CEIDS

2003 CEIDS Master Plan

July 2003

FOREWORD

The Consortium for Electric Infrastructure to Support a Digital Society (CEIDS) management team would like to thank Program partners for generously contributing their time, expertise, and financial support to the development of this document. The CEIDS Master Plan is a living document that will be updated annually to include the views of the newest partners, as well as any changes in vision that result from CEIDS research and development efforts or the evolving needs of society. Others are invited to join CEIDS and to work with its partners and management team.

Broad-based involvement is key to realizing the CEIDS vision of a new electric delivery infrastructure that integrates advances in communications, computing, and electronics to meet the energy needs of the digital society. Although CEIDS recognizes that political, regulatory, economic, technical, and other developments will certainly impact infrastructure development, the Program is not attempting to influence regulatory or market conditions. CEIDS and its partners realize that others are working on infrastructure-related projects and welcome their views for inclusion in future versions of the Master Plan.

CEIDS Master Plan 2003 reflects the perspectives of leaders within the energy and high-technology industries, the manufacturing sector, and state and federal governments as of the summer of 2003. Represented on the CEIDS Steering Committee and in the Project Advisory Groups are Alliant Energy Corporation, Bonneville Power Administration (BPA), Cisco Systems, Consolidated Edison of New York, Electricité de France (EdF), Exelon, Lockheed Martin Corporation, Long Island Power Authority (LIPA), New York Power Authority (NYPA), Polish Power Grid Company, Salt River Project (SRP), TXU Energy / Oncor, U.S. Department of Energy (DOE), and We-Energies. Participating in the CEIDS Public Advisory Group are the Association of State Energy Research and Technology Transfer Institutions (ASSERTI), California Energy Commission, Georgia Environmental Facilities Authority (GEFA), International Brotherhood of Electrical Workers, Michigan Public Service Commission, National Association of Regulatory Utility Commissioners (NARUC), National Association of State Energy Offices (NASEO), New Jersey Board of Public Utilities, New York State Energy Research and Development Authority, Oregon Office of Energy, Public Utility Commission of Texas, and Wisconsin Department of Administration.

EXECUTIVE SUMMARY

Over the past year, a diverse group of stakeholders—including domestic and international energy companies, federal and state agencies, and information technology companies—has come together with a visionary goal: to help today's electric power system evolve into an intelligent infrastructure that integrates major changes in functionality and advances in communications, computing, and electronics to meet the energy needs of the digital society. This unique alliance is the Consortium for Electric Infrastructure to Support a Digital Society (CEIDS)—a public/private partnership managed by the Electricity Innovation Institute (E2I) and Electric Power Research Institute (EPRI).

This Master Plan has been developed to unite the CEIDS partners and other stakeholders in the electric enterprise around the CEIDS vision of the new electric infrastructure, and to provide a process for identifying and developing the technology required to achieve that vision. Specifically, the Master Plan provides a guide for best deploying the resources of CEIDS to facilitate groundbreaking change.

Findings

To create the intelligent infrastructure, CEIDS and its partners determined the needs of major stakeholders and identified key attributes of the infrastructure of the future. In the process, a vision of the system emerged. Gap analysis revealed that several functional gaps—requisite power delivery capabilities that are lacking in the current system—will need to be addressed if we are to help the infrastructure evolve. In-depth analysis of these gaps has revealed seven critical action items that must be undertaken to develop the new infrastructure. These action items will serve to shape CEIDS goals and funding decisions:

1. Create communications infrastructure/open architecture interface
2. Develop fast and accurate computational methods to model and analyze the electric infrastructure
3. Characterize security, quality, reliability, and availability requirements of the infrastructure
4. Develop and implement cost-effective technologies to support automation, real-time monitoring, and control of the power delivery system
5. Enable distributed energy resources to play a role in energy markets
6. Develop effective forecasting tools for supply, load, and market data

7. Create high-value, cost-effective products and services to help consumers and companies control, optimize, and direct energy use in an environmentally acceptable way

Recommendations

CEIDS has already begun building a portfolio of projects that address these critical action items. Two projects are currently underway: the Integrated Energy and Communications System Architecture (IECSA), and the Open Communication Architecture for Distributed Energy Resources in Advanced Distribution Automation (DER/ADA). Four technology areas have also been identified and are being evaluated for possible project funding in late 2003 and early 2004. They are: 1) Fast Simulation and Modeling for the Intelligent Electric Infrastructure, 2) Consumer Communications Portal, 3) Advanced Power Electronics, and 4) Communications Technologies to Support the CEIDS Program.

In addition, five new technology areas have been recommended for further study:

1. Infrastructure Quality and Reliability
2. Monitoring, Communications, Command, and Control
3. Intelligent Network Agents, Information Processing, and Visualization
4. Dynamic Risk and Reliability Management
5. Integration of Energy Storage

These recommended technology areas complement the CEIDS work already underway by increasing coverage of critical action items. To be funded, each technology area must pass through a detailed screening process that focuses on the interrelated nature of all projects and prioritizes them according to stakeholder needs. As each new project is funded, the envisioned electric infrastructure draws another step closer to reality.

CONTENTS

1 Introduction

Over the past year, a diverse group of stakeholders—including domestic and international energy companies, federal and state agencies, and information technology companies—has come together with a visionary goal: to transform today's electric power system—from the busbar to the microchip—into an intelligent infrastructure for the future. This unique and far-reaching alliance is the Consortium for Electric Infrastructure to Support a Digital Society (CEIDS)—a public/private partnership managed by the Electricity Innovation Institute (E2I) and Electric Power Research Institute (EPRI).

This Master Plan has been prepared to unite the CEIDS partners and other stakeholders in the electric enterprise around the CEIDS vision of the new electric infrastructure, and to provide a process for identifying and developing the technology necessary for achieving that vision. It has been developed in close coordination with the EPRI Electricity Technology Roadmap Initiative, an ongoing, collaborative exploration of electricity-based innovation over the next 20 years and beyond. Specifically, the Master Plan provides a guide for best deploying the limited resources of CEIDS to implement groundbreaking change. Members of the CEIDS Steering Committee, Public Advisory Group, and staff from E2I and EPRI have generously provided their input to this document.

The CEIDS vision is: *A new electric delivery infrastructure that integrates advances in communications, computing, and electronics to meet the energy needs of the digital society.*

The mission of CEIDS is: *To develop the science and technology that will fundamentally transform the infrastructure to cost-effectively provide secure, high-quality, reliable electricity products and services with minimal environmental impacts.*

To achieve the CEIDS mission, the Program will combine the financial resources of its partners, while being guided by their shared needs and perspectives and those of the five major stakeholders in the power delivery infrastructure of the future: consumers, energy service companies (investor-owned utilities, municipals, cooperatives, service providers, trading companies, power producers, and regional transmission organizations/independent system operators), technology transformers, society, and regulatory bodies. Specifically, CEIDS will identify the key enabling functionalities and technologies necessary to achieve the new infrastructure, build on the large knowledge and experience base of CEIDS participants and EPRI, and focus on high-impact research and development (R&D) projects that help the electric power infrastructure to evolve.

CEIDS recognizes that the success of creating the new electric infrastructure hinges not only on overcoming technological challenges but regulatory, economic, and environmental barriers as well. While CEIDS cannot directly address these non-technological barriers, they will be considered in shaping technology R&D activities.

The strategic intent of CEIDS is: *To develop a portfolio of interrelated projects, so that each project builds on the others and propels the program toward its vision of the future.*

Each project in the CEIDS R&D portfolio is intended to address the critical science and technology needs that will allow the electric infrastructure of the future to evolve. As the following links show, the CEIDS projects tie into the strategic plans of EPRI, E2I, the U.S. Department of Energy, and the California Energy Commission.

- EPRI: Electricity Technology Roadmap Initiative
  http://www.epri.com/corporate/discover_epri/roadmap/index.html
- E2I: Power Delivery System and Electricity Markets of the Future/Synthesis Document
  http://www.e2i.org/docs/System_of_the_Future.pdf
- EPRI: Power Delivery and Markets Bridge Plan **(*Draft not available at this time*)**
- EPRI: Electricity Sector Framework for the Future
  http://www.epriweb.com/epriweb2.5/ecd/gen/gencouncil/material/Mar03/5ElectricityFuture.pdf
- U.S. Department of Energy: National Electric Systems Vision Document: Grid 2030 **(*The link in the email we received this from states that it is not for distribution.*)**
  http://www.energetics.com/electric.html
- California Energy Commission, Consumer Power and Conservation Financing Authority, and California Public Utilities Commission: State of California Energy Action Plan
  http://www.energy.ca.gov/2003_energy_action_plan/2003-05-08_ACTION_PLAN.PDF

The strategic intent of CEIDS is to focus on developing a portfolio of interrelated projects, ensuring that each project selected for funding builds on the others to propel the program toward its vision of the future. CEIDS itself is interconnected in nature, and this is the unique and compelling opportunity that the program presents. With common goals and strategies, a diverse group of stakeholders is coming together to create something that is greater than the sum of its parts.

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Vision of the Future

The world's electric infrastructure is growing increasingly complex—and vulnerable. While it tries to meet the mounting requirements of competitive energy markets, it also must accommodate increasing numbers of microprocessor-based "digital" devices and cope with the saturation of existing transmission and distribution (T&D) capacity. (Appendix A provides a detailed description of many of the challenges facing the existing infrastructure.) Without accelerated investment and use of new technologies, the power system will age with unplanned acceleration—resulting in reduced productivity, greater costs, and constrained economic growth.

Simply put, today's electric power system cannot meet the increasing demands being placed on it. Indeed, a sharp decline in critical infrastructure investment over the last decade has left portions of the system susceptible to poor power quality, service interruptions, and market dislocations. In many locales, substantial system upgrades are required just to bring service back to the level of quality and reliability expected by consumers, and to allow electricity markets to function efficiently.

> *The infrastructure that served us so well in the past cannot simply be abandoned and a new system put in its place.*

Billions of dollars will be invested over the next few decades in replacing equipment with economic life spans of 40 to 50 years. To ensure clean, efficient, secure, reliable, high-quality, available, and affordable electricity for decades to come, this capital turnover of assets must incorporate the latest technologies and recognize the interrelation between the electric power system and other critical infrastructures. Certainly, the infrastructure that served us so well in the past cannot simply be abandoned and a new system put in its place. Upgrades will need to be done in a managed way, through intelligent and timely replacement of the existing infrastructure.

The Infrastructure of the Future

The electric infrastructure of the future will be integrated, self-healing, and electronically controlled to provide extraordinary resiliency and responsiveness. Transmission and distribution technologies will be designed with the flexibility to accommodate changing end-use needs. They will be fully capable of acting—in real-time—on the billions of decisions made by consumers and their increasingly sophisticated microprocessor agents. The infrastructure will be always on, or "alive." It will be interconnected, interactive, and merged with communications in a complex network of real-time information and power exchange. Ultimately, this electricity and information infrastructure will enable the next wave of technological advances to flourish.

The new infrastructure will be designed with the consumer as its basis. Consequently, consumers will have increased choice and greater control of energy use. New price-driven energy services subject to consumer choice will likely proliferate. As opposed to today's "one-size-fits-all" service, consumers will be able to tailor their electricity service to best suit individual preferences, including costs, environmental impacts, and levels of reliability and power quality.

The new infrastructure will also allow consumers with equipment or processes that are sensitive to power disturbances to purchase a higher "grade" of power, much like purchasing premium-quality fuel at the gas pump. This premium grade of power will have fewer disturbances and outages than "regular" service. Consumers will be able to balance the higher cost of premium-grade service against the economic losses from power disturbances, optimizing the performance of their business. At the same time, their equipment will become less susceptible to power disturbances, as vulnerabilities are better understood and standards are put in place to harden circuitry.

The new infrastructure will be designed with the consumer as its basis, giving consumers increased choice and greater control of energy use and environmental impacts.

A communications network will link consumers to the electricity marketplace on a "24/7" basis, with a consumer communications portal enabling interactive, two-way exchanges—including price signals that flow from service providers to consumers and their array of "smart" appliances and equipment (including self-generation), and consumption patterns and other information that stream back to service providers and others. Smart appliances and equipment will automatically adjust energy use in response to real-time and forecasted price signals and in combination with preset consumer preferences. For example, day-ahead price signals will allow large commercial heating, ventilation, and air conditioning equipment to automatically adjust its operation to ensure the comfort of building occupants at the lowest possible cost. In addition to these benefits, the communications portal linking consumers to services and markets will provide an array of new products and services that we can only dream of today.

Due to advances in small, efficient electric generators and storage technologies—which will connect to the power delivery system as easily as linking a printer and computer at home—growing numbers of electricity consumers will become consumer/producers. This will give consumers the options of purchasing power from the electric delivery system, selling power to the system, or isolating themselves from the system and producing their own power. The consumer communications portal will enable these transactions to occur instantaneously in response to market conditions.

Either by themselves or through a third-party aggregator, groups of consumer/producers with similar power needs will also be able to interconnect with one another to form microgrids. These microgrids will provide the necessary level of electric service reliability at a cost much lower than if the consumer purchased the service alone.

The challenge will be to transform the existing, rigid distribution system to provide a radical level of functionality and flexibility at the lowest possible cost.

The advent of increased consumer choice will bring about profound changes in the electric distribution system, which interfaces directly with the consumer. Traditionally, the distribution system operates from the top down—that is, with power flowing from the generator to the consumer. Greater consumer choice and control—along with the influx of distributed energy resources—will force the redesign of the distribution system, so that it operates from the bottom up and allows power to be moved in both directions along a line. This type of change will need to be accomplished without inconveniencing “the many” for the advantage of a few. The obligation to serve will continue to include responsibilities to consumers, especially as they relate to the economically disadvantaged.

The challenge will be to transform the existing, rigid distribution system to provide this radical level of flexibility at the lowest possible cost. This will be accomplished through extensive use of advanced information technology—communications, monitoring, automated control, and distributed intelligence. This wide-ranging automated system will provide flexibility for consumers, while offering utilities greater reliability, lower operation and maintenance costs, and increased performance and life from distribution equipment.

The distribution system of the future will instantly adapt to the connection and disconnection of distributed generation and storage. Issues around the location of distributed generators, such as breaker duty and fault current limiting, will be alleviated through use of advanced technologies. Signals will pass securely from consumers to the network of intelligent distribution system protection devices, allowing the system to reconfigure itself in real-time.

Decisions regarding maintenance and replacement of distribution equipment will be based on actual equipment condition, as determined by embedded diagnostic systems and performance assessment algorithms that compare current equipment performance to "performance signatures." The diagnostic systems will provide a warning prior to component failure, allowing for repair without disruption of service.

When disturbances do occur, they will be quickly identified and located. Corrective actions will be determined and automatically implemented, so as to minimize any impact. New products and services will allow consumers affected by a disturbance to be notified and continually updated on the progress of service restoration. Technologies will allow for integrated response of end-use systems (e.g., critical processes, distributed generation and storage systems, and advanced end-use power conditioning technologies) when there is a disturbance.

A major challenge in creating the transmission system of the future is that new line construction will continue to be severely constrained by environmental and siting issues. This means that meeting capacity growth will require more productive use of existing rights-of-way. A variety of new technologies will aid this effort. Some lines, for example, could be reconductored using low-sag materials, or they could be replaced with superconducting cables to provide greater throughput. In addition, a new generation of power-electronic, power flow controllers will be needed to replace conventional, electromechanical control devices.

The electric infrastructure of the future will be integrated, self-healing, and electronically controlled to provide extraordinary resiliency and responsiveness.

The existing transmission network moves power produced by large generation stations to distribution substations for delivery to retail outlets, in much the same way as trucks transport products to consumers over the network of interstate highways. Due to today's open competition of electric generation and increased wholesale wheeling, the transmission system—which is designed to move power in a very planned manner—is now being operated in a less predictable way. Like the distribution system, the transmission system will need to become much more flexible to meet the needs of consumers, generators, and society. It also will need to address the new realities of heightened environmental awareness and security concerns.

Coupling information technology with power-electronic, power flow controllers will enable the transmission system of the future to be tuned in real-time to optimize utilization. Incorporating distributed intelligence into the system will enable the creation of a "self-healing" grid that is capable of automatically anticipating and responding to disturbances while continually optimizing its own performance. The system will satisfy stakeholder needs by addressing key attributes that CEIDS staff and partners identified as essential in the future: 1) security, quality, reliability, and availability; 2) economic efficiency and growth; 3) asset performance and control; and 4) environmental stewardship (see Appendix B).

In brief, the electric infrastructure of the future—from busbar to the microchip—will be, as *Wired Magazine* describes it, “awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming—and interconnected with everything else.”[1]

Findings: Critical Action Items

Having established where we want to be in the future, how do we get “from here to there?” Gap analysis provides an avenue for answering this question, while systematically identifying areas of potential research.

Seven critical action items will serve to shape the goals and funding decisions for CEIDS in the near-term.

For CEIDS, functional gaps are defined as capabilities that are lacking in the existing electric power system that must be addressed in order to develop the key attributes of the envisioned electric delivery infrastructure. In early 2003, the CEIDS staff and partners identified 19 functional gaps (see Appendix C). The CEIDS staff assessed these gaps according to their relevance to the key attributes of the future infrastructure. (For a detailed discussion of the decision-making and gap analysis processes, see Appendix D.) Seven gaps emerged as the ones that must be bridged. These gaps form the basis for the critical action items shown in Table 2-1.

The seven critical action items will serve to shape the goals and funding decisions for CEIDS in the near-term. In other words, if a project does not directly address one of these items, it should not be funded. Following is a brief description of critical action items, why they must be addressed, and their corresponding functional gap numbers.

Action Item 1. Create communications infrastructure/open architecture interface

Central to the new electric infrastructure is a high-level communications architecture for exchanging data and information among enterprise constituents.

Central to the new electric infrastructure is a high-level architecture for exchanging data and information among enterprise constituents—including consumers, distribution companies, regional transmission organizations (RTOs), independent system operators (ISOs), energy service providers, and others. The architecture lays the foundation for communications between systems and entities that will enable development of the “intelligent grid,” support modernization of the existing infrastructure, and facilitate

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[1] Silberman, Steve. ‘The Energy Web,’ *Wired Magazine*, Issue 9.07 (July 2001). (http://www.wired.com/wired/archive/9.07/juice.html)

creation and delivery of new consumer products and services. Load management will be made easier while real-time pricing and communication with appliances can become a reality. Without this architecture, communications will be disjointed and coordination across the infrastructure compromised. (Functional Gap 1)

Table 2-1. CEIDS Critical Action Items

CRITICAL ACTION ITEMS
1. Create communications infrastructure/open architecture interface
2. Develop fast and accurate computational methods to model and analyze the electric infrastructure
3. Characterize security, quality, reliability, and availability requirements of the infrastructure
4. Develop and implement cost-effective technologies to support automation, real-time monitoring, and control of the power delivery system
5. Enable distributed energy resources (DER) to play a role in energy markets
6. Develop effective forecasting tools for supply, load, and market data
7. Create high-value, cost-effective products and services to help consumers and companies control, optimize, and direct energy use in an environmentally acceptable way

Action Item 2. Develop fast and accurate computational methods to model and analyze the electric infrastructure

Today, power system operators work with computer models that only approximate generation sources, loads, and the connecting infrastructure. This makes contingency planning problematic. Computer models and faster computation are needed to take data from many points on the T&D and end-use systems and quickly convert it into information that can be visualized and used to optimize or improve system performance. Additionally, models providing faster than real-time, look-ahead simulations are required to anticipate and minimize disturbances, and then to evaluate optimum responses to the disturbances that take into account the characteristics of the end-use systems. Such models and fast computational speeds will be key components of the intelligent grid, and will facilitate faster and optimized responses to outages, constraints, attacks, and other stresses on the system, as well as more efficient continuous operation of the system. (Functional Gap 2)

Action Item 3. Characterize security, quality, reliability, and availability requirements of the infrastructure

The balance between load immunity and power system performance must be optimized to meet the needs of all electricity consumers.

Discussions with energy companies and industrial end users reveal frustration over who is responsible for what level of service quality, in which circumstances. Regulators also have concerns and want to ensure that the distribution system is not "gold-plated" to benefit a few high-tech consumers at the expense of the other consumers. These concerns are likely to grow as digital loads and complex, integrated processes increase. To meet future energy needs and reduce frustration levels, the balance between load immunity and power system performance must be optimized to meet the needs of all electricity consumers. Methods of providing flexible levels of quality and reliability based on the needs of individual consumers and integrated with end-use system operation will need to be developed. Characterization of service, quality, reliability, and availability (SQRA) requirements will provide a framework for open discussion. Additionally, existing information on SQRA levels needs to be researched and analyzed to provide a baseline for future standards. (Functional Gaps 4 and 14)

Action Item 4. Develop and implement cost-effective technologies to support automation, real-time monitoring, and control of the power delivery system

(*Per Rick: This AI seems to overlap with AI#2 in the area of computation.*) Advanced sensors, integrated communications, data collection systems, and computing tools are required to realize automation functions that will enable the transmission and distribution infrastructure and end-use systems to evolve into a flexible network of interconnected, interactive systems. The automated systems are required to reduce the costs of maintaining the complex electrical infrastructure while increasing the reliability and quality of the power delivered. Systems are required to detect, locate, and identify disruptive events or attacks; and then quickly determine and implement corrective actions that will minimize the impact of the event. These systems will require database structures and associated computing tools that can continuously represent the state of the system performance along with the expected performance for alternative configurations, different load response conditions, and system contingencies. The systems will optimize system performance taking into account all the alternatives and constraints. These systems must also take into account new system configurations (e.g. primary networks, microgrids) that will offer increased reliability and flexibility for system operation. (Functional Gaps 6, 10, and 11)

Action Item 5. Enable DER to play a role in energy markets

DER integration holds the promise of increased energy capacity, system support, back-up power, and power quality benefits. DER technologies must take advantage of the standardized communications architecture and integrate with overall system automation and control functions to participate in the system optimization process. This will decrease integration costs for these technologies and support improved value propositions for DER applications. Advances in power electronics and storage technologies must be combined with innovative market and pricing structures to achieve dramatically improved quality and reliability levels with flexible system configurations. DER technology development and integration should be demonstrated at all levels of the system – high power applications to improve transmission and generator system performance; distribution system applications for improved reliability, quality, and efficiency of the local power delivery system; and end-use applications for integrated control of end-use systems. (Functional Gap 3)

DER integration holds the promise of increased energy capacity, system support, back-up power, and power quality benefits.

Action Item 6. Develop effective forecasting tools for supply, load, and market data

Boosting the efficiency of power delivery system operations hinges on the development of accurate forecasts of load minutes-to-hours ahead and hours-to-months ahead for decision making on system security, bulk power transactions, and pricing. Achieving success in the retail marketplace requires accurate forecasts of energy usage, customer needs, customer response, market shares, and other parameters, for up to several years into the future. Future forecasting tools must incorporate accurate models of load and demand response systems based on new market and pricing structures to develop optimum designs for the delivery system (based on quality and reliability constraints). (Functional Gap 5)

Action Item 7. Create high-value, cost-effective products and services to help consumers and companies control, optimize, and direct energy use in an environmentally-acceptable way

This action item has different meanings for different stakeholders. Energy companies require real-time pricing protocols to help with load response, to manage load, and to connect customers to the marketplace, while manufacturers need methods of remotely monitoring and controlling energy costs, and business enterprises seek new market opportunities. Consumers may want more environmentally acceptable product and service choices. Inevitably, needs for products and services will emerge that are not envisioned now. With integrated use of the communications infrastructure, a variety of end-use technologies will be required to support power conditioning needs of the future, local storage and generation alternatives, end-use technologies with load-control functions, and intelligent applications capable of responding in real-time to conditions on the supply system, including prices, quality, and disturbances. (Functional Gap 16)

Needs for products and services will emerge that are not even envisioned now.

3

Creating the CEIDS R&D Portfolio

The two major thrusts of the CEIDS Master Plan are to establish a strategic vision and to create a project selection framework that directs all activities toward that vision. Section 2 of this document lays the foundation for the CEIDS program by presenting a vision of the electric delivery infrastructure of the future, from the generator busbar down to the microchip. Based on this vision, seven critical action items are identified.

This section describes the process for building a portfolio of R&D projects that will address the critical action items needed to accomplish the CEIDS vision. It includes a summary of work underway in the CEIDS portfolio, and presents recommendations for future work, or technology areas.

> *The CEIDS portfolio-building process moves in stages—from a broad level of abstraction to sharply focused detail.*

Portfolio-Building Process

In order to accomplish the critical action items, several questions will need to be considered, such as: What specific action should CEIDS take? Who else is working in this area? What work are they doing? Will EPRI base programs or Strategic Science &Technology programs address this technology area? How can specific projects be created to move this area forward? Can CEIDS afford to do so?

To answer these questions, the CEIDS portfolio-building process moves in stages—from a broad level of abstraction to sharply focused detail. To begin with, E2I, EPRI, and the CEIDS partners identify technology areas that are necessary to accomplish the critical action items. Once the CEIDS Steering Committee accepts recommended technology areas, each area goes through a refining series of steps, as described below. Following each step, CEIDS staff presents the results to the Steering Committee, along with a recommendation on whether or not to proceed, and if so, how. Use of these steps allows CEIDS to avoid larger expenditures on projects that are being pursued elsewhere, have insufficient probability of technical success, or make marginal contribution to the CEIDS vision. The steps also allow CEIDS to focus R&D efforts, and to prioritize and execute projects.

Step 1. Scoping Studies

Scoping studies are an important step along the CEIDS technology development path. Experience has shown that these studies can identify issues requiring further evaluation, improve the success of R&D and demonstration activities, and reduce uncertainties when assessing advanced technologies. While these studies cannot answer every question, they can better define the focus of CEIDS development work and increase the odds of success. It is at this step that CEIDS staff can begin to explore the value of a particular technology area in relation to the vision of the future, and can identify what work others are doing in the area.

Short-cycled and inexpensive, scoping studies provide valuable decision-making information on technical solutions being considered for funding. A CEIDS scoping study can provide brief background and relevant market data on a potential technology solution, along with a competitive assessment of the marketplace. It can identify promising R&D areas and evaluate the solution against existing CEIDS work and screening criteria. Rough order-of-magnitude costs for projects in this area can also be estimated. For example, a scoping study identified that efforts to develop post-silicon power electronics would be beyond the financial resources of CEIDS.

> *Scoping studies can better define the focus of CEIDS development work and increase the odds of success.*

Step 2. Technology Analyses

If scoping study results look promising, the Steering Committee may choose to launch a technology analysis to examine a technology area in greater depth. More comprehensive and costly than scoping studies, technology analyses can identify specific technology applications and requirements; quantify market potential, including intellectual property and revenue opportunities; produce a business case analysis; and identify specific projects for consideration. The scope of analysis may involve consultant reports, workshops with experts in the field, and technical feasibility studies. It also may include developing specific statements of work for projects and/or drafting requests for proposals (RFPs) for recommended projects.

Step 3. Project Funding

After considering the results and recommendations from the technology analyses, the CEIDS Steering Committee selects strategically significant projects for funding. It is at this step that new technology, software, communications protocols, standards, and/or business uses are developed that will enable the CEIDS vision of the future. These projects are likely to be multi-year, and potentially multimillion-dollar efforts. They may be carried out with one or several contractors, and may be awarded competitively, sole source, or a combination of the two.

Step 4. Demonstration Projects

Successful projects often develop technology that requires demonstration in the field before it can be generally accepted in the marketplace. Demonstration projects are likely to require a host site, and will typically require matching funding beyond the resources of CEIDS. Individual Steering Committee and Public Advisory Group members may choose to provide financial spon-sorship for host demonstrations. Additional funding may come from vendors or government agencies. (E.g. BPA’s Energy Web initiative may offer another parallel possibility to quickly provide proof of concept along with practical implementation and business model viability). Ultimately, the nature of demonstration projects and derivative activities will be determined on a case-by-case basis. A plausible path-forward or commercialization plan should be part of any demonstration plan.

The CEIDS partners will play an important role in identifying demonstration and deployment opportunities.

Work Underway

CEIDS has already begun building a portfolio of R&D projects that address critical action items. The CEIDS staff and Steering Committee members have identified and approved two projects for funding—the Integrated Energy and Communications System Architecture (IECSA), and the Open Communication Architecture for Distributed Energy Resources in Advanced Distribution Automation (DER/ADA). In addition, they have identified four technology areas. Three of the four are currently undergoing technology analyses: Fast Simulation and Modeling for the Intelligent Electric Infrastructure (FSM), Consumer Communications Portal, and Advanced Power Electronics. The fourth project—Communications Technologies to Support the CEIDS Program—is undergoing a scoping study. Later in 2003, the CEIDS Steering Committee will determine if projects are to be launched in these areas.

Critical action items are already being addressed by CEIDS work.

Table 3-1 shows the extent to which critical action items are already being addressed by CEIDS work. Shaded areas in the table signify action item coverage; unshaded areas represent R&D opportunities.

Integrated Energy and Communications System Architecture

> ***IECSA:*** *An open, standards-based systems architecture for the monitoring, communications, distributed computing, command, and control infrastructure needed to support the intelligent electric infrastructure of the future.*

Status: IECSA is an active project. The IECSA project is developing an open, standards-based systems architecture for the monitoring, communications, distributed computing, command and control infrastructure needed to support the intelligent electric infrastructure of the future. The project is building upon current standards and industry infrastructure development activities, and it will actively engage stakeholders in both visioning and requirements development. This far-reaching project will enable the integration of a wide variety of intelligent electric power system components, and will greatly accelerate the development and creation of the intelligent grid of the future. The project was launched in January 2003 and will be completed in 18 months**.**

Table 3-1. Work Underway as it Addresses CEIDS Critical Action Items

WORK UNDERWAY	CRITICAL ACTION ITEMS						
	1 Communications Infrastructure/ Open Architecture Interface	2 Fast and Accurate Computational Methods to Model/Analyze Electric Infrastructure	3 SQRA Characteristics/ Requirements of Electric Infrastructure	4 Technologies to support automation, real-time monitoring, and control	5 DER Role in Energy Markets	6 Forecasting Tools for Supply, Load, and Market Data	7 High-Value, Cost-Effective End-Use Products and Services
Integrated Energy/Comm System Archit.	▨	▨	▨	▨	▨	▨	▨
Distributed Energy Resources for Adv. Distribution Automation	▨				▨		▨
Fast Simulation & Modeling		▨		▨		▨	
Communications Portal	▨			▨		▨	▨

Advanced Power Electronics				▨		▨	▨
Communication Technologies	▨	▨			▨		▨

IECSA is the foundation for the other projects in the CEIDS R&D portfolio and serves to integrate them all. The DER/ADA and communications portal projects build on the functional requirements developed in IECSA, flesh out the requirements in much greater depth, and then return the expanded information to IECSA. IECSA defines the applications and requirements for fast simulation and modeling. The availability of advanced power electronics-based controllers will have a profound impact on the architecture of the future electric infrastructure. A next phase for this project would focus on a more detailed design based on the architecture.

Open Communication Architecture for Distributed Energy Resources in Advanced Distribution Automation

Status: DER/ADA is an active project. Whereas IECSA is concerned with the broad requirements for the energy and communications architecture, the DER/ADA project is focused more narrowly on object models for distributed energy resource devices. Object models allow DER devices to automatically identify themselves and be identified by parts of the infrastructure, much like a personal computer can identify a new printer when it is hooked up. Having these object models will enable the strategic use of DER in advanced distribution automation for functions such as routine energy supply, voltage regulation, power factor control, emergency power supply, disaster recovery operations, and harmonic suppression.

DER offers the potential to significantly impact the design and operation of the power system.

Because of the potential for DER to significantly impact the design and operation of the power system, the CEIDS Steering Committee has identified this project as a high priority. It was selected following a detailed scoping study, which determined critical technology needs and identified work being done by other organizations, including the U.S. Department of Energy and California Energy Commission. This project is an enabling technology for advanced distribution automation concepts such as microgrids.

Fast Simulation and Modeling for the Intelligent Electric Infrastructure

Status: The FSM Technology Analysis will be complete in July 2003. The FSM project is designed to provide mathematical underpinning and look-ahead capability for the electric infrastructure of the future, which will be capable of automatically anticipating and responding to power system disturbances while continually optimizing its own performance. Creating this infrastructure will require judicious use of numerous intelligent sensors and communication devices and integrating them with power system control through the newly developed architecture. IECSA will provide the framework for fundamentally changing power system functionality. The FSM project will augment these capabilities by

- Providing faster-than-real-time, look-ahead simulations, making it possible to avoid previously unforeseen disturbances;
- Performing "what if" analysis for large-region power systems from both operations and planning points of view; and
- Integrating market, policy, and risk analysis into system models, and quantifying their effects on system security and reliability.

Consumer Communications Portal

Status: The Portal Technology Analysis will be complete in December 2003. This project will develop the enabling technology required to implement and manage two-way communications between consumers in the electricity marketplace and power system operators. It will be based on open systems and will be robust and adaptable to policy and technology changes. It will also leverage technical development within major initiatives related to portal development from other industries. The consumer communications portal will enable information to be passed to intelligent equipment and appliances within the consumer's premises. Successful portal development will enable a variety of new advanced energy services for consumers, while reducing peak demand, overall growth of energy demand, and associated environmental impacts.

> *Successful portal development will enable a variety of new advanced energy services for consumers, while reducing peak demand, overall growth of energy demand, and associated environmental impacts.*

Advanced Power Electronics

Status: The Power Electronics Technology Analysis will be complete in December 2003. The power electronics is going to provide variety of smart electric and electronic components enabling increase the functionality of the power system in the future. This project will develop a low-cost, reliable, and highly versatile converter structure for both transmission and distribution applications. The goal of the project is to significantly reduce the cost and improve the reliability of these types of controllers—exactly what is needed to ensure widespread adoption of advanced power electronics-based controllers. Emerging power-electronics technology promises a much wider range of functionality and applications than current controllers, and offers the potential to reduce the complexity, size, weight, and cost of highly sophisticated, multifunctional controllers for T&D systems.

Communications Technologies to Support the CEIDS Program

Status: The Communications Scoping Study will be complete in July 2003. Communications is an enabling theme in the CEIDS vision and in every project. While other CEIDS projects are dealing effectively with developing the communications architecture required to support the CEIDS vision, this project will help to answer the vital question of what technologies will be employed to support the flow of information from source to destination.

This project will both explore the potential of existing communications technology to support the CEIDS vision and identify areas where further technology development is necessary. Although this project leverages past CEIDS research in the area of power line communications (PLC), this entry point into communications has expanded to include all current communications technologies available. PLC technology will remain an integral part of this project, but represents only one of numerous technology options being researched.

Recommendations: New Technology Areas

The CEIDS staff is recommending to the Steering Committee that five new technology areas be considered for funding under the portfolio-building process. (For a description of the process used to identify technology areas, see Appendix D.) These five technology areas complement the CEIDS work already underway by increasing coverage of critical action items. The proposed technology areas are summarized here and the critical action items addressed by each technology area are indicated.

Five recommended technology areas complement the CEIDS work already underway by increasing coverage of critical action items.

Table 3-2 shows the extent to which the recommended technology areas will address critical action items. Shaded areas signify action item coverage; unshaded areas represent R&D opportunities.

Technology Area 1. Infrastructure Quality and Reliability

This technology area addresses critical action items 3 and 6. The research challenge in the Infrastructure and Reliability area is to find the optimum level of investment in both the supply infrastructure and end use technologies to maximize the overall economic benefits associated with quality and reliability levels. This requires a better understanding of the economics of power delivery system quality and reliability characteristics and of the economic consequences of different quality and reliability levels.

This area must start by establishing the relationship between investment in the infrastructure and the reliability and quality levels that can be achieved. Previous monitoring and survey projects have established databases of existing power quality characteristics and the database management tools for characterizing performance of large systems. The next stage must extend the understanding to include the effect of system design and operating characteristics (and investment level needed to achieve these characteristics). This knowledge then provides the basis for extending the understanding to future system architectures, application of advanced technologies, and advanced communication and control functions.

Table 3-2. Recommended Technology Areas as They Address CEIDS Critical Action Items

RECOMMENDED TECHNOLOGY AREAS	CRITICAL ACTION ITEMS						
	1 Communications Infrastructure/ Open Architecture Interface	2 Fast and Accurate Computational Methods to Model/Analyze Electric Infrastructure	3 SQRA Characteristics/ Requirements of Electric Infrastructure	4 Technologies to support automation, real-time monitoring, and control	5 DER Role in Energy Markets	6 Forecasting Tools for Supply, Load, and Market Data	7 High-Value, Cost-Effective End-Use Products and Services
1 Infrastructure Quality and Reliability			▨				▨
2 Monitoring, Communications, Command, and Control	▨			▨	▨		
3 Intelligent Network Agents, Information Processing, and Visualization		▨		▨		▨	
4 Dynamic Risk and Reliability Management	▨	▨		▨			▨

On the other side of the equation, research must continue on the immunity characteristics of end use equipment and processes and on advanced technologies that can improve performance at the end use level. This research is needed to determine the optimum investment strategy for future systems to achieve the compatibility between supply system characteristics and the end use equipment performance and reliability. The optimum investment strategy will be a mix between system design, advanced technologies and controls, and end use equipment design and coordination. Economic evaluation methodologies will deal with the global (system-wide) economic costs and benefits of different strategies for achieving compatibility.

It is likely that optimum solutions will involve differentiated levels of quality and reliability based on specific requirements and economics of different end users. New power conditioning technologies will help make this possible and then combinations of these new technologies with new distributed system topologies and advanced communications and control systems will allow further optimization of power quality and reliability and compatibility. This area will demonstrate these new technologies and new system infrastructures in successive stages to optimize quality and reliability compatibility with end use equipment technology and requirements.

Finally, standards are needed to provide a reference for both manufacturers and system designers to achieve compatibility. These quality and reliability standards will be the basis of new technology and new infrastructure demonstrations that will support advancements in both productivity at the end use level and system quality and reliability.

Potential R&D areas include

- Develop a comprehensive knowledge base of electrical system quality and reliability as a function of important system design characteristics (applicable to evolving and future designs).
- Develop a knowledge base of end use equipment and process immunity characteristics and costs associated with supply quality variations. Characterize the role of future advanced power conditioning technologies and end use equipment enhancements in shifting the optimum investment strategy for quality and reliability compatibly.
- Assess the economics to determine the optimum balance between electrical system quality and reliability performance and the investment required in end use equipment immunity and power conditioning for next generation end use

equipment. Demonstrate technologies that can shift the economics towards overall reduced costs and improved productivity.

- Identify, develop, and demonstrate compatibility enhancement through advanced communication and control functions (including automated coordination between the power system infrastructure operation and end use facility and equipment operation).
- Evaluate SQRA enhancements that can be achieved through distributed generation, storage, new system topologies, and the integration with end use facility operation. Demonstrate the economic benefits and productivity gains associated with these technologies.
- Throughout these R&D efforts, coordinate with international standards organizations to facilitate standardized approaches to system performance characterization and compatibility assessment procedures.

Technology Area 2. Monitoring, Communications, Command, and Control

This technology area addresses critical action items 1, 4, and 5. The implementation of the automated self-healing electric infrastructure of the future starts with the ability to continuously assess the current state of the system through a combination of monitoring, communications, and real-time state estimation (simulation) tools. Understanding the current state of the system involves continuous monitoring of system conditions all the way from the transmission system to end use devices. Obviously, this requires a communications infrastructure that can support the requirements for continuous data collection and the implementation of control decisions based on this data. This technology area builds on the Integrated Energy and Communications System Architecture (IECSA) project specifications for the future communications infrastructure.

The next requirement for continuous system performance requires assessment will be cost-effective, accurate sensor technologies that can be deployed throughout the system and integrated directly with the communications infrastructure. These will likely be intelligent sensors that can make local decisions about data required for different functions and incorporate integrated communications. They will be simple to install and non-intrusive. In many cases, sensors will be integrated with devices performing specific functions (transformers, protective devices, voltage regulators, switches, meters, etc.). However, other sensors with wireless communications will be located on the system at key locations to support the overall system performance assessment and control requirements.

Continuous system performance requires intelligent sensors that can make local decisions about data required for different functions and incorporate integrated communications.

Continuous processing of the information from all these sensors will require major advancements in the database structures for accurate electrical and physical representation of the entire infrastructure. The data management functions to accomplish the continuous system infrastructure performance assessment and optimization are tremendous. The system will support the representations of interactions all the way from transmission to end use devices, including flexible system configurations and widespread application of distributed resources and demand response systems.

Widespread implementation of the system monitoring and control infrastructure is dependent on the economies that will be achieved through the communications infrastructure standardization ("plug and play" technologies) and ongoing developments in sensors and computing technologies. However, important concepts that are part of the system monitoring, communications, command, and control (MC^3) functions can be developed and demonstrated in parallel with the ongoing development of the communications architecture. Individual technologies for monitoring functions, new sensor technologies, data management systems, and control functions can be demonstrated and tested to help refine the overall system requirements and to identify specific integration issues that may be associated with the communications architecture. In many cases the CEIDS partners are already leaders in advancing MC^3 technology. Ideally, the demonstrations would build upon work that is already planned or underway.

> *CEIDS partners are already leaders in advancing MC^3 technology. Ideally, demonstrations will build upon their work.*

Potential R&D areas include

- Define the requirements for sensors for the electric infrastructure of the future.
- Develop intelligent sensors that can be deployed throughout the system with wireless communications and the ability to interface with a variety of applications for system and equipment performance assessment functions.
- Develop and demonstrate advancements in MC^3 technology. For example, Bonneville Power Administration (BPA) has pioneered the development and implementation of the Wide Area Measurement System (WAMS). BPA currently is expanding on the capabilities of WAMS by implementing a Wide-Area Stability and Control System (WACS) that will provide a flexible platform for rapid implementation of generator tripping as well as reactive power compensation for voltage support and stability. The system will provide improved voltage security through better preventive and corrective countermeasures. It will also automate the actions of an experienced operator. Opportunities exist to expand on the work currently underway by this industry leader.

Technology Area 3. Intelligent Network Agents, Information Processing,

and Visualization

This technology area addresses critical action items 2, 4, and 6. Automation of power system operations, market operations, and consumer services implies accurate information that is available in the right place at the right time. Therefore, it is crucial to understand the increasingly complex requirements for data management across disparate systems, and to develop methods for maximizing the accuracy and consistency of databases.

> *Solutions in the Intelligent Network Agents technology area can immediately be translated into economic savings at the stakeholder level.*

In almost all enterprise activities assessed during the first task of the IECSA project, data management surfaced as a concern for both the present and the future. Solutions in this technology area can immediately be translated into economic savings at the stakeholder level. Given the high visibility of data management and the understanding that it is an enabling technology for power system operation, the proposed scoping study will investigate potential research that can be done in this area. The scoping study will be closely coordinated with the IECSA project team.

This area will also investigate the requirements for the intelligent agents required to automate diagnosis and repair of problems on the self-healing grid of the future. Technologies include the intelligent network agents that will help to increase the robustness, resilience, and security of the electric infrastructure by gathering and communicating system data, making decisions about local control functions, and coordinating decisions with overall system requirements. Although the goal is to eventually create an agent-on-a-chip, these agents currently exist only in simulation. Considerable progress has been made, however, in developing realistic test cases for simulated agents, introducing new techniques for coordination and on-line context interpretation, and identifying ways to use the agents to help integrate physical network operations with real-time market functions. This technology area will also include development of software for converting data into useful information.

Potential R&D areas include

- Establishing requirements for data management, calibration, and validation to identify erroneous, missing, or malicious data;
- Developing methodology and tools for processing and simplifying wide-area measurement data, including real-time processing of large data sets via pattern extraction (data mining and cluster analysis), and techniques for correlating information from separate data sources;
- Developing adaptive load forecasting techniques and technologies; and

- Creating methods for converting data into visual images or other means to help operators quickly understand the current state of the system.

Technology Area 4. Dynamic Risk and Reliability Management of T&D and End-Use Equipment

This technology area addresses critical action items 1, 2, 4, and 7. The power delivery infrastructure of the future will have extensive monitoring, communications, and data processing capabilities, including coordination with end-use systems. The Dynamic Risk and Reliability Management (DRRM) technology area will investigate how these capabilities can be used to dynamically improve the performance and overall reliability of the infrastructure, from the supply system to end-use equipment. Research in this area will develop and demonstrate advanced technology applications that are continually assessing the performance of individual components and the overall system to anticipate equipment and system problems. Risk assessments will help prioritize maintenance, repairs, and equipment replacement to improve system performance.

The research in this area will build on existing research in preventive maintenance programs and advanced asset management systems. However, this research will focus on taking advantage of the advanced communications, monitoring, and controls infrastructure that will make real-time risk assessment and decision-making more valuable for improving system reliability.

The continuous assessment of system reliability and equipment performance will operate in a number of different timeframes. Short-term changes (seconds to hours) in equipment characteristics (unbalance voltages and currents, distortion levels, transient conditions) may be cause for notification and immediate action. Longer-term condition monitoring will influence maintenance schedules, system investments, and equipment replacement. Table 3-3 shows the types of forecasts envisioned, data requirements, and forecast timeframes for the infrastructure of the future.

Potential R&D areas include

- Develop new database structures and tools that support a combination of equipment information and system performance information. They must include equipment design data, system topologies (updated in real-time), system electrical data for simulation and state estimation, geographical data, and real-time performance information. Distributed database structures that allow processing at many different levels are needed. Methods for automatically maintaining these databases and verifying their accuracy are needed.
- Demonstrate fast simulation and modeling tools (as being developed under different project, i.e. FSM) to facilitate continuous state estimation so that the system performance is always completely characterized based on input from

limited monitoring information. This state estimation must incorporate knowledge of the end use system characteristics as well as the supply system.

- Develop and demonstrate intelligent systems (neural networks, rules-based systems, fuzzy logic systems, etc.) that can process performance information to identify equipment and system problems automatically and recommend remedial actions.
- Develop systems for coordinated response to equipment and system problems identified by the intelligent systems. The coordinated response will take advantage of advanced communications architecture and will include end user system response options, distributed resources integration, and specific response requirements for the supply system.
- Develop industry-wide database systems and organizations to assess common equipment performance issues, failure mechanisms, and new equipment opportunities. Identify solutions and improvements on a timely basis to the benefit of the entire industry and society.

Technology Area 5. Integration of Energy Storage

This technology area addresses critical action items 4, 5, and 7. Unlike most other commodities, electricity isn't bottled or boxed, and can't be placed in a warehouse in its "raw" form. Electricity is produced instantaneously in response to consumer demand, and storing it is difficult. Existing storage methods are based on converting and storing the electricity in another form—mechanical stored energy, chemical stored energy, or direct-current energy. Examples include pumped hydro, flywheel, battery, capacitor, and superconducting magnetic energy storage (SMES) plants. Even though such storage methods are theoretically available today, only about 2.5% of the generation capacity in North America currently uses storage plants. This is because most storage options (except pumped hydro and compressed air) are relatively unproven. In addition, their value proposition is complex and poorly understood, and the uncertainty of changing regulations makes storage options too risky for most investors.

Energy storage technologies offer potential solutions to several challenges currently facing the electric power industry, including the needs to strengthen the power delivery infrastructure, increase asset utilization, provide high-quality power, facilitate provision of a range of

Table 3-3. Forecast Capabilities of the Electric Infrastructure of the Future

FUNCTION	FORECAST OBJECTIVE	DATA REQUIRED	TIMEFRAME
Asset Management	End-of-life and remaining-life assessments for asset groups (i.e., transformers, breakers, etc.) at the level of asset family, make, model, application, and age (FMMAA) Early detection of changes in failure mechanisms for FMMAA	Company- and industry-wide asset performance data, including maintenance and operation history	Years
Maintenance Management	End-of-life estimate for individual pieces of equipment Early detection of changes in individual equipment performance	Real-time measured parameters of individual assets and operating conditions Individual asset-specific performance data, with maintenance and operation history FMMAA company- and industry-wide	Weeks and months
System Operations	Early detection of deterioration of individual assets and critical components that could lead to operational disruption and might not be addressed through a regular maintenance program Asset failure anticipation to provide time for preventive operational actions with minimum impact on system performance	Real-time monitoring of critical parameters of specific equipment Individual asset-specific performance data, with maintenance and operation history	Hours and days

services to consumers, and provide consumers lower-cost, higher-SQRA power. However, various impediments stand in the way of widespread realization of these benefits. A key challenge for distributed generation and storage technologies, for example, is to develop ways to seamlessly integrate these devices into the power system, and then dispatch them so that they can contribute to overall reliability and power quality.

The new electric infrastructure must be designed to accommodate a stable and open energy market, and to benefit and engage stakeholders along the entire energy value chain.

This technology area seeks to develop tools and technologies to accelerate the integration of distributed energy storage systems to power the digital economy and better exploit the strategic value of energy in society. The initial challenge is to identify ways of effectively demonstrating the value proposition of these systems in the electric infrastructure of the future.

Potential R&D areas include

- Establishing the value proposition for storage options. This would include a detailed assessment of options, including costs and benefits of existing storage technologies; developing software capable of estimating future costs associated with large-scale production of novel technologies; and developing models capable of simulating future regulatory scenarios as well as the benefits of implementing energy storage programs.
- Evaluating storage technologies to validate reliability and performance. As an example, the cost of modular, advanced battery storage systems has dropped dramatically over the last few years. Yet transmission, distribution, renewable, and consumer application demonstrations are needed to prove the reliability of their performance and life characteristics, as well as their real world costs at 100-kW and 100-MW scale levels appropriate to a wide variety of applications. Small flywheels (up to 300 kW for one hour) have been commercially successful, but further work is needed to develop higher-energy wheels. High-voltage utility applications of supercapacitors—electrical storage devices that are ideal for large power storage over short discharge times—remain in the development and early testing phase. Current commercial applications are less than 100 kW for less than one second. Advances in high-temperature superconductors make SMES technology—which stores direct current in a doughnut-shaped, electromagnetic coil of superconducting wire—potentially attractive. However, further advances are needed for this technology to become cost-effective. It also needs to be made cheaper and smaller, so it will fit into existing infrastructure footprints.

Conclusion

The CEIDS Program is a collaborative effort led by CEIDS staff and members of the CEIDS Steering Committee with support from the Public Advisory Group. Staff from E2I and EPRI manages CEIDS. Together, they have:

- Created a vision for the electric infrastructure of the future,
- Determined critical science and technology action items for achieving this vision,
- Recommended technology areas to address critical action items,
- Developed a process for identifying R&D projects within the technology areas, and
- Created an initial portfolio of R&D projects.

Figure 3-4 illustrates the launching and execution timeline for CEIDS work.

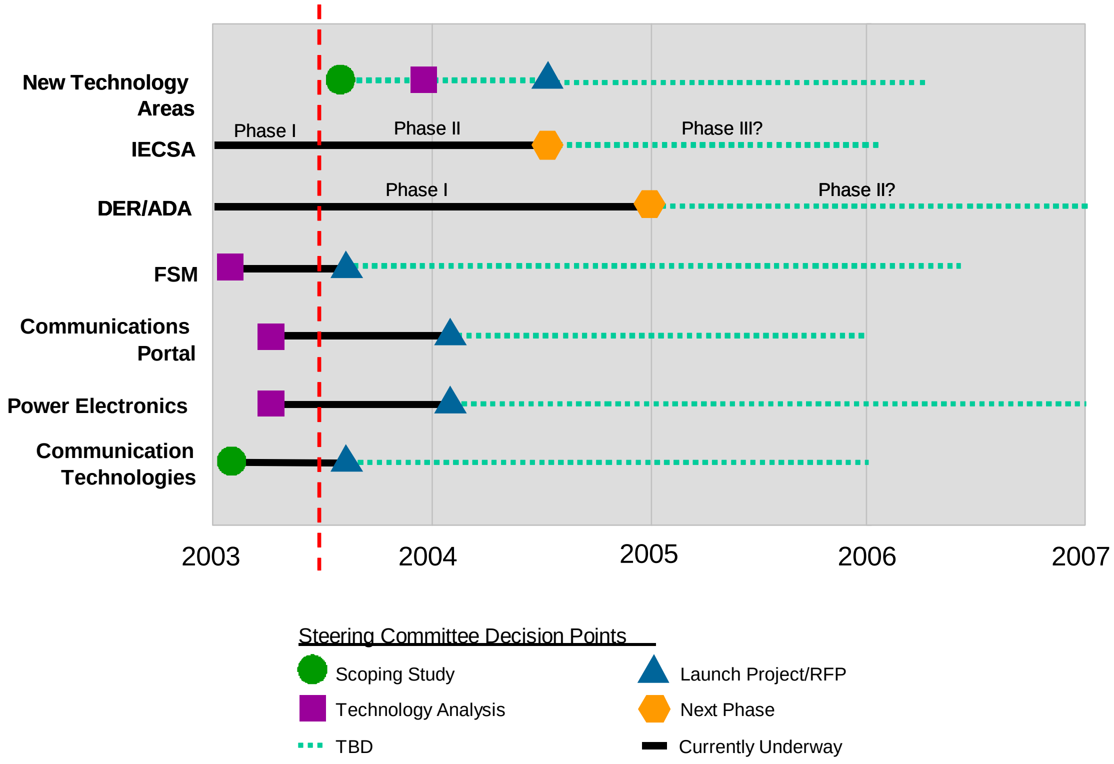

Figure 3-4. Phased Project Launch and Execution Timeline

A

Appendix A: Today's Electric Power System

Our existing electric power grid is under tremendous strain. It is aging, constrained, underutilized, and inadequate to satisfy the growing needs of consumers and meet expectations for tomorrow's economy. It has become a patchwork of technologies and systems not really made to share data or applications.

Indeed, a sharp decline in critical infrastructure investment over the last decade has left portions of the system vulnerable to power quality-related service interruptions, market dislocations, and external threats, including natural disasters, terrorist and cyber attacks, and simultaneous threats. The events of September 11, 2001, significantly impacted the energy sector, revealing vulnerabilities that must be addressed. These include public concerns about sharing information given the threat of cyber attacks, operations exposures, and cost recovery and rate regulations for unanticipated energy security costs.

In addition to these issues, microprocessor-based technologies have radically altered the nature of electric load, making electricity demand incompatible with a power system created to meet the needs of an analog economy. The obsolescence of this industrial-era system puts the stability of our "always connected" digital society in serious jeopardy—and it has led to losses in the tens of billions of dollars each year.

Consumers these days are also installing increasing numbers of distributed energy resource (DER) systems, which need to be managed as dynamic participants in a power delivery system. Meeting the energy requirements of society in the future will require the use of a combination of advanced technologies—from generating devices such as conventional power plants, fuel cells, and microturbines, to interface devices, end-use equipment, and circuit boards.

Transmission Systems

Today's transmission systems present serious challenges to utilities. For one, the original transmission network was designed by vertically integrated utilities for centralized control. The planners never envisioned it in a competitive environment with numerous players and large-scale, wholesale power trading along the grid.

Compounding this problem is an increase in electricity demand of nearly 30% over the last decade, while the transmission network grew by only 15%. In the same period, wholesale transactions increased by 400%. During the next decade, demand is expected to grow by 20%, while planned transmission system growth is only 3.5%.

This soft outlook is due to the considerable barriers that utilities face when siting new transmission assets, notably environmental and societal concerns. They also must contend with an uncertain return on investment and inadequate incentives for continued investments in network upgrades.

As a result of increased loads, curtailed investment in the grid, and industry restructuring, bottlenecks are occurring along transmission paths throughout the United States. A 2001 FERC study puts the costs of individual grid constraints at between $5 million and $50 million, and notes that in one instance in eastern New York, the cost was more than $700 million.[2]

Inadequate transmission capacity costs money in other ways. With fewer generators able to access the market at critical times, the remaining generators may be able to exercise market power to drive up prices. Smaller, less-stable markets can lead to price volatility, making consumers more susceptible to price spikes, or forcing them to pay higher-risk premiums to insure against spikes.

Distribution Systems

Most of today's distribution systems are based on designs that originated in the 1950s. While these systems were adequate to serve the analog loads that predominated during the last half-century, the demands placed on distribution systems have increased dramatically in the last decade. Now, with consumers expecting greater reliability and higher-quality power, the leading challenge for distribution system owners/operators is to balance consumer needs with the cost of upgrading their systems, while also addressing regulatory and economic pressures to reduce operating costs.

Although many may argue whether industry restructuring will ever achieve its goals for expanded consumer choice and lower costs for electricity, it continues to have a tremendous impact on distribution utilities. Many have begun expanding their service offerings to include telecommunications, natural gas, and water, while others have turned to outsourcing traditional functions, such as customer service and billing, and offering premium power and other retail services to enhance revenues and build consumer loyalty.

Enormous opportunities exist for integrating the electric distribution system with the communications infrastructure. The convergence of technologies and capabilities will provide consumers with access to a variety of electricity-related, valued-added services. Real-time access to energy markets, for example, will allow consumers to better control their energy costs and utilization.

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[2] FERC, 2001, Electric Transmission Constraint Study, Division of Market Development.

DER has the potential to bring about the most significant changes to the distribution system in the past 50 years. Hailed as the technology with the greatest promise to improve distribution system reliability and security, DER also presents significant challenges. Chief among these are lack of control systems, lack of power quality standards, high costs, and grid integration complexities. Presently, each DER installation must be custom-engineered, which raises costs and reduces flexibility. A standard method needs to be developed for connection and synchronous operation of distributed generators with utility and consumer systems. Communication protocols and devices also must be developed and standardized to enable dispatch and control of DER. Additionally, new technologies will be required to effectively limit fault currents from numerous DER installations.

End-Use Technologies

With more than 12 billion microprocessors currently in use—a number that is expected to grow dramatically in the near future—utilities, industry, and government agencies must find ways to ensure the integration and compatibility of current and next-generation end-use devices.

Power quality problems are already costing industry billions of dollars each year. A recent EPRI estimate puts the annual figure at between $118 billion and $188 billion. Outages due to the aging infrastructure and operating constraints are also costing industry. A 1998 Cal ISO study estimated that an eight-hour outage costs consumers between $95 and $200 per kW of lost load.[3] According to a 1998 Sandia National Laboratories study, voltage sags cost industry $114 billion annually.

As a result, a growing number of consumers are installing power conditioning and energy storage systems and devices. Total sales for power conditioning, energy storage, and distributed energy resources were between $5.3 billion and $6.5 billion in 2000.[4, 5, 6] By 2005, sales of fuel cells and microturbines are projected to be $900 million and $500 million, respectively.[7] Overall sales for power quality equipment are expected to grow by 11% per year, to $7.1 billion, by 2006.[8]

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3 Cal ISO 1998 Transmission Reliability Report.

4 Poised for Growth: DG & Ride-Through Power, by Nathan Andrew, Power Quality, January 1, 2002.

5 Renewable Energy Annual 2000, U.S. Department of Energy, Energy Information Association, March 2001.

6 Business Communications Company, Inc., 25 Van Zant Street, Norwalk, CT 06855; Telephone: (203) 853-4266, ext. 309; Email: publisher@bccresearch.com; RE-083R–The Power Quality Equipment and Service Market: A 21st Century Growing Industry, October 2001.

7 Op.cit. 3

8 Op.cit. 5

B Appendix B: Key Attributes of the Infrastructure of the Future

The roles and requirements of stakeholder groups point to the pressing need to enhance the functionalities of today's electric power system. The least-cost approach to meeting the major needs of stakeholders is to create an intelligent system that will coordinate generation, transmission, distribution operations, load management, and customer response as a unified, market-driven entity.

To gather input and gain consensus on the key attributes of the new infrastructure, CEIDS staff conducted extensive interviews and meetings of the CEIDS Steering Committee and Public Advisory Group. Key attributes were determined to fall into four categories: 1) security, quality, reliability, and availability; 2) economic efficiency and growth; 3) asset performance and control; and 4) environmental stewardship.

Security, Quality, Reliability, and Availability

Tomorrow's electric delivery infrastructure will include a self-healing transmission and distribution (T&D) system that is capable of automatically anticipating and responding to disturbances, while continually optimizing its own performance. This electronically controlled, "intelligent" grid will provide the network capability needed for integrating distributed energy resources (DER), increasing capacity, and giving the grid the strength and resilience to dynamically reconfigure itself in the event of a natural disaster, terrorist or cyber attack, or simultaneous threats.

In addition to providing improved monitoring and control of the existing electric system, the new infrastructure will include powerful predictive modeling tools that integrate market, policy, and risk analysis and enable planners to better determine and quantify the effects of various market designs and policy changes on power system reliability. The creation of an open communication architecture to sustain the intelligent grid will ultimately transform the physical operation of the entire energy chain into a web that links end-use devices through an "information/energy portal."

Economic Efficiency and Growth

The electronically controlled, intelligent grid will provide low-cost, high-value energy service. It will offer consumers greater control over energy usage and expenses, and will drive economic growth. By linking stakeholders through an open market structure, it also promises to facilitate development of new products and services by energy companies.

The power delivery infrastructure will provide the speed, reliability, and security needed to support the digital economy and the pace and complexity of competitive, open markets. In the new infrastructure, technologies of supply (generation and T&D) will be superseded by intelligent technologies of demand, which will enable ever-broader consumer choice. Because more stakeholders will be able to actively participate in infrastructure operations, new and expanded technology applications will be developed to respond to the increased pressures for managing system reliability.

Asset Performance and Control

The intelligent grid will optimize use of the existing electric power system and resources, providing capacity to accommodate new demands and help stretch the useful life of assets, thus freeing up capital for investment in innovation and advanced technologies. The infrastructure of the future will take advantage of emerging technologies with enormous potential to reduce the complexity, size, weight, and costs of controllers, energy storage, and other devices.

Transmission lines will be transformed from passive to active elements used to relieve transmission bottlenecks. Standardized communication protocols, equipment, operations, maintenance, and designs that support modernization of the electric system will help to enhance the performance of existing digital devices and enable the seamless connection of next-generation devices with the grid.

By exploiting the convergence of telecommunications with energy technologies, new value will be created within the electricity industry. Electric utilities will be able to expand the portfolio of their business services to include communications; Internet access; real-time, on-line monitoring; and other associated value-added services.

Environmental Stewardship

In the new electric infrastructure, the key will be to move from "punishing the polluters" to rewarding rapid progress toward clean energy by stimulating the development, implementation, and use of clean distributed resources, clean-fuel technologies, and highly efficient combined heat and power technologies. The electricity industry will have a leadership opportunity to use public funding and public/private expertise to respond to increasingly stringent energy and environmental policies, and to help accelerate the transition to clean energy. It will also maximize the use of existing assets to limit the environmental impacts of new construction.

Demand-side management programs will re-emerge, this time as a competitive business opportunity, not a regulatory mandate. The focus on industrial ecology will emphasize new environmentally benign approaches to production and transportation, creating opportunities for increasing sales that more than compensate for the loss in kWh sales from increased efficiency.

New businesses will arise, initially dealing with pollution control through market mechanisms, but ultimately incorporating ecological asset management as a tool for balancing ecosystem values against emissions.

C Appendix C: Functional Gap Descriptions

1. ***CRITICAL ACTION ITEM:* Need communications infrastructure/open architecture interface**

   A high-level architecture for exchanging data and information among electric enterprise constituents—consumers, distribution companies, independent system operators, energy service providers, etc.—is critical to building the electric delivery infrastructure of the future. It lays the foundation for enabling development of an intelligent grid, supporting modernization of the existing power system, and facilitating the creation and delivery of new products and services.

2. ***CRITICAL ACTION ITEM:* Need fast and accurate computational methods to model and analyze the electric infrastructure**

   Computer models are needed to convert data taken from many points on the transmission and distribution (T&D) system into information that can be used to improve system performance. Additionally, models providing faster-than-real-time, look-ahead simulations are required to anticipate and prevent disturbances. These models are key components of the intelligent grid, which will facilitate a better understanding of and shorter response times to outages, constraints, attacks, and other stresses on the system. By integrating market, policy, and risk analysis into system models, energy providers will be able to quantify and predict effects on system security, quality, reliability, and availability (SQRA).

3. ***CRITICAL ACTION ITEM:* Need to enable distributed energy resources (DER) to play a role in energy markets**

   Easier, faster, simpler ways to integrate DER with the electric infrastructure are required. Initial focus will be on communications integration. DER integration holds the promise of increased energy capacity, system support, back-up power, and power quality benefits. Decreasing transaction costs through seamless integration of communications and devices with the underlying infrastructure will make these benefits more widely available.

4. ***CRITICAL ACTION ITEM:* Need clear understanding of infrastructure SQRA characteristics and requirements**

   The first step to meeting future energy needs is to assess the optimum balance of load immunity and power system performance required to meet the needs of precision electricity consumers. This involves identifying the baseline target immunity levels and power system compatibility issues of original equipment manufacturers and others in the design of next-generation digital equipment. It also includes providing standards for distribution system performance and quality, reliability, and availability.

5. ***CRITICAL ACTION ITEM:* Need effective forecasting tools for supply, load, and market data**

   Improving asset utilization, forecasting, and planning requires sophisticated tools capable of performing dynamic "what-if" analyses for large-region power systems, from both operations and planning points of view.

6. ***CRITICAL ACTION ITEM:* Need cost-effective technologies to support automation, real-time monitoring, and control of the distribution system**

   Defining the value of advanced distribution automation will create a strong incentive for energy enterprises to adopt advanced technologies that increase the SQRA of the distribution system and reduce associated operation and maintenance costs. Use of advanced technologies—including smart sectionalizing, switched capacitors, sag correctors, voltage regulators, multifunction distributed generation, load management devices, new sensors, and power-electronic controls—will enable the electric infrastructure to evolve into a complex network of interconnected, interactive devices.

7. **Need to increase capacity of existing rights-of-way**

   It is increasingly difficult to site new rights-of-way in today's society. By increasing throughput capacity on existing rights-of-way (T&D) through adoption of new hardware, software, and operational strategies, energy enterprises can meet increasing demand for electric services, while minimizing environmental impacts of new construction.

8. **Lack of understanding of electromagnetic incompatibility (EMI) as major issue in telecommunications/energy applications**

   Increased understanding of the potential impact of EMI on the electric and communications infrastructures is required to ensure compatibility and integration of the two systems.

9. **Insufficient regional transmission and supply planning and operations**

   Sophisticated planning tools to model uncertainties—such as location, size, and timing of new power plants; interregional power transfer patterns; and on-line congestion monitoring—are needed to expand and enhance the North American transmission grid and improve coordination of transmission planning and operations.

10. ***CRITICAL ACTION ITEM:* Need to quickly anticipate, detect, locate, and identify disruptive events and attacks on the infrastructure**

    Advanced sensors, communication infrastructures, intelligent applications, and control technologies are required to detect, locate, and characterize problem conditions on the system. These applications will be used to identify problems from the generator to the end user, will accelerate response and recovery times, and will result in overall system reliability and productivity management.

11. ***CRITICAL ACTION ITEM:* Need to quickly and automatically implement corrective actions in response to events**

    Advanced intelligent systems that use information from monitoring and simulations will identify the optimum response to problem conditions, including evaluation of options on the supply system integrated with the end-use systems.

12. **Need cost-effective technologies for energy storage**

    There is a need to reduce the complexity, size, weight, and costs of energy storage and controllers, and to develop a better understanding of how energy storage can be used to add value to the electricity infrastructure. This must be achieved by optimizing load factors, increasing reliability, reducing costs, and integrating intermittent renewable energy devices at the system level. It will also require improving power quality, providing lower-cost back-up and ride-through capabilities, and reducing environmental impacts of chemical batteries at the consumer level.

13. **Need to clearly define system security requirements and develop methods to secure communications**

    Concerns about terrorist and cyber attacks on the electric infrastructure have increased. As communications become more integrated into the system, the potential for damage from such attacks increases. To reduce system vulnerability, a secure communications infrastructure must be defined and established, along with requirements for equipment design, communications, and operating procedures.

14.*CRITICAL ACTION ITEM:* **Need a benchmark for SQRA of the existing electric power system**

Information on current SQRA levels is inadequate, indicating a need for research and analysis to provide a baseline for future standards. This functional gap is critical to establishing a baseline for informing all future activities.

15.**Need effective end-use and distribution system SQRA tools to select the optimal mix of solutions for given conditions**

By developing the analytical tools and hardware needed to provide the appropriate level of SQRA required by consumers, energy enterprises can minimize the costs of outages, disruptions, and transitory events to consumers.

16.*CRITICAL ACTION ITEM:* **Too few high-value, cost-effective products and services to help consumers and companies control and direct energy use and interactively determine the quality and reliability of service**

New tools and technologies that facilitate offerings of new products and services will allow consumers to better control their energy use in response to internal needs and external factors. This will help consumers save money and improve production, while reducing peak demands on system operators, overall growth of energy demand, and associated environmental impacts. Technologies for controlling energy use will also facilitate SQRA compatibility at the end-use level.

17.**Need to optimize the balance between maintenance and reliability and the decision to repair or replace an asset**

There is a pressing need to develop tools to inform and guide decisions on whether and when to replace or repair existing equipment, and to determine the amount of maintenance required to achieve a certain level of reliability. To bridge the gap between today's system and the infrastructure of the future, the existing infrastructure will need to be replaced by a newer and more advanced infrastructure, but this will not happen all at once. These tools will help minimize disruptions from rebuilding the system and manage the cost and environmental impacts of system upgrades. They will also help maximize the SQRA, life, and performance of the existing and new systems, while reducing operation and maintenance expenses.

18.**Need low-cost method for undergrounding T&D lines**

The increasing demand to underground T&D lines to reduce the visual and environmental impacts of overhead lines has created a need for innovative and lower-cost methods for underground installations.

19. Need to manage environmental impact of sensitive materials in equipment

Much of the grid expansion will be aboveground, and utilities must take into consideration the growing public opposition and environmental pressures regarding use of environmentally sensitive materials, such as SF6, oil, and lead. To continue using these materials, it will be necessary to develop effective management processes to resolve the energy-environment conflict.

D Appendix D: Program Development Decision-Making Process

During the first year, the CEIDS staff has worked closely with the members of the CEIDS Steering Committee and Public Advisory Group, conducting meetings, mini-workshops, Web conferences, and on-line exercises to lay the foundation for the CEIDS program. Together, they have made several vital decisions regarding the vision, strategy, and scope of CEIDS. They have 1) assessed stakeholder needs, 2) identified key attributes of the future electric infrastructure, 3) developed vision and mission statements, 4) selected and funded the core IECSA project, and 5) conducted gap analysis.

The CEIDS staff has compiled the results of these activities to develop critical action items for the program, and to recommend five technology areas for further study. Findings and recommendations are embodied in this Master Plan. Following is a description of the steps that have been taken to define the groundbreaking CEIDS program.

Assessing Stakeholder Needs

Between December 2002 and March 2003, the CEIDS staff conducted a series of brainstorming sessions with Steering Committee and Public Advisory Group members to determine the needs of the five major stakeholders in the power delivery infrastructure of the future: consumers, utilities and service companies, technology transformers, society, and regulatory bodies. The staff gathered pivotal input from the CEIDS partners on the various stakeholder points of view. They also reviewed lists provided by outside organizations, including the Blue Ribbon Panel of the Consumer Energy Council of America. Results of this stakeholder needs assessment are detailed in Appendix E.

Developing Vision and Mission Statements

CEIDS has had vision and mission statements in place since the inception of the program in 2001. These statements were reexamined, however, after the December 2002 Steering Committee meeting for the following reasons: new partners had joined CEIDS; time had elapsed since the last review; and several projects had been selected and launched, giving the Committee more experience in evaluating the vision and mission of the program. The reevaluation process was a simple one. After discussion at the December 2002 Steering Committee meeting, the CEIDS staff proposed revised vision and mission statements. They posted these statements on Linkify, a Web-based collaboration tool, and Committee members responded with their comments over the Web. The CEIDS staff and Steering Committee members discussed further revisions at each of three mini-workshops in the first quarter of 2003. Public Advisory Group members also provided comments at their meeting in February 2003. CEIDS staff edited the statements to reflect all of this input, and the Steering Committee approved the current vision and mission statements at its March 2003 meeting.

Identifying Key Attributes of the Future Infrastructure

The CEIDS staff originally derived the key attributes of the infrastructure of the future from the stakeholder needs identified in Appendix E. Then, using a process similar to the one just described, the staff and CEIDS partners worked together to characterize the key attributes, in parallel with the refinements to the vision and mission statements during the first quarter of 2003. The CEIDS staff created a straw proposal, which was reviewed and debated by the Steering Committee and Public Advisory Group members. The agreed-upon attributes were grouped under the following four headings, and then used to develop, analyze, and prioritize gaps.

1. *Increases Security and Reliability*
    - Enhances security and reduces the grid's vulnerability to attack
    - Provides reliable, high-quality power
    - Comprehensively monitors and quickly responds to changes in the grid or power delivery markets
    - Facilitates distributed energy resource integration with the grid
2. *Promotes Economic Efficiency and Growth*
    - Facilitates development of new products and services
    - Offers consumers greater control over energy usage and expenses
    - Drives economic development
3. *Enhances Asset Performance and Control*
    - Optimizes use of the existing electric power system and resources, while providing sufficient capacity to accommodate new demands
    - Takes advantage of technological advances
    - Exploits the convergence of telecommunications with energy technologies
    - Achieves optimization through automation
    - Standardizes communication protocols, equipment, operations, maintenance, and design

4. *Minimizes Environmental Impacts*

    - Limits environmental and societal impacts of new construction by maximizing use of existing assets
    - Promotes the adoption of energy-efficient equipment and systems
    - Takes advantage of clean distributed resources; clean-fuel technologies; and highly efficient, combined heat and power technologies

Conducting Gap Analysis

Continuing the same process, the CEIDS staff and partners identified 19 functional gaps in the existing power system between December 2002 and April 2003. The staff then assessed these gaps according to their relevance to the key attributes of the future infrastructure. Table D-1 shows the results of this process.

Table D-1. Functional Gaps Mapped to Attributes of the Infrastructure of the Future

FUNCTIONAL GAPS*	ATTRIBUTES			
	1 SQRA	2 Econ	3 Asset	4 Environ
1. Need communications infrastructure/open architecture interface	X	X	X	X
2. Need fast and accurate computational methods to model and analyze the electric infrastructure	X	X	X	X
3. Need to enable distributed energy resources to play a role in energy markets	X	X	X	
4. Need clear understanding of infrastructure security, quality, reliability, and availability characteristics and requirements	X		X	
5. Need effective forecasting tools for supply, load, and market data	X	X	X	
6. Need cost-effective technologies to support automation, real-time monitoring, and control of the distribution system	X		X	
7. Need to increase capacity of existing rights-of-way			X	X
8. Lack of understanding of electromagnetic incompatibility as a major issue in telecommunications/energy applications	X	X		
9. Insufficient regional transmission and supply planning and operations			X	
10. Need to quickly anticipate, detect, locate, and identify disruptive events and attacks on the infrastructure	X		X	
11. Need to quickly and automatically implement corrective actions in response to events	X		X	
12. Need cost-effective technologies for energy storage	X		X	X
13. Need to clearly define system security requirements and develop methods to secure communications	X			
14. Need a benchmark for security, quality, reliability, and availability of the existing electric power system	X			
15. Need effective end-use and distribution system security, quality, reliability, and availability tools to select the optimal mix of solutions for given conditions	X			
16. Too few high-value, cost-effective products and services to help consumers and companies control and direct energy use		X	X	X
17. Need to optimize the balance between maintenance and reliability and the decision to repair or replace an asset			X	
18. Need low-cost method for undergrounding transmission and distribution lines				X
19. Need to manage environmental impacts of sensitive materials in equipment				X

*The numbers assigned to each gap serve as reference markers to facilitate discussion and do not indicate priority ranking.

Determining Critical Action Items

Once these 19 functional gaps were established, the CEIDS staff and partners worked together to explore the links between them. Links can be categorized into three types of relationships:

- Causal or Sequential: Where one gap needs to be addressed before another, or where solving one helps eliminate another gap.
- Horizontal: Where gaps share the same root. That is, multiple gaps represent different problems within the same technology, industry, or capability space.
- Vertical: Where gaps reflect the same need across several diverse functional areas.

Incorporating these links allowed the CEIDS staff and partners to determine which gaps were more critical than the others to building the new electric infrastructure. Functional gaps 1, 2, 4, 6, 10, 11, and 16 originally emerged as the ones that must be bridged. However, during the June 2003 Steering Committee meetings and web conferences, functional gaps 3 and 5 were added to the list. At the same time, gaps 6, 10, and 11 were consolidated, bringing the final number selected as critical to seven. In practice, these seven functional gaps became critical action items.

Identifying Technology Areas for Study

The CEIDS staff began selecting technology solutions that would address the seven critical action items. The EPRI Power Delivery and Markets (PDM) Bridge Plan has already identified 57 potential technology solutions, and CEIDS staff has expanded that list by four. Appendix F contains a complete list of the 61 potential technology solutions.

Each solution complements EPRI R&D work currently underway by PDM; however, some projects address critical action items better than others. By applying screening criteria to map only solutions that directly address at least one item, the CEIDS staff was able to cut the list nearly in half. Table D-2 illustrates the results of this mapping. (Please note that this table reflects mapping to the seven original gaps as selected by CEIDS staff. No additional mapping was performed for the two new gaps selected by the Steering Committee in June 2003.)

Table D-2. Technology Solutions Addressing CEIDS Critical Action Items

CRITICAL ACTION ITEMS						
Gap #1	Gap #2	Gap #4	Gap #6	Gap #10	Gap #11	Gap #16
Technology Solutions 2, 6, 17, 19, 35, 52, 58	Technology Solutions 4, 10, 20	Technology Solutions 15, 24, 34, 59, 60, 61	Technology Solutions 2, 6, 8, 9, 10, 11, 12, 14, 22, 23, 26, 27, 31, 37	Technology Solutions 2, 6, 10, 15, 16, 19, 21, 22, 24, 25	Technology Solutions 6, 7, 8, 9, 10, 12, 16, 19, 20, 21, 22, 23, 26, 31, 37	Technology Solutions 11, 12, 22, 23, 24, 25, 26, 27, 30, 31, 35, 37, 48

Having selected 33 unique technology solutions—with several addressing more than one functional gap—the CEIDS staff applied a second screen to further narrow the field to solutions that most effectively support the critical action items. Whereas the first screen was a "Yes/No" exercise to select only those solutions that directly addressed critical action items, the second screen ranked the remaining solutions against one another by assigning numerical values. Table D-3 lists the six selection criteria.

Table D-3. Technology Area Selection Criteria

SELECTION CRITERIA
1. Addresses at least one functional gap
2. Supports the key attributes of the electric infrastructure of the future
3. Enables other technology areas in the CEIDS portfolio
4. Is essential for achieving the vision of the future
5. Contributes to a balanced CEIDS portfolio
6. Is not being adequately addressed by another entity

The CEIDS staff began this segment of screening using a scoring system of 1 to 4 for each of the six criteria. However, they discovered that, in most cases, Criterion #6 was difficult to evaluate at this point in the R&D process and was better left for scoping study decision-making. Similarly, they found that Criterion #5 would be difficult to judge until the CEIDS portfolio consisted of more projects.

The screening exercise validated the importance of the critical action items and the timing of technology development efforts. Criteria #1 and #3 were found to be the most helpful. Consequently, the solutions that would bridge gaps and propel CEIDS down the critical path more rapidly were considered more important than those that could not. Solutions that needed to be executed in the near-term to facilitate other mid- and longer-term technology development efforts were also given priority. Table D-4 lists the resulting recommendations—the top-priority technology areas generated by the screening process.

Table D-4. Recommended Technology Areas

TOP-PRIORITY TECHNOLOGY AREAS
1. Infrastructure Quality and Reliability
2. Monitoring, Communications, Command, and Control
3. Intelligent Network Agents, Information Processing, and Visualization
4. Dynamic Risk and Reliability Management
5. Integration of Energy Storage

For the R&D planning process to begin, the technologies that can help CEIDS realize its vision must be selected. These will be the technologies that bridge functional gaps and address critical action items. Of key consideration in this selection process are CEIDS' ties to the EPRI Electricity Technology Roadmap Initiative and the PDM Bridge Plan. The "Difficult Challenges" identified in the Roadmap relate directly to development of a new electric infrastructure. Table D-5 lists the Difficult Challenges that CEIDS shares with PDM.

Table D-5. Difficult Challenges Shared by CEIDS and EPRI Power Delivery and Markets

NUMBER	DIFFICULT CHALLENGE (DC) DESCRIPTION
DC1	Increasing transmission capacity, grid, and stability
DC2	Improving power quality and reliability
DC3	Increasing robustness, resilience, and security of the energy infrastructure
DC4	Exploiting the strategic value of energy in society
DC6	Creating an infrastructure for a digital society

Incorporating this valuable output will ensure that CEIDS is not "reinventing the wheel" as it focuses on changes that can begin to be made over the next five years. These changes will be done in conjunction with the other EPRI planning processes, while involving a more diverse set of stakeholders, setting a more specific scope of development, and targeting a different timeframe than other EPRI programs. CEIDS efforts will complement and build on the other programs.

Developing Demonstration and Deployment Strategies

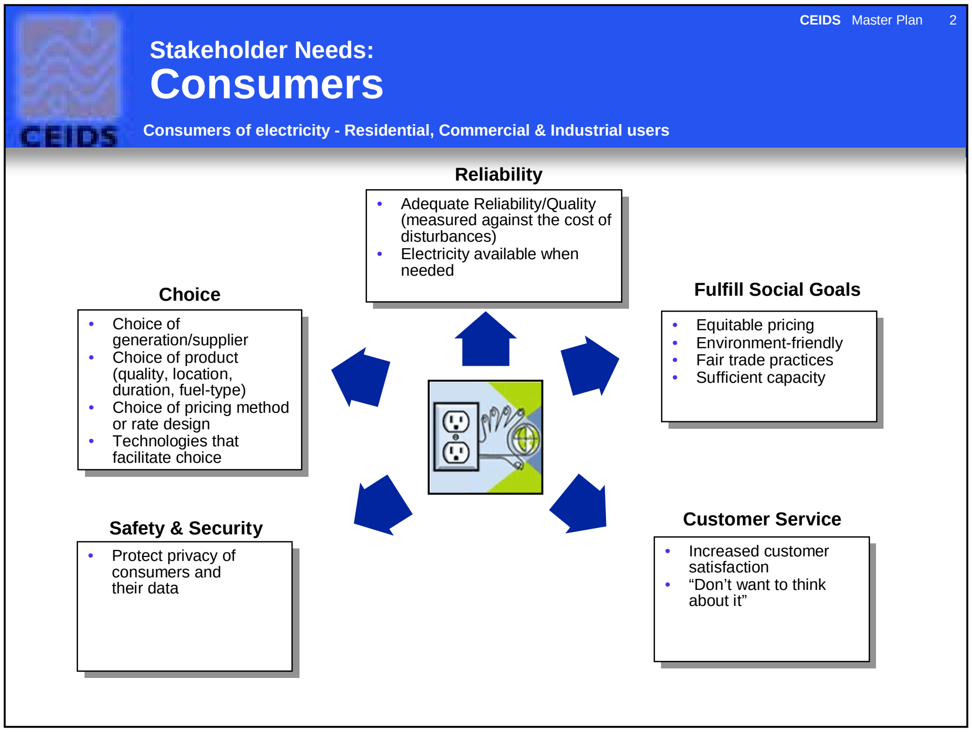
The CEIDS staff and partners provide a powerful team for identifying and coordinating the research to develop the technologies that will facilitate a migration to the integrated infrastructure of the future. Demonstrations will be key to this effort. They will not only illustrate the value of the technologies, but will provide incentives for other stakeholders to share the vision and join in technology development.

As technology areas are identified for detailed analysis and actual development projects, finding opportunities for demonstration and validation of the technologies will be crucial to the overall research plan. The CEIDS partners will play an important role in identifying demonstration and deployment opportunities.

Appendix E: Stakeholder Needs

Consumers of the future will have increasingly sophisticated energy requirements. They will expect greater choice and control of energy use, and many will operate their own distributed generators. The new electric infrastructure must be designed to accommodate a stable and open energy market, and to benefit and engage stakeholders along the entire energy value chain. Five major stakeholders directly affect or are affected by the power delivery system.

First are the consumers—the residential, commercial, and industrial end users of electricity. Reliability is their primary need; others include choice, control, social goals, safety and security, customer service, and equitable pricing. In terms of choice, consumers desire options for generation and supplier, based on quality, location, duration, fuel type, and other factors. The energy market of the future should be able to segment and differentiate consumer tastes and satisfy them. For example, fuel type is a major choice for residential users, while location of power, quality, and ability to increase consumption during peak hours are key needs for large industrial users.



CEIDS Master Plan 2

Stakeholder Needs:

Consumers

Consumers of electricity - Residential, Commercial & Industrial users

Reliability
- Adequate Reliability/Quality (measured against the cost of disturbances)
- Electricity available when needed

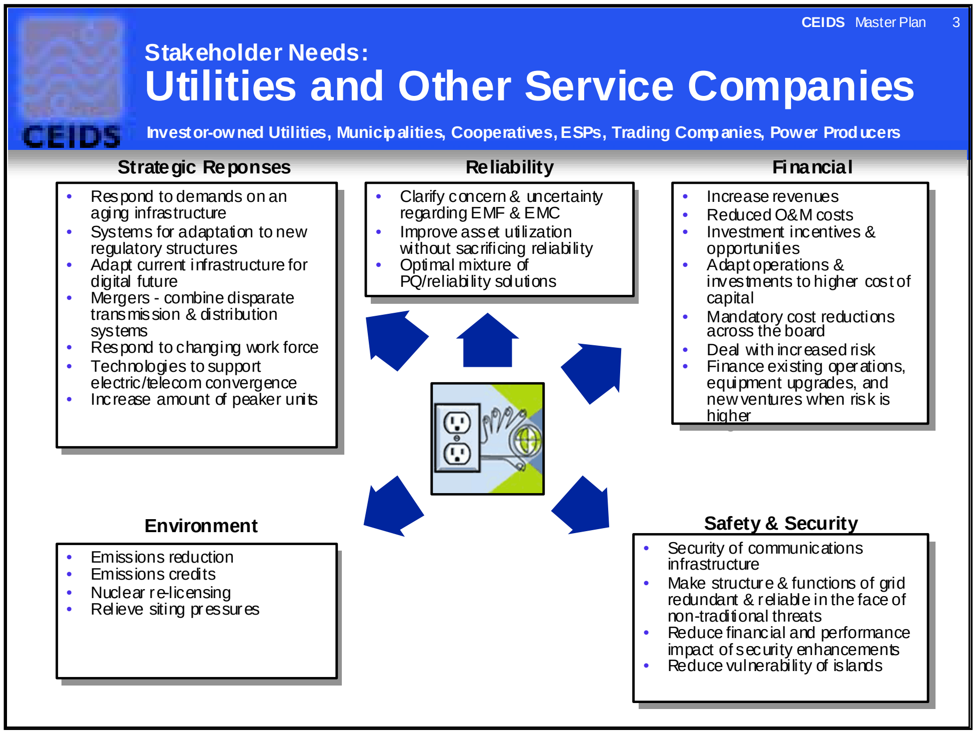
Choice
- Choice of generation/supplier
- Choice of product (quality, location, duration, fuel-type)
- Choice of pricing method or rate design
- Technologies that facilitate choice

Fulfill Social Goals
- Equitable pricing
- Environment-friendly
- Fair trade practices
- Sufficient capacity

Safety & Security
- Protect privacy of consumers and their data

Customer Service
- Increased customer satisfaction
- “Don’t want to think about it”

Second are utilities and service companies, which face the biggest hurdles in responding to the needs of the other stakeholders. Challenges include upgrading the aging distribution system, adapting to regulatory and market changes, responding to society's use of complex digital devices, developing environmentally friendly components and materials, shifting to performance-based rates or other means to increase reliability and optimize returns on assets, mitigating operating risks, and ensuring continued security of the infrastructure. Utilities and service companies also need good information to work with regulators to create proper market incentives.



CEIDS Master Plan 3

Stakeholder Needs:

Utilities and Other Service Companies

Investor-owned Utilities, Municipalities, Cooperatives, ESPs, Trading Companies, Power Producers

Strategic Reponses

- Respond to demands on an aging infrastructure
- Systems for adaptation to new regulatory structures
- Adapt current infrastructure for digital future
- Mergers - combine disparate transmission & distribution systems
- Respond to changing work force
- Technologies to support electric/telecom convergence
- Increase amount of peaker units

Reliability

- Clarify concern & uncertainty regarding EMF & EMC
- Improve asset utilization without sacrificing reliability
- Optimal mixture of PQ/reliability solutions

Financial

- Increase revenues
- Reduced O&M costs
- Investment incentives & opportunities
- Adapt operations & investments to higher cost of capital
- Mandatory cost reductions across the board
- Deal with increased risk
- Finance existing operations, equipment upgrades, and new ventures when risk is higher

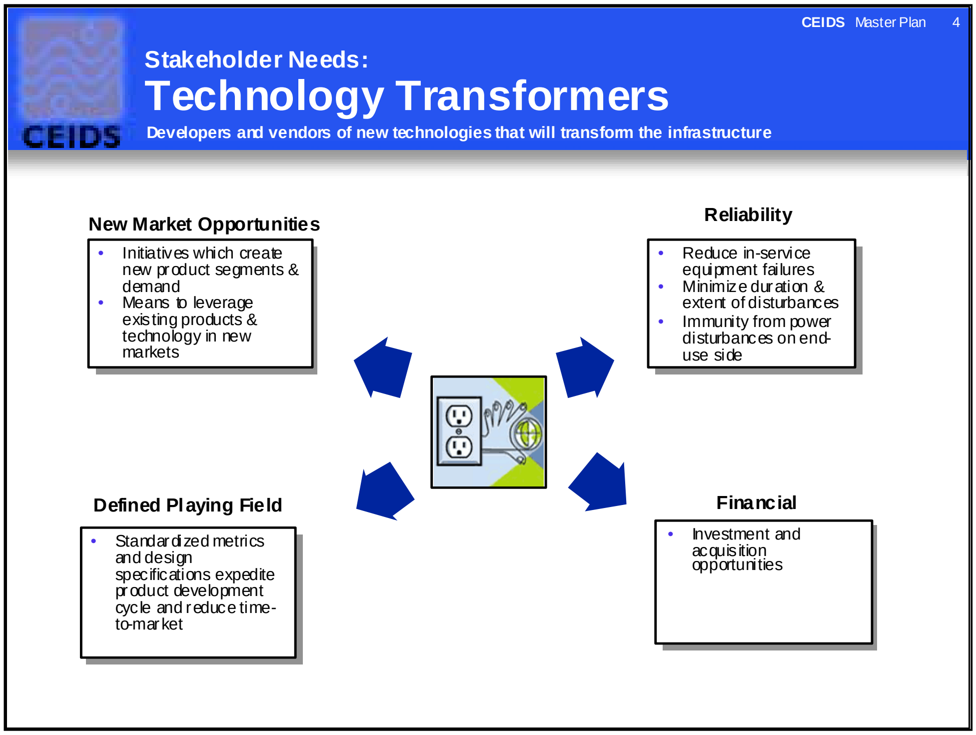
Environment

- Emissions reduction
- Emissions credits
- Nuclear re-licensing
- Relieve siting pressures

Safety & Security

- Security of communications infrastructure
- Make structure & functions of grid redundant & reliable in the face of non-traditional threats
- Reduce financial and performance impact of security enhancements
- Reduce vulnerability of islands

Third are technology transformers—the developers and vendors of equipment and devices to modify the electric system. They require the assistance of institutions and other forces that promote innovation and push technology in the right direction. Such forces include standards and architecture development and other initiatives to define specifications for product development. These forces tend to reduce time-to-market and to expand marketing opportunities. Reliability is a concern because technology for the future infrastructure will require longer economic life, fewer in-service equipment failures, and higher power quality. The manufacturing processes of these stakeholders will also require high levels of power quality and reliability.



Stakeholder Needs:

Technology Transformers

Developers and vendors of new technologies that will transform the infrastructure

New Market Opportunities

- Initiatives which create new product segments & demand
- Means to leverage existing products & technology in new markets

Reliability

- Reduce in-service equipment failures
- Minimize duration & extent of disturbances
- Immunity from power disturbances on end-use side

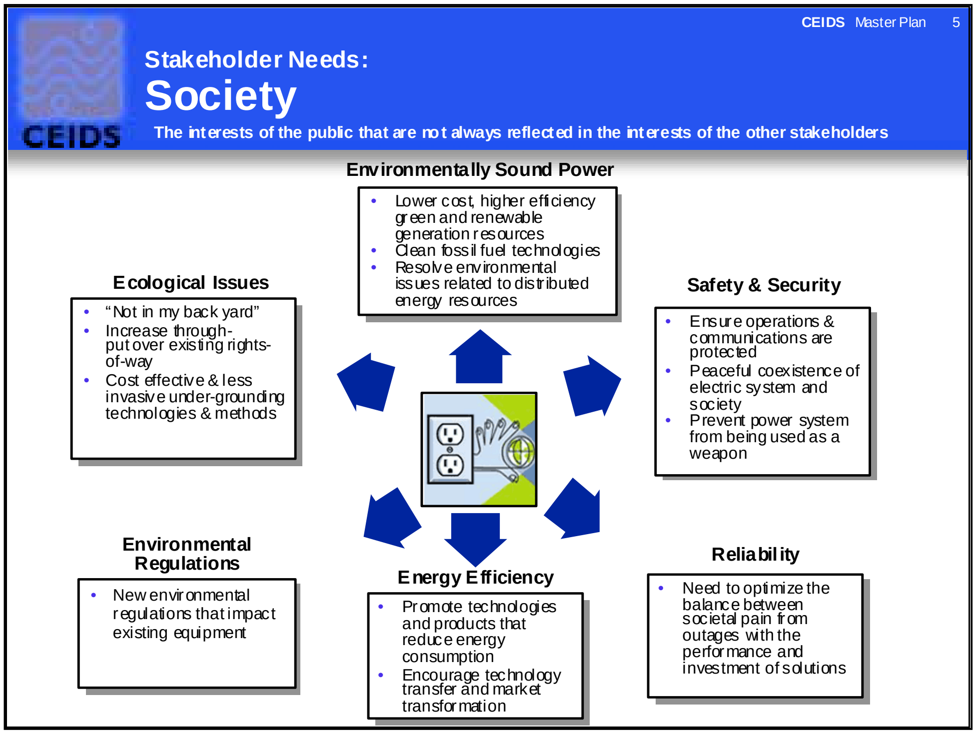
Defined Playing Field

- Standardized metrics and design specifications expedite product development cycle and reduce time-to-market

Financial

- Investment and acquisition opportunities

Fourth is society, representing the interests of the public. Society requires reliability, safety, and security, and seeks to lower the costs of electricity and outages. It desires clean fossil fuel technologies; lower-cost, renewable-generation resources; and distributed resources with little environmental impact. Regulations are often a solution to these needs, and how regulations affect existing equipment is a cost that society often must bear. Environmental concerns, along with the desire to lower costs, lead to the need for increased energy efficiency in products and processes.



CEIDS Master Plan 5

Stakeholder Needs:

Society

The interests of the public that are not always reflected in the interests of the other stakeholders

Environmentally Sound Power

- Lower cost, higher efficiency green and renewable generation resources
- Clean fossil fuel technologies
- Resolve environmental issues related to distributed energy resources

Ecological Issues

- "Not in my back yard"
- Increase through-put over existing rights-of-way
- Cost effective & less invasive under-grounding technologies & methods

Safety & Security

- Ensure operations & communications are protected
- Peaceful coexistence of electric system and society
- Prevent power system from being used as a weapon

Environmental Regulations

- New environmental regulations that impact existing equipment

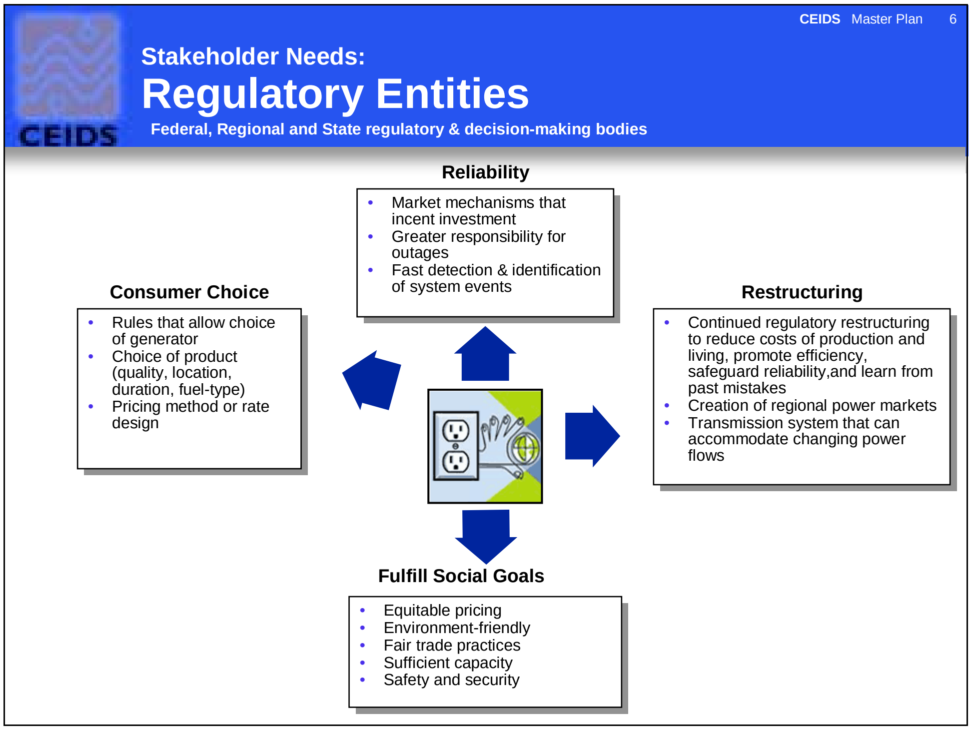
Energy Efficiency

- Promote technologies and products that reduce energy consumption
- Encourage technology transfer and market transformation

Reliability

- Need to optimize the balance between societal pain from outages with the performance and investment of solutions

Fifth are regulatory bodies—such as the Federal Energy Regulatory Commission (FERC) and state regulatory commissions—and regional organizations, which have the authority to make changes in the system. They do so via direct policies or through creation of incentive and market mechanisms. Regulatory bodies are mandated to fulfill social goals such as equitable pricing, environmentally friendly generation, and reliability.



CEIDS Master Plan 6

Stakeholder Needs:

Regulatory Entities

Federal, Regional and State regulatory & decision-making bodies

Reliability

- Market mechanisms that incent investment
- Greater responsibility for outages
- Fast detection & identification of system events

Consumer Choice

- Rules that allow choice of generator
- Choice of product (quality, location, duration, fuel-type)
- Pricing method or rate design

Restructuring

- Continued regulatory restructuring to reduce costs of production and living, promote efficiency, safeguard reliability,and learn from past mistakes
- Creation of regional power markets
- Transmission system that can accommodate changing power flows

Fulfill Social Goals

- Equitable pricing
- Environment-friendly
- Fair trade practices
- Sufficient capacity
- Safety and security

Appendix F: Potential Technology Solutions

A key component of the technology selection process is discussion and consideration of CEIDS' ties to the EPRI Electricity Technology Roadmap Initiative and the Power Delivery and Markets (PDM) Bridge Plan. Difficult Challenges (DC) identified in the Roadmap relate directly to the development of a new delivery infrastructure. The PDM Bridge Plan contains 57 potential technology solutions, and the CEIDS staff has expanded that list by four. Table F-1 contains a complete list of the 61 potential technology solutions and related DCs.

Table F-1. Potential Technology Solutions Drawn from the EPRI Power Delivery and Markets R&D Plan and New Ideas Generated by CEIDS

POTENTIAL TECHNOLOGY SOLUTIONS
1. Monitoring and control technologies and methods for market-based transmission planning, congestion management, and pricing (DC1)
2. Advanced sensors, communications technologies, and maintenance technologies (DC1)
3. Models and tools to comprehensively assess and communicate technical and policy constraints in the transmission system (DC1)
4. Tools to enable system operators to perform real-time, risk/reward tradeoff assessments (DC1)
5. Regional transmission expansion plans for 10-20 year horizons that guide location of new generation based on alleviation of local reliability problems and provision of adequate reserves (DC5)
6. Wide-area measurement and monitoring technology capable of continental deployment in support of transmission and distribution automation (DC1)
7. Regional transmission organization (RTO) system of power electronics-based, integrated network control (DC1)
8. Wide-band gap power electronics in support of integrated network control (DC1)
9. Adaptive islanding and restorative grid control technologies (DC1)
10. System optimization algorithms and technologies for operator use (DC1)
11. Approach for integrating distributed energy resources (DER) into grid operations and control (DC1)
12. Tools and technologies to enable centralized dispatch and coordination of DER (DC1)
13. Approach and technologies for use of DER for automatic generation control (DC1)

14. Approach and technologies for modifying grid infrastructure to support two-way power flow and integrate reactive power capabilities of DER (DC1)
15. Multi-resolutional grid model to assess system vulnerabilities through computation of a vulnerability index (DC3)
16. Fast pattern recognition and diagnostic software to allow automated, adaptive islanding in response to propagating disturbances (DC3)
17. Technical basis and requirements for a wide-area, secure communications system as an alternative to Internet-based critical monitoring and control functions, including data authentication and encryption requirements and capabilities (DC3)
18. Strategic Power Infrastructure Defense (SPID) system concept using intelligent network software agents for automation (DC3)
19. Systems architecture for self-healing grid (communications, data, control) (DC2, DC6)
20. Fast look-ahead simulation software for dynamic contingency planning and rapid restoration, enabling self-healing systems to integrate real-time information and update predictive models (DC2, DC6, DC3)
21. Software infrastructure for self-healing grid (dynamic optimization, adaptive islanding, automated system reconfiguration/restoration) (DC3)
22. Intelligent network agents on a chip (DC3)
23. Communication object models enabling strategic use of DER in distribution automation (e.g., routine energy supply, voltage regulation, power factor control, emergency power supply, disaster recovery operations, and harmonic suppression) (DC2, DC6)
24. Software tools and monitoring systems that detect leading indicators of impending critical equipment failure (DC2, DC6)
25. Design and functional specifications (architecture, hardware, and software) of a wavelet transform-based, data-mining tool or smart monitor for a facility's electrical distribution system or utility distribution grid (DC6)
26. Technologies necessary to support effective integration of DER into the grid to achieve increased grid performance and reliability (DC2)
27. Design and architecture for a microgrid-based, power distribution system (DC6)
28. State-of-the-art dc rectifier to provide digital-grade power at the plug with "six-nines" of availability (99.9999%) (DC6)
29. Scenarios for the virtual utility concept (e.g., developmental requirements, impacts on other electricity infrastructure stakeholders) (DC2, DC6)
30. Advanced switch-mode power supply capable of providing efficient, reliable power to sensitive electronic processors, controls, and communication equipment without creating electrical pollution (conducted or radiated) (DC6)
31. Advanced power conditioning interface technologies that connect bulk electric power supply systems with consumer premises (including a common platform for integration of diverse power conditioning capabilities, such as ac-dc conversion, energy storage, on-site generation dispatch,

load shedding, metering, and monitoring) (DC6)

32. Technical basis and criteria for Dynamic Voltage Restorer with Integrated Transformer (DVRIT), to provide voltage transformation and power conditioning within the service transformer for commercial and industrial consumers (DC6)
33. Equipment applications in which synthetic inductors or new inductor concepts offer an advantage over present inductor technology in terms of cost, performance, weight, space requirements, and other attributes (DC6)
34. Knowledge base of electrical disturbances pertaining to various electric system configurations and equipment characteristics, resulting in a probability matrix based on event characterization that supports development design specifications for equipment immunity and compatibility (DC6)
35. Technology requirements for providing data and conditioned power over a single communications line (for Internet or data communication lines such as DSL, cable, and future replacements; and for Internet appliances and equipment) (DC6)
36. Tools to quantify benefits of energy storage (e.g., spinning reserve, load leveling, grid security, etc.) (DC4)
37. Cost study and comparison of energy storage technology options (DC4)
38. Improved compressed air energy storage (CAES) and advanced battery technologies (e.g., Regenesys) (DC4)
39. Improved storage technology portfolio (e.g., supercapacitor, superconducting magnetic energy storage [SMES]) (DC4)
40. Improved storage technology portfolio (e.g., modular pumped hydro, H2 production and storage) (DC4)
41. Improved storage technologies tailored for intermittent generation (DC4)
42. Improved energy storage technologies associated with power flow control technologies (e.g., Flexible AC Transmission System [FACTS]) (DC4)
43. Sustainable market design minimizing risk of systemic failures and coordinating with regulatory provisions to ensure planning and funding of adequate resources, and efficient allocation of risk (e.g., ensuring solvency of defaulting service providers) (DC5)
44. Comprehensive analysis and comparison of the Independent Transco vs. nonprofit ISO/RTO form, relying on a standard market design (DC5)
45. Approaches to improve the efficiency of ad hoc schemes (e.g., ACAP, RMR agreements), on which ISOs rely to manage the grid and ensure resource adequacy (DC5)
46. Power marketing simulation software based on common information models to support development and implementation of optimal market designs (DC5)
47. Forecasting models that include data on effects on emission prices from environmental and market developments over large regions (DC5)
48. Specifications for implementing a real-time pricing infrastructure based on open system standards (DC6)

49. Approach for independent system operator (ISO) control over generation dispatch to assure transmission reliability (DC5)
50. Optimal, comprehensive scheme for evaluating supply-side and demand-side reserves in terms of quality attributes such as response time or ramp rate, and means of comparing two-part bids for reserved capacity and called energy (DC5)
51. Procedures for transmission allocation and congestion pricing and reserve procurement (e.g., contract forms for congestion revenue rights that facilitate expansion of wide-area, competitive markets for trading energy and transmission) (DC5)
52. Integrated transmission reliability and security criteria incorporating market security criteria (DC5)
53. Approaches and technologies to substantially reduce energy consumption for office equipment via power management (DC8)
54. Direct current and multi-mode motor technologies (DC8)
55. Model for understanding data and the relationship between economic productivity and electricity intensity (DC8)
56. Increased efficiency and lower-cost electrotechnologies in key areas (e.g., freeze-concentration separation processes, microwave-enhanced chemical processes) (DC8)
57. Advanced lighting technologies with substantially higher efficiencies (DC8)
58. Communications technology assessment (new)
59. Benchmark of today’s system security, quality, reliability, and availability performance (new)
60. Identification of future security, quality, reliability, and availability requirements (new)
61. Economic assessment to determine optimal mix of power conditioning solutions (consumer vs. grid sides) (new)

G Appendix G: Roster of CEIDS Partners and Advisors Participating in Master Plan Development

Steering Committee Co-Chairs

- Bruce Germano, Vice President - Retail Services, Long Island Power Authority (LIPA)
- Jimmy Glotfelty, Senior Policy Advisor - Office of the Secretary, U.S. Department of Energy (DOE)

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- Mike Hoffman
- Terry Oliver

CISCO SYSTEMS

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- Randy Sisk
- Tom O’Donnell

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- Ted Maffetone
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- Richard Schomberg, Vice President – EDF International
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- Dave DeCampli, Vice President - Engineering and Technical Analysis
- Florence Glazebrook
- Del Hudson

LOCKHEED MARTIN CORPORATION

- Gery Cardenas

LONG ISLAND POWER AUTHORITY (LIPA)

- Gerry Pallotta
- Thomas Welsh – representing Keyspan

NEW YORK POWER AUTHORITY (NYPA)

- Shalom Zelingher
- Bruce Ferdanesh

POLISH POWER GRID COMPANY

- Wojciech Lubczynski
- Magdalena Wasiluk-Hassa

SALT RIVER PROJECT (SRP)

- John Blevins

TXU ENERGY / ONCOR

- Bill Muston

U.S. DEPARTMENT OF ENERGY (DOE)

- Eric Lightner, Program Manager, Office of Electric Transmission and Distribution for the U.S. Department of Energy
- Paul Wang, Concurrent Technologies Corporation

WE-ENERGIES

- Charley Cole, Vice President
- Bob Huber
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- Tom Wick

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- Brett Perlman, Commissioner - Public Utility Commission of Texas
- Jeffrey Pillon, Statistical Analysis, Executive Secretary Division - Michigan Public Service Commission
- Peter Smith, Vice President for Programs - New York State Energy Research and Development Authority (NYSERDA)
- Dr. Terry Surles, Manager, Public Interest Energy Research (PIER) - California Energy Commission (CEC)

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- Rick Counihan – E2I, Vice President
- Robert Gee – E2I, Vice President
- Don Von Dollen – CEIDS Project Integration Manager
- Rich Lordan – EPRI, Director
- Adriene Wright – E2I, Director
- Yu Ting Huang – E2I/CEIDS Program Specialist

About E2I

E2I, an affiliate of EPRI, has been established as a non-profit, public-benefit organization to conduct strategic, breakthrough R&D in energy-related science and technology. Bringing together public and private resources, E2I and participating stakeholders support and direct science and technology innovation in electricity supply, delivery, and utilization to address the socio-economic needs of our future.

To join CEIDS or for more information, please contact Marek Samotyj at (650) 855-2980 or msamotyj@e2i.org.

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