s_law&oldid=344054138

envisioned Grid 2.0. Grid 2.0 is the result of integrating millions of intelligent devices through an advanced telecommunications network linked to sophisticated computing systems that monitor, analyze and automatically control the entire electric grid, which itself has undergone an engineering redesign to improve operating performance, accommodate intermittent renewable and distributed resources and resist cyber or physical threats.

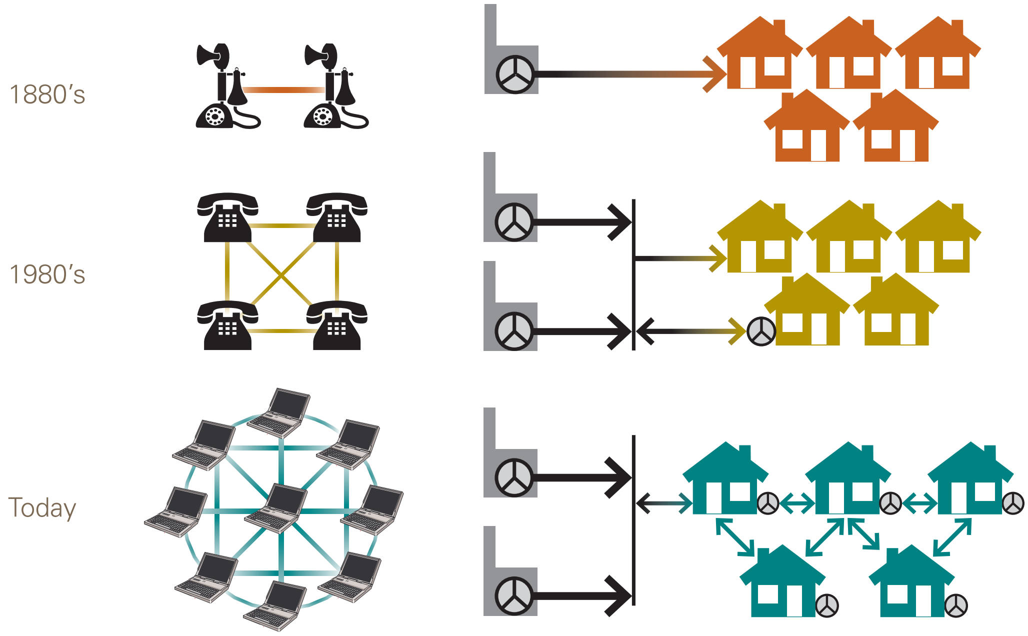


Figure 6 - Information & Electric Network Evolution, Source: SCE adapted from Wikipedia

The following sections explore in more detail several design elements of SCE's Grid 2.0 electric system vision.

Transmission and Substation Design

Changes to transmission system and substation design will be required to improve electric grid reliability within the utility and across the western region in light of increasing levels of renewable and other low-carbon generation. In addition, design enhancements must consider the goal of achieving a more efficient grid that optimizes throughput and reduces system losses.

The deployment of a synchrophasor-based wide-area situational awareness system will begin to support the accurate information needs required for real-time decision making by both the utilities and independent system operators in order to better understand and respond to system disturbances. Over time it is anticipated that wide-area situational awareness will evolve to also include wide-area control (WAC) and wide-area protection (WAP) applications. These advanced applications will require the exchange, processing and management of data/messages not only from phasor measurement devices, but also from various types of Intelligent Electronic Devices (IED). These IEDs include protective relays, programmable controllers and stand-alone digital fault recorders. Examples of wide-area control and wide-area protection applications that would be enabled include coordinated and automated reactive power control based on wide-area measurements, adaptive system islanding and resynchronization, and advanced protection mechanisms such as centralized remedial action scheme (C-RAS) systems.

In addition to wide-area monitoring and control technology, advanced materials will also begin to be utilized in transmission and substation design. New equipment incorporating advanced materials, such as superconducting fault current limiting transformers, will begin to be deployed to increase system performance, to improve energy savings by reducing power consumption and system losses, and reduce stress on protection systems. Moreover, these deployments will provide improvements in power quality and reliability in an environment that will increasingly be characterized by intermittent energy sources. Today's conventional (and aging) substation transformers have been cited as the source of up to 40% of total grid energy losses. Fractional improvements in the efficiency of this equipment would lead to significant reductions in the carbon footprint resulting from typical grid operations.

Finally, with environmental policies driving increased levels of renewable energy resources interconnected to the grid, transmission systems will be designed to incorporate large amounts of energy storage that can provide dynamic response and energy shifting capabilities to mitigate the intermittency, ramping, and dump power issues associated with renewable generation. Furthermore, because these new renewable energy resources are typically low-inertia generation sources, and because California's proposed once-through-cooling policies may lead to accelerated decommissioning of higher-inertia coastal generation plants, future transmission designs will likely need to incorporate the interconnection of equipment to provide increased system inertia, such as synchronous condensers.

Distribution System Design

Distribution circuits that were originally designed for one-way power flow are increasingly called upon to support two-way power flow associated with distributed energy resources, including distributed renewable and storage resources which may have variable output. Two-way power flow presents a technical challenge for traditional methods of distribution system voltage regulation and protection. Looped and networked distribution circuit designs are being explored as alternatives to the traditional radial design of these circuits, such that advanced protection, monitoring, and system operation technologies can be readily applied to support mitigation of issues resulting from increased two-way power flow.

Distribution automation technologies will evolve and 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. Advances in distribution automation will be driven by:

- The need to improve reliability, particularly as existing system components age. More flexible and intelligent switches and interrupters on distribution circuits will help to minimize the extent of outages and speed restoration through Fault Detection, Isolation and Restoration (FDIR).
- Increased penetration levels of distributed energy resources, most notably renewable distributed generation and energy storage. These resources can help achieve renewable portfolio goals and provide grid support capabilities, but can also destabilize the grid if not managed correctly.
- Increased need for demand response and advanced load control to mitigate peak demand issues. Advanced distribution automation can offer a more precise level of control over demand side resources, allowing for increased levels of demand response to be achieved without significantly impacting the comfort or convenience of customers. Load control will be available to respond to various electric system needs, ranging from lack of generation resources to local distribution system overloads.
- The need to limit distribution line losses and to operate circuits more efficiently in a future characterized by carbon constraints, increasing energy prices and customer requirements for improved power quality. We anticipate that this will be achieved in part through Advanced Volt VAR Control (AVVC), which maintains better Conservation Voltage Reduction (CVR) at the service point.

Distribution system design will also begin to incorporate advanced materials. One example is found in the development of intelligent and communicating distribution transformers, which can provide performance metrics and monitoring information on transformer life. In addition, new distribution level energy storage technologies, called “community energy storage,” will start to be designed into distribution circuits. This should buffer distribution-connected renewable generation, provide localized load leveling and power factor correction, and serve as a source of backup power for customers. To help control and manage distributed storage and other distributed energy resources such as photovoltaic installations, communicating smart inverters will also begin to be incorporated into circuit automation and distribution management schemes which will extend all the way to behind-the-meter generation and storage resources.

Advanced Protection

New protection and control systems will be used to manage increasing amounts of bulk renewables, distributed energy resources, and dynamic and dispatchable demand side resources. This will require adding a variety of complex digital controllers and protection devices to both new and retrofitted circuits.

Voltage instability in the transmission networks has directly led or contributed to wide-area blackouts around the globe. Improved timeliness in the recognition of these instabilities is crucial to effective control and protection interventions. There is growing worldwide interest in using synchrophasor technology to supply very fast measurements of system electrical variables that can provide effective real-time voltage stability indicators. These indicators can in turn be used to automatically trigger protection schemes, pre-defined load shedding algorithms, or intelligent devices such as Static VAR Compensators (SVCs) in an attempt to mitigate voltage stability issues. In addition, C-RAS systems are being deployed in critical transmission corridors to coordinate and optimize the multiple remedial action schemes in place at those locations. Such corrective action schemes could include generation runback or tripping, load shedding or system configuration changes. C-RAS also uses synchrophasor data as an input and operates through a high-speed communications network to increase the speed of SCE's response to events on the transmission network.

At the distribution level, when today's standard radial circuits experience a fault caused outage, the typical result is that the entire circuit loses power until a manual switching process can be completed. With a looped circuit design incorporating smart grid technologies such as Universal Remote Controlled Interrupters (URCI), a new protection mechanism can be established so that the fault can be isolated automatically in less time than it takes for the circuit breaker at the substation to trip. This would allow for the remainder of the circuit to be fed independently from both supply ends, with little or no loss of power to customers served by that circuit.

3.2. Smart Grid Information System Architecture

In addition to the need for an updated Smart Grid Electric System Design, SCE will also need to develop and adopt a complementary enterprise-wide Smart Grid Information Systems Architecture. To achieve each of the elements of the SCE smart grid vision, this future architecture will need to be agile and flexible in order to meet increasing data management and analytics demands, support unanticipated needs, and readily enable the integration of new smart grid technologies that emerge over time.

"An agile and flexible information systems architecture will fulfill data management and analytics demands allow integration of emerging smart grid technologies, and provide robust cyber-security"

Information demands will include not only those from the utility to support operations, but also from customers and third parties looking to support their own near real-time decision making needs. At the same time that it provides flexibility and interoperability with varied and evolving technologies, the SCE Smart Grid Information Systems Architecture will also need to incorporate robust cyber-security features in order to meet constantly changing and uncertain security challenges. The NIST Smart Grid Framework 1.0 in Figure 7 below provides a reference model for SCE's Smart Grid Information Systems Architecture. It is comprised of integrated layers incorporating the various elements in the emerging system of systems including markets, generation, grid operations, customers, field components, operational and information applications, services, and multi-level networked telecommunications.

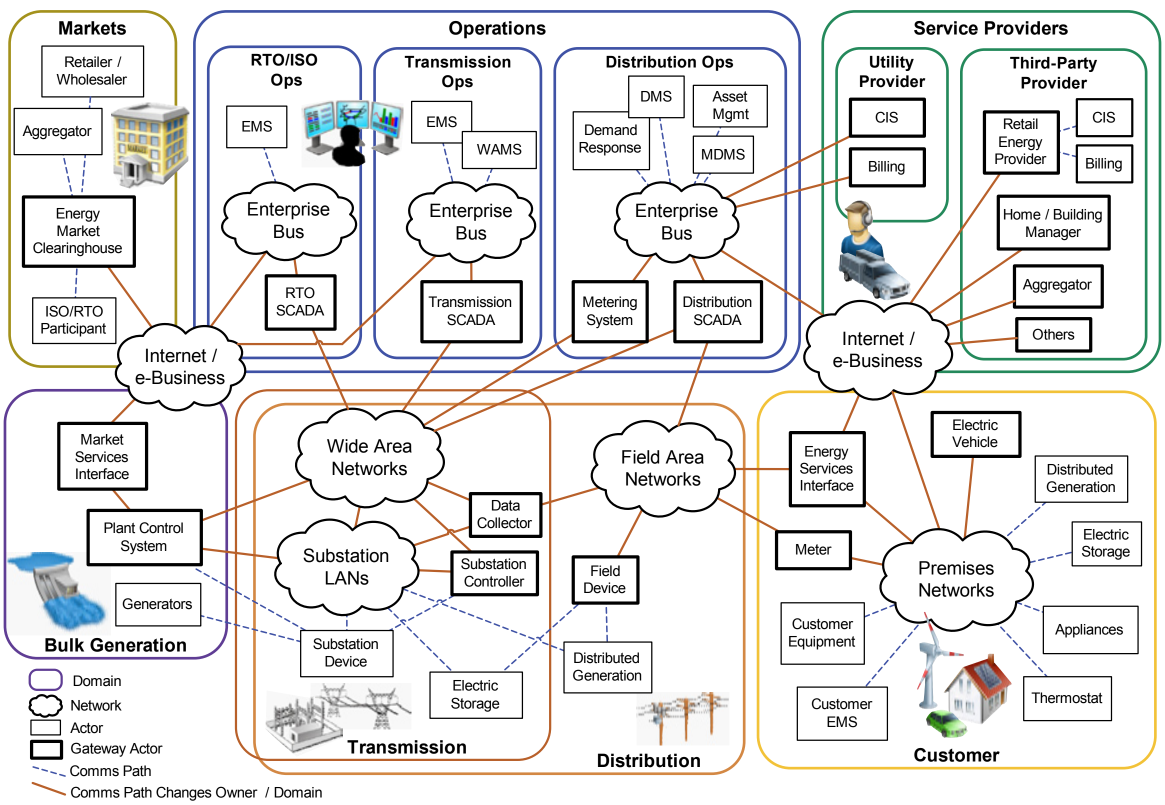


Figure 7 - NIST Smart Grid Framework 1.0

The SCE Smart Grid Information Systems Architecture must also provide for a graceful transition from existing systems to the future state. SCE believes that by integrating legacy systems with new technology in a layered, loosely coupled architecture, the ability to achieve the smart grid vision is enabled while minimizing capital costs for deployed information systems. SCE's proposed smart grid *Secure Common Operating Environment (SCOE)* architecture has been designed to help meet systems integration and cyber-security challenges posed by the SCE smart grid vision. It also leverages the collaborative efforts of the NIST Architecture Team that developed the initial version of the NIST Smart Grid Conceptual Model during Phase I of the NIST effort.

The NIST Architecture Team was a group of distinguished IT architects from technology providers, consultants, researchers and utilities that came together in the Summer 2009 to build a conceptual information reference model for the smart grid. The result of this team's efforts was the NIST Smart Grid Framework 1.0. SCE hosted and actively participated in the NIST Architecture Team under NIST's Smart Grid Interoperability program. Since the formal creation of the Smart Grid Interoperability Panel (SGIP), the responsibilities of the Architecture Team to maintain and evolve the NIST Smart Grid Conceptual Model have been transferred to the new Smart Grid Architecture Committee (SGAC) – one of two permanent committees within the SGIP. Many of the original members of the original NIST Architecture Team are now members of the SGAC, including two of SCE's smart grid architects. Their continued participation will ensure that the SCE smart grid architecture remains in step with the architectural models and templates produced by the SGAC.

Figure 8 below presents a depiction of SCE's proposed smart grid SCOE architecture.

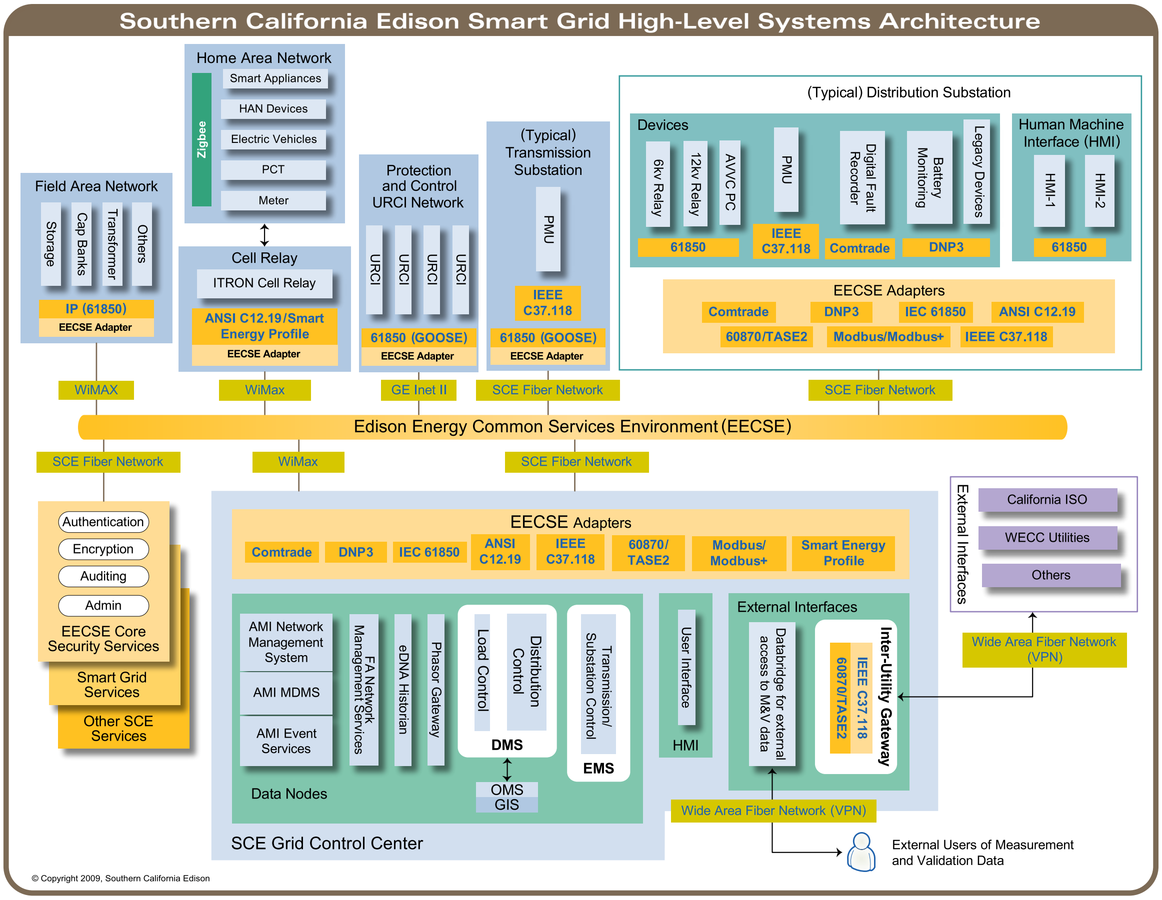


Figure 8 - SCE's Proposed Smart Grid Architecture

This top level smart grid information systems architecture depicts the automation component interfaces across the end-to-end solution, and it includes the communication protocols and standards that will be used to integrate the devices, systems and services across the various network domains. The architecture will ensure interoperability, utilizing a common service environment that incorporates the latest industry standards. It will accommodate SCE's AMI meters, HAN devices, substation devices, energy storage, distributed renewable generation, grid control systems, security and network management systems, as well as other new or future smart grid technologies. The architecture also takes into account the low latency communication performance requirements for managing and dispatching control commands, and sending and receiving measurement data critical to establishing wide-area and deep situational awareness across the electric grid. The resulting telecommunication network-of-networks will utilize a variety of backbone and field area wireless technologies that will be Internet Protocol (IP) centric. As such, this approach will allow for compliance and risk and security management, as well as ensure functional quality, scalability, manageability and system performance.

One major challenge faced by any smart grid architecture is how to interface with customer and third party owned devices and systems. This key interface must not only be highly secure but also balance the interests for customer control of the devices and home area network. SCE has expended significant effort over the past five years considering this engineering challenge in close collaboration with many stakeholders across the world. This effort led to the development of an approach that allows customer control of their home area network, through their gateway or that of a services provider, while establishing a clear demarcation point at the smart meter. This design recognizes the customer's right to voluntarily connect to the meter to access their real-time energy usage information. The architecture does not require connection to the meter for any other information exchange which can be provided through the internet or other non-utility means of communications. SCE has adopted the home area network architecture developed by OpenHAN to address the issues above and has served to guide development of Smart Energy Profile 2.0, OpenADE and ZigBee IP 2.0.

Another architectural challenge is addressing cyber-security. Secure communications between smart grid devices and the utility is a basic requirement of the SCE Smart Grid Information Systems Architecture. The smart grid necessitates a secure information technology backbone to support U.S. smart grid policy, as described in the 2007 EISA, Title XIII. SCE will be testing and demonstrating components of this SCOE architecture framework with its forthcoming Irvine Smart Grid Demonstration (ISGD) project. Lessons learned from this project will provide the input to further develop commercial technologies and the requisite integration for secure communications with and between smart grid technologies. SCE expects that the resulting architecture will further inform cyber-security and interoperability standards, and ultimately accelerate smart grid deployment efforts.

SCE is also actively involved in the permanent SGIP working group on cyber-security. This NIST lead SGIP group, called the Smart Grid Cyber Security Working Group (SGCSWG), is collaborating closely with EPRI, DOE, utilities, and other industry players through the ASAP-SG project that SCE is funding to accelerate the effort. SCE's SCOE architecture is designed to fully support the requirements and architectural elements coming out of the SGIP SGCSWG and evolve with them as they are adjusted and extended over time.

4. Smart Grid Development Roadmap

Previous chapters defined SCE's vision for the smart grid, the components of a strategic approach and methodology for achieving that vision, and the architectural and design elements needed to support it. This chapter presents SCE's high-level development roadmap for the smart grid. This roadmap identifies the types of technologies that SCE plans to pursue over the course of the next two decades in order to make the SCE smart grid vision a reality.

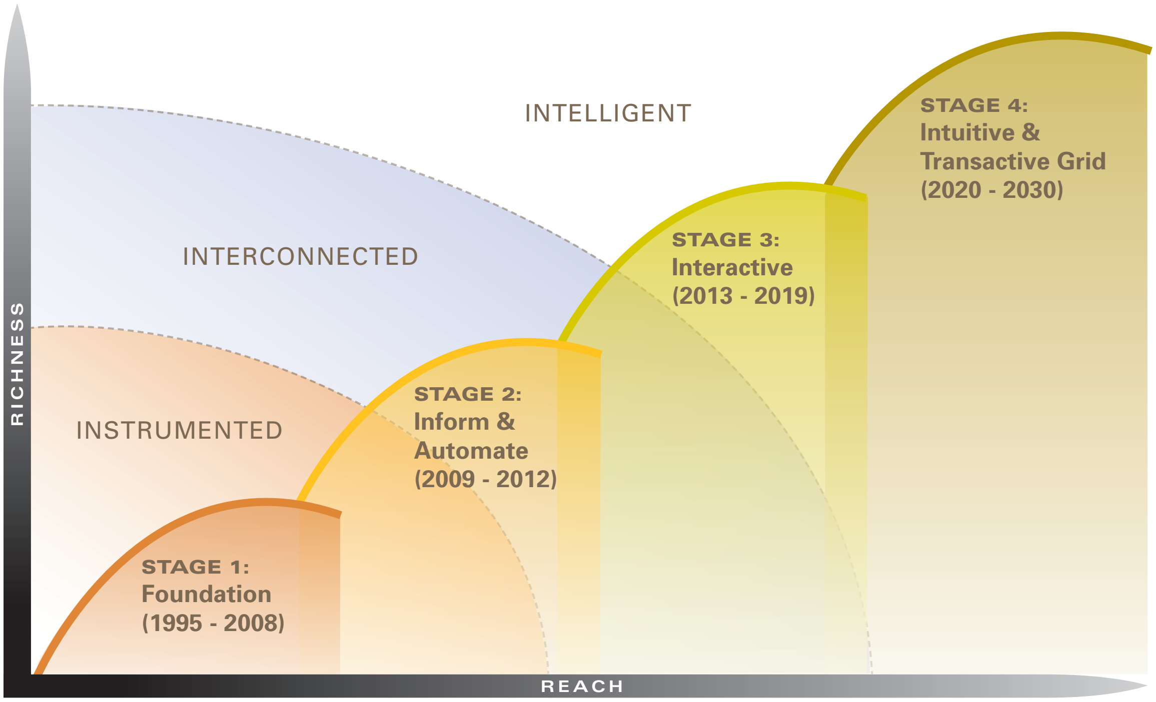


Figure 9 - Smart Grid Development Roadmap - Stages of Evolution to 2030 [7]

The smart grid will evolve in complexity and scale over time as the richness of systems functionality increases and the reach extends to greater numbers of intelligent devices. The fundamental elements of evolution as defined by IBM are Instrumented, Interconnected, and Intelligent. Instrumented involves the deployment of measurement capabilities across the grid from phasor measurement units to smart meters. Interconnected involves both the linkage of devices through pervasive telecommunications networks and also the integration of operational applications, such as the integration of distribution management systems with advanced load control. Intelligent involves the synthesis of the information, controls and integrated systems in combination with analytics and artificial intelligence to create an intelligent, self-optimizing and resilient energy platform that enables broad market participation and highly reliable quality of service. This evolution will not follow a strictly linear path, but will instead consist of four overlapping steps, as depicted in Figure 9 above, which will transition from one phase to the next as innovations in smart grid technologies emerge and become commercially available.

7 *Adapted from IBM presentation at CPUC Smart Grid Workshop on March 18, 2010*

Within each development roadmap stage, there are two portfolios of activities to be managed simultaneously. The smart grid deployment project portfolio includes smart grid technologies that are commercially ready for deployment. The technology evaluation portfolio includes initiatives to identify, evaluate and test emerging technologies which may be deployed during a later stage. Figure 10 below illustrates the distinction between these two portfolios in terms of technology maturity over time.

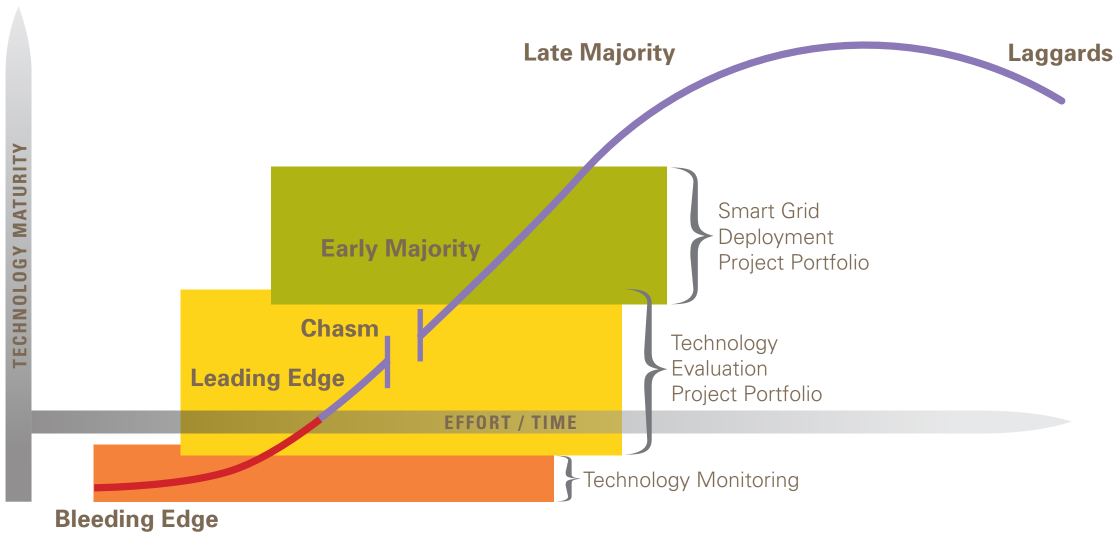


Figure 10 - Smart Grid Project Portfolios as a Function of Maturity

Technology evaluation portfolio projects are those which fall into the 'Bleeding Edge' or 'Leading Edge' areas of the maturity curve. These projects require further evaluation of emerging technologies to better understand the capabilities such technologies would contribute to the smart grid vision, their progress towards technical maturity, and the corresponding value that they might unlock. SCE will pursue projects in the technology evaluation portfolio by working closely with partners at research universities, research institutes and national labs, and by monitoring technology evaluation efforts at other utilities. SCE has had a long history of early collaboration that has led to successful adoption or adaption of grid technologies, including distribution automation and the previously mentioned smart metering and synchrophasors. Most of SCE's advanced technology labs[8] are currently ISO-certified and all of our labs will be certified within the next stage of the smart grid development roadmap.

Smart grid deployment portfolio projects, on the other hand, involve the planning and execution of deployment plans for commercially available smart grid technologies. Although these technologies have "crossed the chasm" of the maturity curve, given the urgency of California and national policy goals they increasingly fall within the "Early Majority" or later areas of curve (Figure 10). Historically, SCE and most utilities have preferred to adopt technology later in its maturity lifecycle, allowing for greater confidence in the implementation and operation. Earlier adoption and adaption introduces significant project risks that SCE believes can be substantially mitigated through an effective technology evaluation process as described previously in Section 2. SCE employs best practices from the Project Management Institute and the Software Engineering Institute for execution and deployment of technology projects.

8 SCE has extensive technology test facilities that are used to evaluate supplier products. See the appendix for a reference to a document which summarizes SCE's laboratory capabilities.

The sections which follow provide descriptions of each of the smart grid development roadmap stages depicted in Figure 9, along with high level plans for the types of potential deployment and technology evaluation projects to be included within each stage.

4.1. Stage 1: Foundation (1995-2008)

Stage 1 of the smart grid development roadmap refers to foundational work in the deployment of advanced measurement and control systems that was completed from the mid 1990s through 2008. SCE's smart grid accomplishments over this period included early experience with wide-area measurement and control technologies, pioneering efforts in Synchronized Phasor Measurement Systems, industry leadership in substation and distribution system automation and the rollout of smart metering to large commercial and industrial (C&I) customers. SCE also launched Energy Manager, an online portal for large C&I customers to access their smart meter data. SCE's early smart grid deployments were based on addressing the highest value opportunities first, across transmission, distribution and customer engagement. Table 2 below provides some additional highlights of SCE's Stage 1 smart grid accomplishments. SCE has received a number of awards for its early smart grid efforts. These awards include the 2007 T&D Automation Project of the Year for SCE's Synchronized Phasor Measurement System, the 2006 Utility Planning Network's North American Smart Metering Project of the Year, and the 2003 Peak Load Management Alliance Outstanding Research Award for Electricity Pricing Research Projects.

SCE Smart Grid Development Statistics	
Total synchrophasors on bulk transmission system	27
Advanced EMS System	✔
Total substations automated (% of 900 substations)	56%
Total substation transformers with DGA	0%
Total substations with low latency, high bandwidth telecoms	33%
Distribution management and load control systems	✔
Total circuits with outage mitigation (% of 4,400 circuits)	41%
Total circuits with field automation (% of 4,400 circuits)	41%
Total microprocessor relays	31%
Total fiber optic cable miles	3,100
Total renewable resource capacity integrated	
Transmission	2,784 MW
Distribution	2.4 MW
Total Demand Response Capacity	1,548 MW
Smart Metering	
Large C&I	100%
Residential and Sm C&I	0%

Table 2 - Smart Grid Development Roadmap Stage 1 Statistics

4.2. Stage 2: Inform & Automate (2009-2012)

Stage 2 Smart Grid Deployment Plan

Building upon a set of initial smart grid technologies deployed during Stage 1, SCE is currently executing a $1.5 billion capital deployment plan for advanced information, measurement and automation systems through 2012. SCE's largest investment is in deploying smart meters to all 5 million SCE customers with the completion of the Edison SmartConnect™ program. As part of this program SCE will be launching a smart communicating thermostat program along with an online customer portal for customers to access their smart meter usage information. A rebate program is also included to buy down the cost of home area network devices that customers can use to access real time information from their Edison SmartConnect™ meter.

This period will also include the deployment of phasor measurement units across all of SCE's 500kV and 230kV substations, in conjunction with a western region deployment of synchro-phasors coordinated by the Western Electric Coordinating Council (WECC). SCE is also making significant improvements in its grid operations and control systems to support increasing amounts of renewable resources and distributed energy resource integration. Our efforts include a focus on expanding our protection and control systems involving C-RAS and wide-area controls. SCE is also planning capital upgrades to accommodate the mass-market introduction of PEV in our service area. Each of these investments includes state-of-the-art cyber-security capabilities and technologies that are NIST open standards based. Figure 11 depicts SCE's smart grid deployment projects that are currently authorized for Stage 2 of its smart grid roadmap.

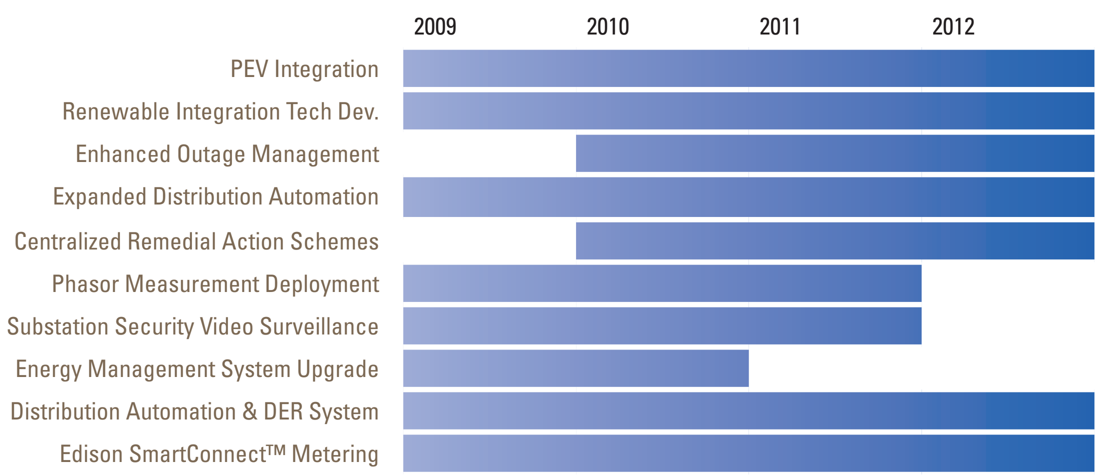


Figure 11 - Stage 2 Smart Grid Deployment Timeline

Stage 2 Smart Grid Technology Evaluation Plan

Technology evaluation efforts during Stage 2 will be primarily focused on:

- Evaluation of energy storage
- Integration of renewable and distributed energy resources
- Development and interoperability testing of home area network devices and vehicle charging equipment
- Ongoing development of interoperability and cyber-security standards
- Electric system studies and engineering analysis regarding operational impacts from dynamic resources, bi-directional distribution flows and new operating paradigms
- Workforce safety and productivity technologies

A priority in terms of technology evaluation projects during Stage 2 will be execution of Department of Energy (DOE) American Recovery & Reinvestment Act (ARRA) stimulus projects. In 2009, the DOE awarded SCE several grants to support its various smart grid efforts. These projects include:

Irvine Smart Grid Demonstration- Demonstrate an integrated, scalable smart grid system that includes all of the interlocking pieces of an end-to-end smart grid system, from the transmission and distribution systems to consumer applications like smart appliances and electric vehicles. The demonstration will include a number of homes retrofitted to be zero net energy compliant with solar PV, energy smart appliances, home energy storage and energy efficiency upgrades. This demonstration also includes a Waukesha superconducting substation transformer and focuses on the interoperability and interactions between the various field technologies and information and communications systems. This project will also explore dynamic links between distributed resources and wholesale markets and bulk power system operations with CAISO.

Tehachapi Wind Energy Storage- Deploy and evaluate an 8 MW utility-scale lithium-ion battery technology to improve grid performance and aid in the integration of wind generation into the electric supply. This project is being done in partnership with CAISO. The project will evaluate a wider range of applications for lithium-ion batteries that may spur broader demand for the technology, bringing production to a scale that will make this form of large energy storage more affordable.

Other DOE ARRA and non-ARRA projects in which SCE is a sub-recipient or participant include: EPRI PHEV Bucket Truck, WECC Wide-Area Disturbance Monitoring, High Penetration Solar Deployment, American Superconductor Fault Current Limiter Project, and Application of Advanced Wide-Area Early Warning Systems with Adaptive Protection. SCE has also received several CEC research grants and has pending applications for additional funds from CEC and CPUC to support the ARRA projects, other research areas and to study the integration of distributed energy resources resulting from the California Solar Initiative.

Another technology evaluation portfolio priority during Stage 2 will be SCE's continued engagement in the near term priority standards development efforts found in Table 3 below.

Theme	Near Term Priority Standards
Customer Empowerment	Automated Data Exchange (ADE) Standards development and pilot for delivery of data to customer-authorized third parties
	PEV Communications Standards Identification and Development
	PEV Charging Infrastructure Standards Development
	Interoperability Standards for various in-home smart grid devices such as smart appliances, home energy management systems, displays etc.
Workforce Safety & Effectiveness	Next Generation Worker Safety Standards
Renewable & Distributed Energy Resource Integration	Renewable & Distributed Energy Resource Integration Standards
	Energy Storage Standards Development
Grid Efficiency & Resiliency	Grid Control Standards (Distribution/Substation Automation, Phasor Measurement, etc.)
Information and Telecommunications Technology & Cyber-security	Field Area Communications Standards Analysis and Development
	Home Area Network Communication Standards
	Cyber-security Standards
	Interoperability and Data Management Standards

Table 3 - Stage 2 Near Term Priority Standards Development

Finally, there are a limited number of near-term analytical studies, as well as lab-based and field-based technology evaluation projects, that support stimulus projects and/or technologies that might be considered for the longer term deployment portfolio for 2013-2020. Highlights of such study and evaluation projects for Stage 2, listed by smart grid definition domain, are included in Table 4 on next page.

For additional information, please review the sited documents in the appendix for more details regarding Stage 2 deployment and technology evaluation projects. At the completion of Stage 2, SCE expects to have a robust measurement, control and automation infrastructure in place. These achievements will set the stage for further investments to support California's policy objectives and SCE's business objectives to meet 2020 targets.

Theme	Project Title	Partners
Customer Empowerment	3rd Party Product Compatibility Testing – In-Home Displays, Demand Response Technologies	PG&E, SDG&E, CAISO
	Energy smart appliance and device testing	GE, UC Irvine
	PEV Integration Technology Development and Testing	Itron, Ford, GM
	Vehicle to Grid Engineering Assessment	Calstart
	Medium and Heavy Duty Vehicle Development	Ford, Eaton, Altec
Workforce Safety & Effectiveness	Field Worker Safety Equipment Development	TBD
	Smart Grid Knowledge Management Development	Cal Poly Pomona, CSULA
	Systems Operations Visualization	IDEO
	Robotics Demonstration	TBD
Grid Efficiency & Resiliency	Advanced Wide-Area Monitoring and Control System Applications	DOE
	Avanti "Circuit of the Future" Test Bed extension	DOE
	System Inertia Loss Mitigation Studies	PSERC
	Air Conditioner Stalling Project	TBD
	Smart Inverter Evaluation and Demonstration	Various
	Electro-magnetic pulse (EMP)/ Geomagnetic disturbances (GMD) Hardening	DOE, NERC
	138kV Transmission High Temperature Superconducting FCL demonstration	American Superconductor
	Superconducting Distribution Sub-Transformer	Waukesha
	Grid Efficiency	EPRI, GE
Renewable & Distributed Energy Resource Integration	Renewable Integration Grid Impact Study	TBD
	System Inertia Loss Mitigation Studies	PSERC
	Tehachapi Wind Energy Storage Demonstration	A123, DoE, CAISO, CEC, Cal Poly Pomona
	Wind Power Storage Assessment	CEC, UWIG
	Home Battery Pilot Program	TBD
	Community Energy Storage Program	Tesla, GE, Others
	Compressed Air Energy Storage (CAES)	EPRI, PG&E
Information and Telecommunications Technology & Cyber-security	Complex Systems Architecture	Caltech
	Advanced Cyber-security Systems	USC ISI, Carnegie Mellon
	Distributed Control Systems Architecture	Stanford
	Field Area Network Technology Demonstration	GE
	Smart Grid Information Systems Architecture	TBD

Table 4 - Stage 2 Technology Evaluation Projects

4.3. Stage 3: Interactive (2013-2019)

Stage 3 Smart Grid Deployment Plan

Stage 3 of the SCE smart grid roadmap will focus on those technologies that leverage prior investments and retrofit new technologies to begin the process of building Grid 2.0. The anticipated evolution from Grid 1.0 to Grid 2.0 is depicted in Table 5 below for various different grid characteristics. Among other attributes, Grid 2.0 will result in full automation of the energy delivery system across the entire value chain, focusing on increased levels of interaction between smart grid devices, the utility, and customers. It will consist of both "hard grid" assets that incorporate new physical materials such as advanced energy storage and super-conducting equipment, and "soft grid" assets such as next generation computing and analytics systems which unlock the full value of the smart grid for both the utility and its customers. Several documents, including "Grid 2.0: The Next Generation" which is highlighted as a source for Table 5, suggest a fully decentralized grid. By 2030, SCE expects a highly interactive and hybrid grid that includes large central resources and increasing numbers of decentralized supply and demand resources. This is not unlike the hybrid information networks of today that link large centralized data centers, cloud computing, highly distributed personal computing and smart phones.

Grid 1.0	Grid 2.0
Centralized	Decentralized
One-way	Multi-way
Limited Feedback	Constant Feedback
Small Number of Large Investments	Large Number of Small Investments
Emphasis on Throughput of Energy	Emphasis on Investment and Infrastructure
Active Producers, Passive Consumers	Producers and Consumers Linked and Active
Focus on Supply of Electricity and Gas	Focus on Providing Heat and Power
Expertise is Centralized	Expertise is Distributed
Supply Based on Predictions of Demand (Predict-and-Provide)	Demand and Supply Linked to and Influenced by Each Other

Table 5 - Grid 1.0 evolution to Grid 2.0[9]

This renewed electric system will enable seamless integration of large renewable and distributed generation resources. It will also support the deployment of energy storage technologies to support state and federal legislation and policy goals such as greenhouse gas reduction, RPS and electric transportation initiatives. Grid 2.0 will also incorporate the next generation of broadband wireless and field area telecommunications technologies needed to support requirements for high speed, low latency information exchange among highly distributed devices. Smart grid systems efforts will include the integration of advanced data analytics and intelligent systems into SCE's existing grid control systems, resulting in a complex system-of-systems to provide

9 Source - Grid 2.0: The Next Generation

totally integrated grid control and real time information regarding the state of the grid at any point between generator and customer. As a result, the opportunity to reliably link customer demand response and other smaller distributed resources into CAISO wholesale market operations will emerge and the requisite ability to coordinate operational dispatch between wholesale market objectives and distribution grid objectives will also be enabled.

SCE's envisioned smart grid investment roadmap for the 2013 – 2019 period is identified in Figure 12 in section 4.5 below. Initiation of many of these projects will depend upon successful technology evaluation efforts over the 2010 – 2017 time period. It should be noted that each of the deployment efforts we include in the roadmap is subject to future CPUC and/or Federal Energy Regulatory Commission (FERC) approval and funding, once plans are submitted though general rate cases or other regulatory proceedings. SCE is and will be committed to evaluating and deploying best-fit solutions to meet our customers' needs and policy goals without sacrificing system reliability or customer service. The discussion below provides additional information about some of the key technology areas to be included in the Stage 3 smart grid deployment plan.

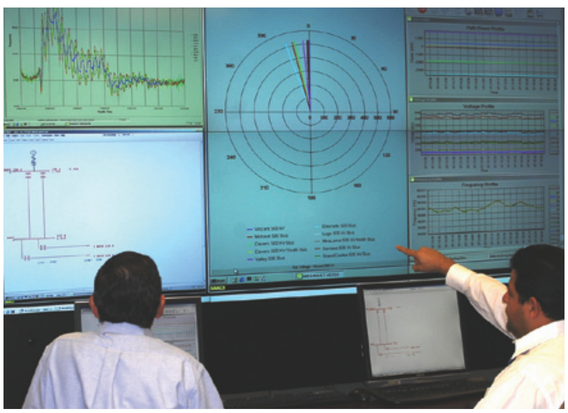
Integration of Customer Devices will continue to be explored through additional and more sophisticated demonstrations that link customer distributed supply and demand resources into wholesale market and utility grid operations. A key technical hurdle to be addressed involves the conceptual design of a robust multi-agent system that can manage the potential for a trillion transaction market to be dynamically linked to grid operations. An intermediate step is to demonstrate the linkage of customer devices to the advanced distribution system described below.

Advanced Distribution and Substation Automation will upgrade SCE's current version 1.0 distribution automation systems to an advanced 2.0 system that leverages the capabilities evaluated through the Irvine Smart Grid Demonstration projects and the Avanti Circuit of the Future. Examples of advanced distribution automation technologies include fault interrupters, advanced voltage/var control (AVVC), and high-speed communications technologies providing communications all the way to the customer meter and "beyond the meter" devices. The 2.0 system also includes the anticipated increase in the number and variety of distributed generation and demand side resources that may be linked both to wholesale market operations and SCE's grid operations. Advanced substation automation technologies will provide automation for greater fault tolerance and will lead to replacement of switched capacitors with static VAR compensators for increased efficiency and voltage control.

Advanced distribution and substation automation efforts will be focused on improving SCE's abilities to monitor and manage increasing levels of bulk and distributed renewable energy resources, to enable advanced demand side management functionality, and to operate the grid more efficiently by limiting system losses.

Wide-Area Control and Advanced Synchrophasor Applications will support grid operations by offering increased intelligence and control over the transmission network. Advanced Wide-Area Control deployments will include digital fault recorder (DFR) installation, transmission/substation capacitor upgrades to support advanced volt/var control at the transmission level, and further deployments of FACTS devices which can be operated or adjusted in response to near real-time analysis of syncrophasor data. This effort would also include integration of advanced centralized back-office and distributed software to support management of sensory and control devices required for wide-area control.

4G Wireless Telecommunications Network will be deployed in order to meet the future communications needs of both utility grid operations and customers requiring near-real time availability of their energy information. A 4G telecomm network will enable monitoring and control of increasing levels of distributed energy resources and allow for the coming shift from centralized to distributed peer-to-peer control of network devices. The network will allow SCE to manage communications with proliferating smart grid sensors and devices (including those located behind the customer meter), enable advanced mobile work-force automation, provide next generation backhaul for the smart metering system and support high volume, low latency requirements for near-real time system state measurement and control.



Advanced Analytics will enable smarter, faster decisions by utility personnel, automated utility information systems, and customers. Analytics systems will provide analytical tools which leverage integrated databases containing smart grid data collected from Edison SmartConnect™ meters, customer devices, distribution and substation automation infrastructure, phasor measurement unit (PMU) devices, and smart inverters associated with distributed energy resources, among other data sources. Visualization and intelligent alarming tools will use the results of these data analytics tools to provide useful and actionable information to system operators responsible for real-time decision making. Engineers and system planners will be able to make improved design decisions based on intelligence derived from system loading and asset performance metrics, resulting in improved grid optimization. Customer service representatives will have access to analytical tools to help them guide customers towards optimal rate, product, and service selection choices. These are only a few of the many potential future examples of smart grid data-driven decision making made possible by advanced analytics systems.

Energy Storage Deployment involves widespread development and deployment of energy storage technologies throughout SCE's smart grid system. Energy storage has the potential to support the electric system with various applications such as reliability, power quality, and generation resource or energy functions, as well as provide customer-side energy management. For example, California's current and proposed energy policies relating to intermittent renewable resource integration are pushing the need for energy storage as an asset that can be used to mitigate renewable energy intermittency and enable energy shifting to harmonize differing periods of peak demand and peak renewable supply. The next few years will be critical to identify and test the feasibility of these applications and to determine how best to integrate them with the smart grid.

Inertia Loss Mitigation Technology will support power system stability in light of potential system inertia losses associated with a reduction of local generation sources. California's proposed once-through-cooling regulation has the potential to negatively impact Southern California's ability to retain existing in-basin generation. Loss of this generation will likely cause a significant loss of system inertia, which is critical for stability. Although studies are needed to better understand this issue, SCE expects the projected loss of inertia will require mitigation by repurposing the existing generation to provide a synchronous condenser function. Where that is not possible, deployment locations for new synchronous condensers will be identified.

Stage 3 Technology Evaluation Plan

Stage 3 technology evaluation initiatives will include technologies that were in the earliest stages of development during Stage 2. In addition this stage will consider studies which will pursue unanswered questions and next steps resulting from the ARRA stimulus projects including the Irvine Smart Grid Demonstration Project, the Tehachapi Wind Energy Storage Project, and others. Technology evaluation efforts in Stage 3 will likely focus on the following areas, among others:

Theme	Project Title
Grid Efficiency & Resiliency	Development of grid asset lifecycle management systems
	Development of transmission and distribution system power flow and voltage control systems to reduce system losses
Renewable & Distributed Energy Resource Integration	Development of 2G and 3G energy storage technologies (electrochemical and non-electrochemical)
	Advanced monitoring & control of intelligent inverters associated with distributed energy resources
Customer Empowerment	Exploration of advanced measurement and charging control for electric vehicles
	Development of a unified communications schema with and between networks of evolving and increasingly interactive customer technologies
Information and Telecommunications Technology & Cyber-security	Development of advanced analytic and visualization tools to support interpretation of increasing volumes of data
	Assessment and development of unified cyber-security systems across multiple computing and telecommunications platforms
Workforce Safety & Effectiveness	Evaluation and development of knowledge management expert systems to support the anticipated large turnover in utility workforce due to retirements

Table 6 - Stage 3 Technology Evaluation Projects

4.4. Stage 4: Intuitive & Transactive Grid (2020-2030)

The 2020 decade will see continued deployment of Grid 2.0 capabilities across SCE's system as well as the introduction of highly distributed intelligent controls that will increasingly involve machine-to-machine transactions. Stage 4 of the smart grid development roadmap assumes full convergence of information and energy systems, as well as continued breakthroughs in computing architectures, cyber-security, internet technologies, autonomous multi-agent control systems, artificial intelligence applied to electric system operations, wireless telecommunications, energy storage, power electronics, energy smart consumer devices, consumer information technology and sensing technologies. Results should include wider deployments of distributed computing technologies for faster system response times, the integration of many more sensory and control nodes at the distribution and customer levels, and the ability to manage and precisely react to supply and demand imbalances at the micro level or, through aggregation, at any level or nodal point across the T&D grid.

We currently anticipate that several significant milestones will be achieved during the decade of 2020 to 2030. SCE anticipates that renewable resources will reach 33% of power delivered on its system. Plug-in electric vehicles in SCE's service area should exceed one million before 2025. The decade will see the mass introduction of zero net energy residential and commercial buildings in California that may incorporate onsite renewable supply, energy storage, high efficiency envelopes, energy smart appliances/devices and autonomous control systems interfaced to grid and wholesale market operations. This will result in an integrated network with the potential of 20 million agents (people & devices) on SCE's system. Also, vehicle-to-grid, microgrids and dynamic scheduling across the western region using distributed resources will become operationally and economically feasible options. As such, Grid 2.1 would need to provide a ubiquitous, highly reliable and secure network that seamlessly integrates a wide variety of demand and supply resources to enable broad market participation by consumers, suppliers and autonomous devices involving trillions of micro-transactions per year.

Table 7 below highlights several of the technology innovation activities that will be pursued over the next five years to help spur the development of commercial solutions in the 2020 decade. These items frequently involve very long development and testing cycles for broad commercial introduction on a utility system. SCE recognizes the need to begin the technology development lifecycle and is partnering on each of these areas with universities, research institutes, national labs and other utilities to facilitate the development process and sharing of knowledge.

Theme	Project Title
Grid Efficiency & Resiliency	Electric grid as an increasingly complex network of networks • Applied research and design to manage the increasing complexity for transmission, distribution and customer systems and their integration • Redefining the limits of optimization at acceptable levels of instability risk • Identifying potential system inertia deficiencies and solutions
	Application of high-temperature superconducting materials to grid equipment • Superconducting transformers & fault current limiters • Superconducting cable • Superconducting Magnetic Energy Storage (SMES)
Renewable & Distributed Energy Resource Integration	Development of 2G & 3G energy storage technologies (electrochemical and non-electrochemical)
	Advanced monitoring & control of intelligent inverters associated with distributed energy resources
Customer Empowerment	Evaluation and development of vehicle-to-grid capability
	Converting the electric grid to support a trillion micro-transactions market dynamically driving grid operations thru multi-agent based control systems dynamics
Information and Telecommunications Technology & Cyber-security	Evaluation and development of business applications using artificial intelligence to manage critical business operations
Workforce Safety & Effectiveness	Continued evaluation of potential adaptive technologies from other industries such as defense and transportation

Table 7 - Stage 4 Technology Evaluation Projects

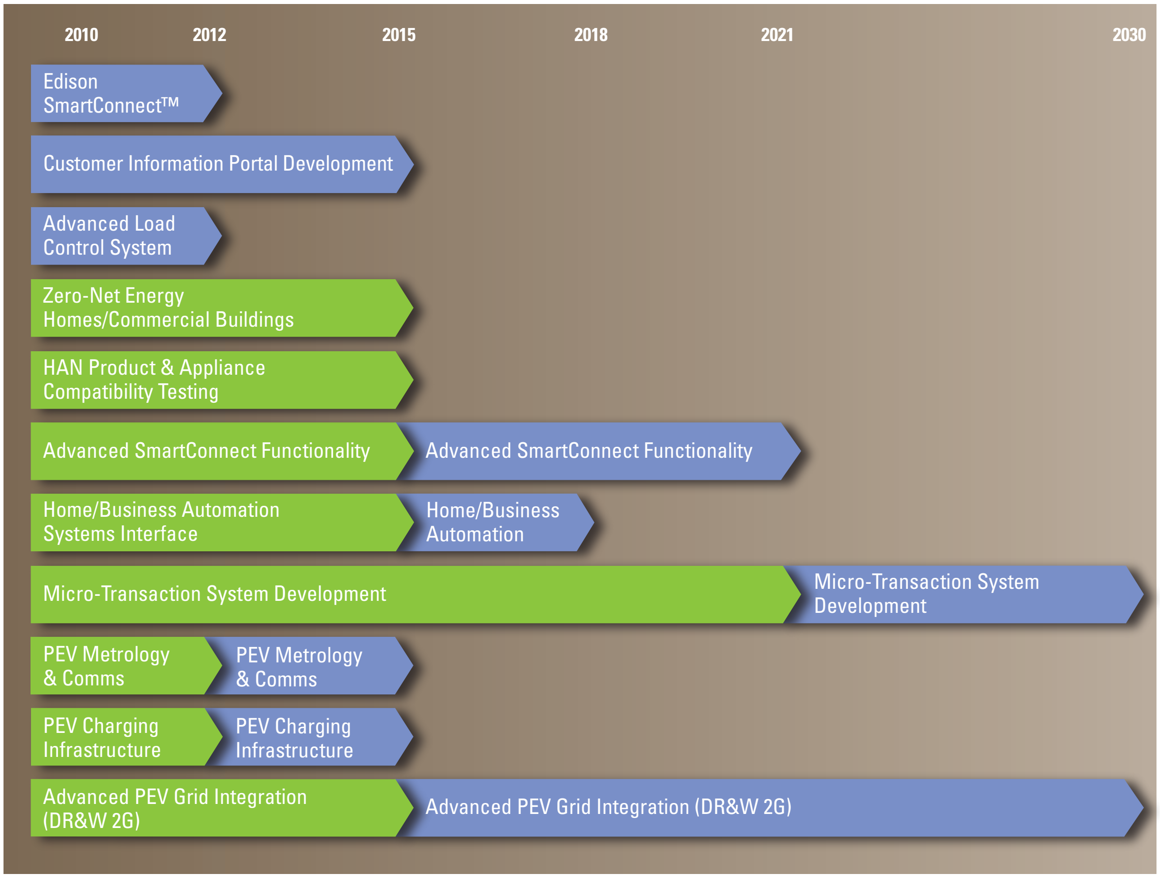
4.5. Summary of Technology Roadmap

The development of the smart grid will be a journey that will likely take 30 years to fully accomplish, with key milestones along the way. A significant near-term milestone is the completion of the deployment of SCE's smart metering to all of its five million customers by the end of 2012. The next key milestone is enabling the many state and federal climate and energy policy objectives targeted for 2020. These and other policy milestones create significant timing and time alignment challenges related to the relative maturity of the technologies required to meet these goals, as well as key dependencies and predecessor relationships between unique technology deployments. In an attempt to address these challenges, SCE is simultaneously pursuing capital projects to deploy smart technologies and managing a large portfolio of concurrent technology evaluation activities with development periods spanning 5 years, 10 years and 20 years. The net result of these activities is the transformation of the electric grid and utility operations to a grid for the 21st century. The challenge of course is that this transformation is occurring as SCE is replacing most of its existing core grid infrastructure, supporting the development of an economy that is increasingly reliant on cleaner, but intermittent, electricity resources and anticipating the retirement of 50% of its workforce by 2020. As such, the pace and cost of the transformation from today's electric grid to the smart grid are critical questions. These issues must be explicitly considered in the development of smart grid investment policy because reasonable cost and reliability of electric service are essential to our customers. The evolution of this transformation is illustrated in the technology roadmap summarized in Figure 12 on the following pages.

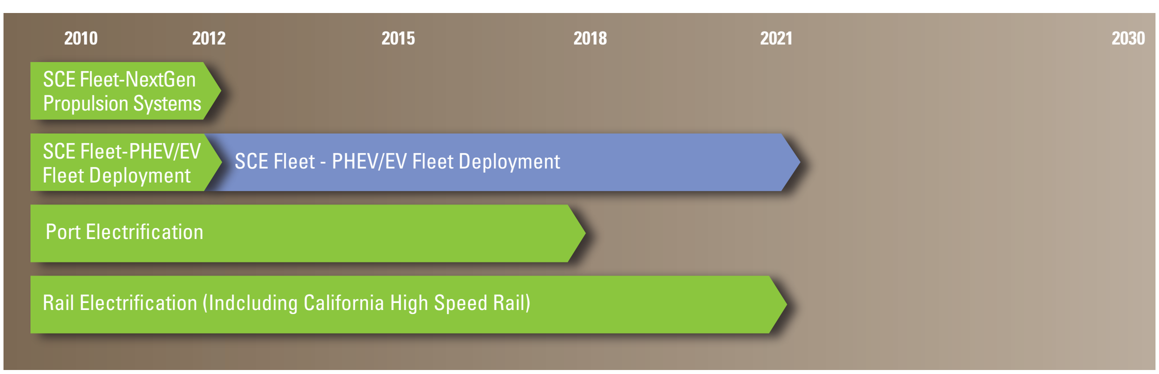
Customer Empowerment

■ Technology Evaluation ■ Deployment

Customer Energy Smart Solution

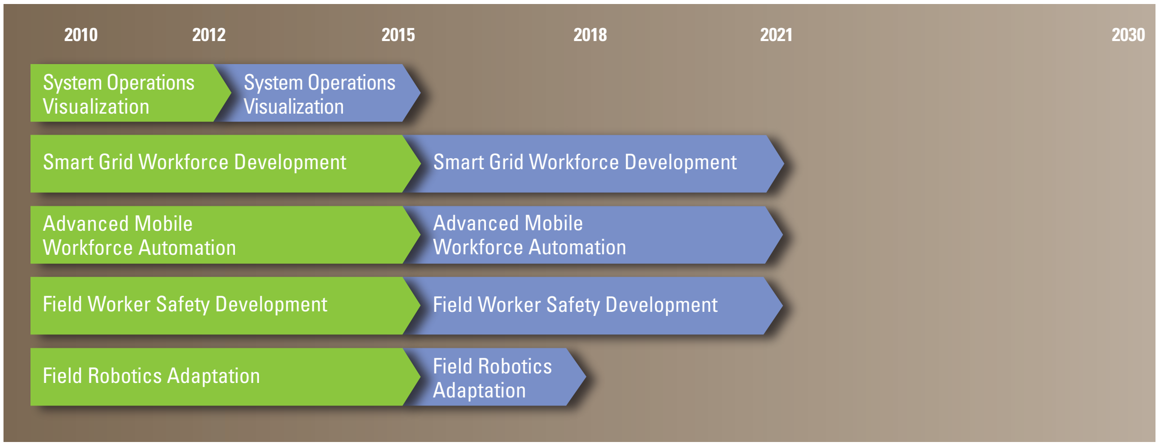


Advanced Electric Transportation



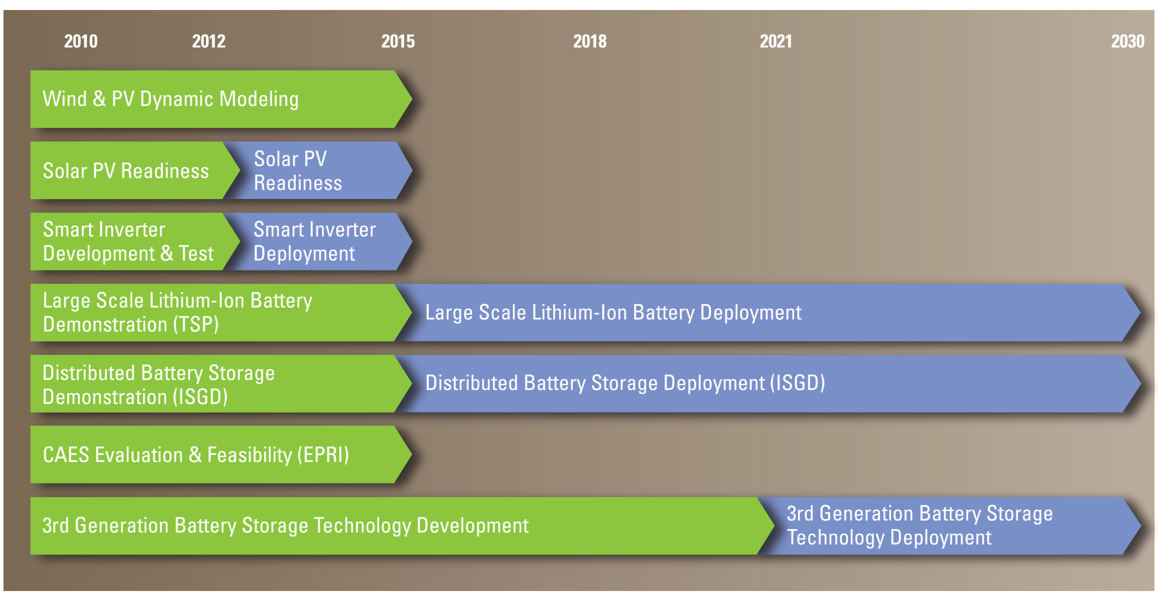
Workforce Safety & Effectiveness

■ Technology Evaluation ■ Deployment



Renewables & DER Integration

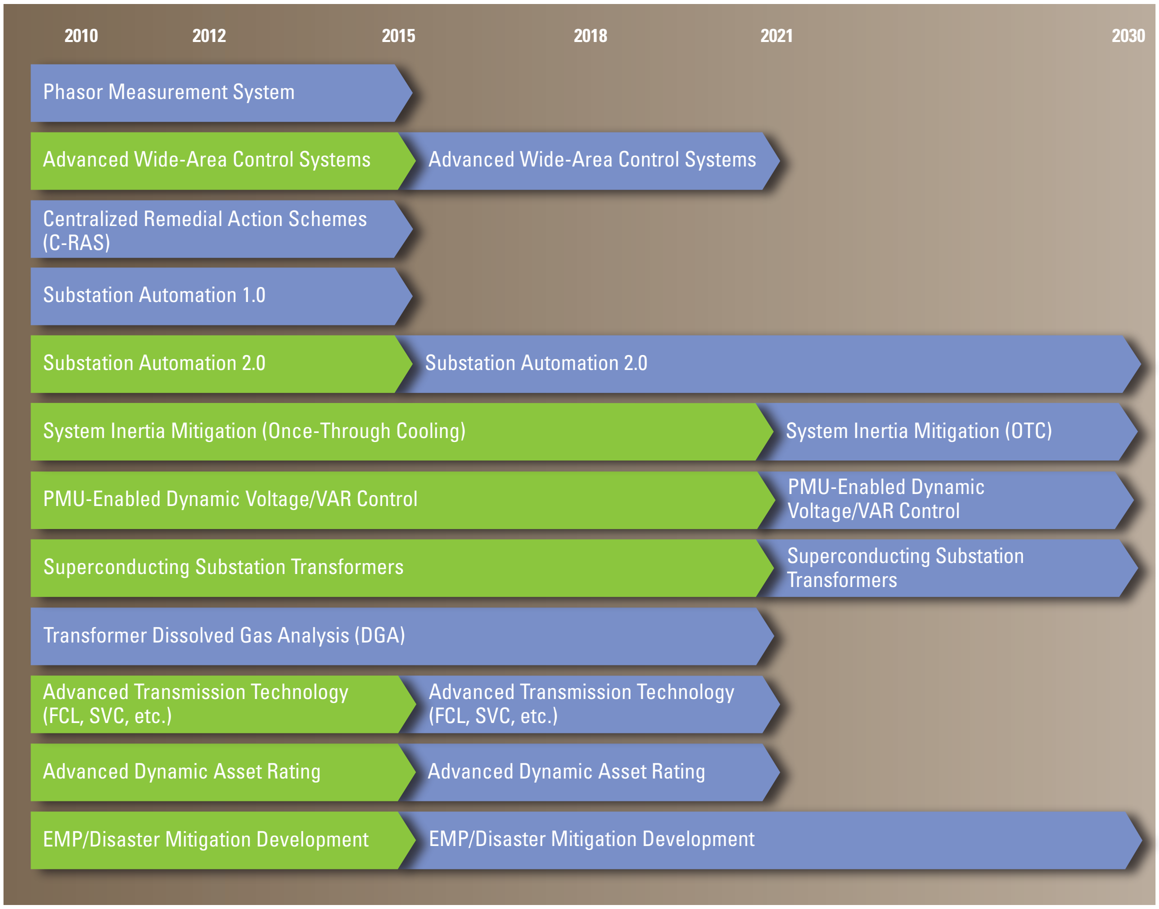
■ Technology Evaluation ■ Deployment



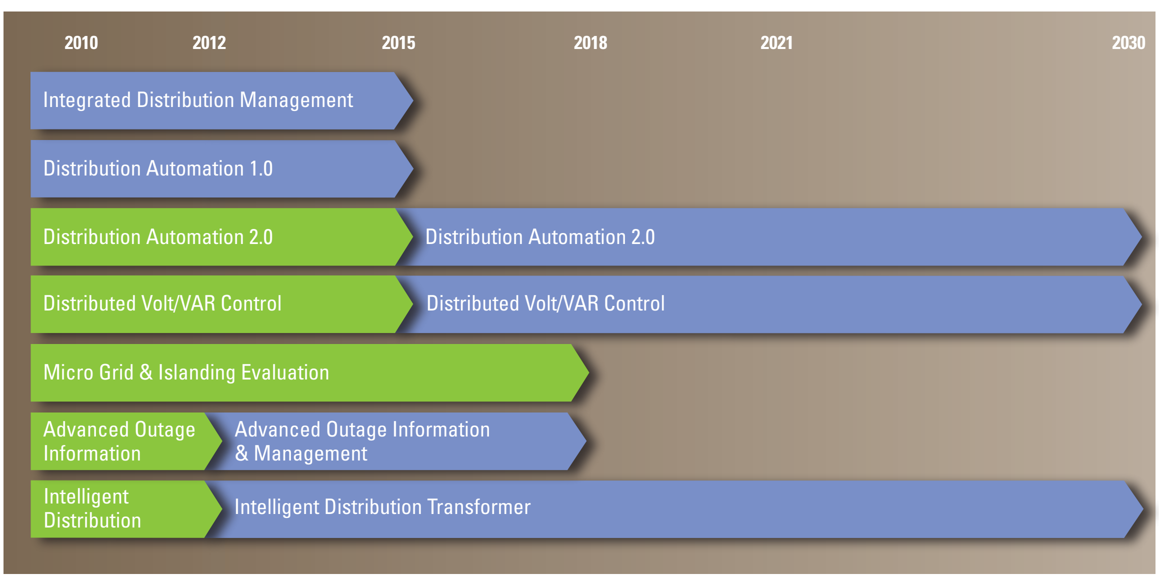
Grid Efficiency & Resiliency

■ Technology Evaluation ■ Deployment

Transmission/Substation



Distribution



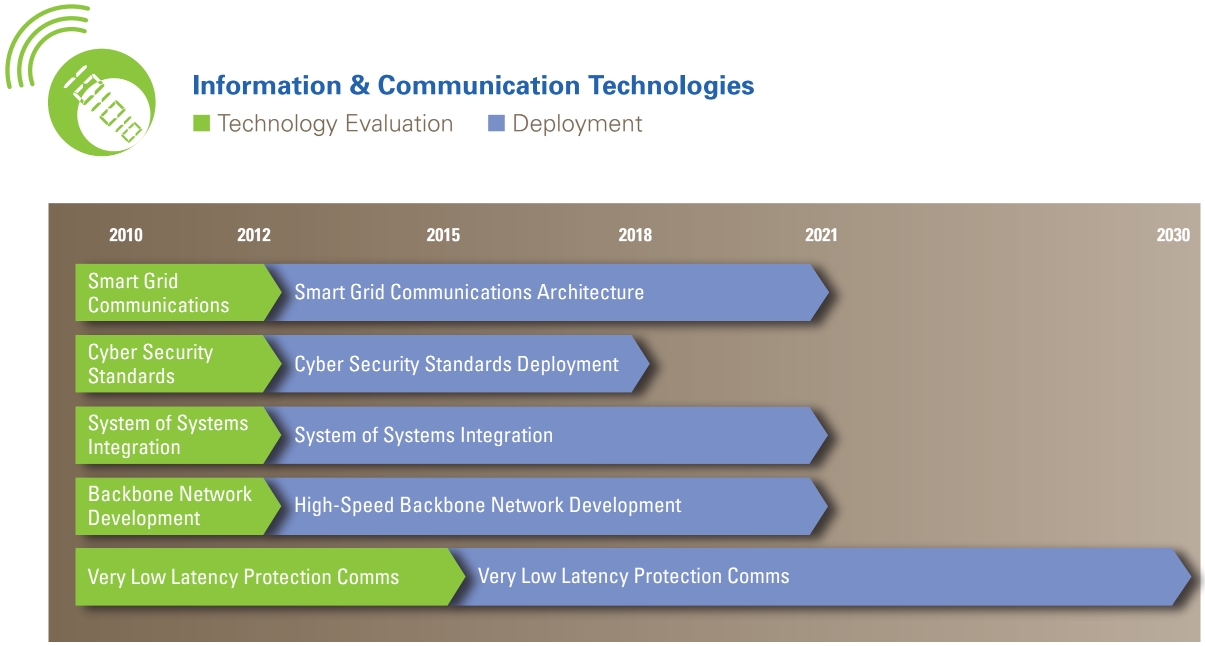


Figure 12 - Summary Technology Roadmap

4.6. Managing and Maintaining the SCE Smart Grid Development Roadmap

Because of the staged and staggered deployment approach described above, the SCE smart grid development roadmap must be flexible, particularly in the later years, and able to handle adjustments and changes to the scope and sequencing of deployments. Re-evaluating and reconsidering the smart grid deployment roadmap will be an important periodic activity as detailed business cases are developed for specific smart grid initiatives, as lessons are learned through technology deployment experience, and as policy drivers and business objectives change and evolve. To be able to respond to such adjustments, SCE has created a function within its Advanced Technology organization to manage and update its Smart Grid Strategy and Roadmap on an ongoing basis. This effort will track both smart grid deployment and technology evaluation project portfolios. It will closely monitor changes to state and federal policy, corporate goals, business case developments, and emerging technology innovation, as well as broader macro-economic and energy market developments (i.e. scenario planning 'signposts'), to identify necessary course corrections to the staged roadmap over time.

5. Appendices

5.1. SCE Smart Grid Reference Documents

Relevant SCE Documentation

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