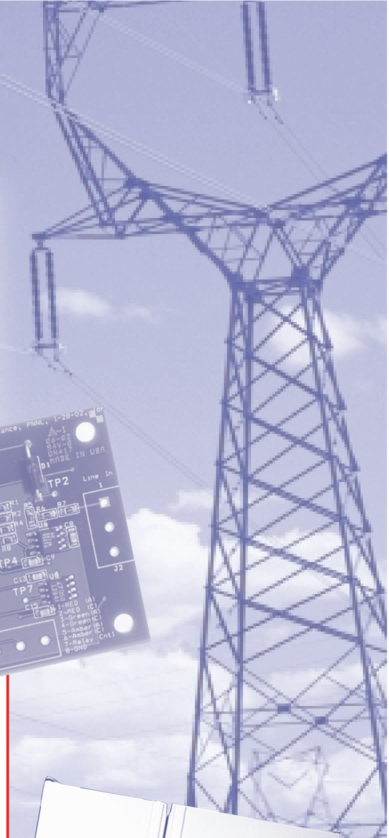
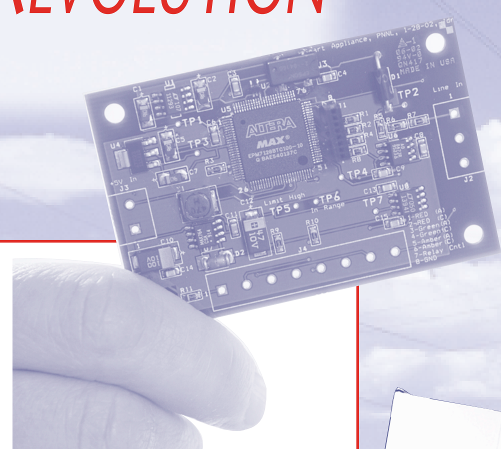


The Smart Energy Network: *Electricity's Third Great Revolution*

By Patrick Mazza



Information Technology Meets Electrical Power

Electrical power is entering its greatest revolution in a century, bringing profound changes in its production, delivery and use. With the emergence of cheap computing power and low-cost bandwidth, the electrical grid is on the way to becoming a smart energy network.

"So far information technology has had a fairly small impact on the energy infrastructure," says Rob Pratt, a scientist at the U.S. Department of Energy's Pacific Northwest National Laboratory. "That's about to change."

The smart network will provide economical alternatives to traditional power plant and line upgrades, taking significant pressure off escalating power costs. Smart technologies that sharply increase energy efficiency will also shave bills. With greater capacity to bounce back from troubles the smart network will suffer fewer blackouts and brownouts. Smart energy will also reduce air pollution and greenhouse gas emissions.

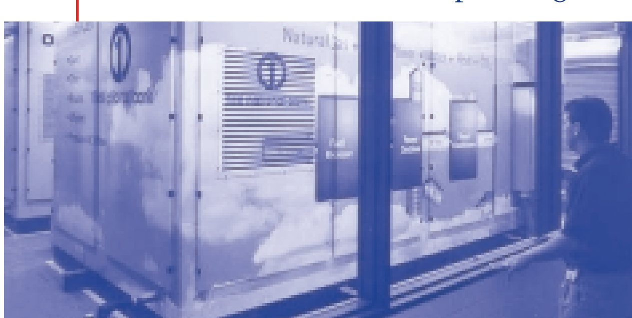
The key to smart energy is information technology's capacity to optimize grid operations. Electrical devices represented by intelligent software agents will communicate their operating status, collect information on grid conditions and respond in ways that most benefit their owners and the grid. Constant interactions of millions of smart agents will optimize the grid, creating a collaborative network nearly as complex as biological systems. This smart network is now picking up speed and will reach critical mass over the next decade.

The network will offer two fundamentally new capabilities discussed in sections below:

1. **Precision Power Management** – coordinating electrical demand down to the residential level.
2. **Distributed Energy Networking** – linking vast numbers of small-scale energy generation and storage devices.

Those two basic capabilities will open the way to a tremendous flow of new electrical power devices, services, markets and players, promising sweeping changes along with profound benefits and potential instabilities. A comprehensive approach is crucial if society is to avoid pitfalls and realize the full range of benefits in the earliest possible timeframe. The Energy Systems Transformation Initiative (ESTI), an effort of Pacific Northwest National Laboratory (PNNL) based in Richland, Washington, is a multidisci-

This report is based on an in-depth paper by the same name that can be downloaded for free from www.climatesolutions.org. See publications. Climate Solutions gratefully acknowledges support by Pacific Northwest National Laboratory for development of this report and paper.



plinary team of scientists, engineers and economists working in coordination with companies, researchers and public agencies at the leading edge of smart energy to make sure the new network develops in a coherent fashion. This paper, based on the vision and analysis emerging from this broad ranging collaboration, covers key issues including:

- Economics involved in making the right energy investment decisions over the next 20 years
- The core role of information technology in assembling a coherent system that unleashes the full value of new energy devices
- Smart energy's potential capacities and benefits, and places where smart energy applications are already reaching the marketplace
- How information technology allows far more efficient use of energy and reduces the need for costly peaking power infrastructure
- The explosion in small-scale energy resources and how their full economic benefits can be realized through the smart energy network
- How smart technologies will reduce air pollution and create a self-healing grid capable of bouncing back from disasters.

AT THE CRUX: HOW BEST TO USE $450 BILLION

Today's power grid suffers from a capital investment backlog. While electrical power demand surged over recent years restructuring left unclear who is responsible for upgrading power infrastructure. This has produced a slow-moving crisis and a grid subject to disruption.

"Given that transmission line construction has a long lead time, five to seven years, it is highly likely that the nation will face critical, but localized, shortages of power by the end of the decade," PNNL economist Mike Warwick says.

Based on U.S. Energy Information Administration projections, PNNL calculates that keeping up with expected growth in electrical demand along the traditional infrastructure route would require $450 billion through 2020. Replacing a legacy of cheap, 1950s vintage systems with their far more expensive modern equivalents would produce power bill-sticker shock. On the other hand, a PNNL scenario for rapid smart energy adoption could provide $78 billion in economic benefits by 2020. Taking the intelligent systems route the nation could:

- Lighten interest payments $10 billion by reducing financial risks of power infrastructure upgrades
- Reduce plant operation costs $3 billion by making existing plants operate more efficiently
- Save $10 billion through energy efficiency gains from advanced electronic controls and diagnostic sensors
- Lessen outage expenses by $5 billion through improved reliability
- Save $50 billion by avoiding the need to add 100 gigawatts of generating capacity.

"We can either invest the way we have in the past, or we can use intelligent systems to do for energy what the Internet has done for communications," notes Mike Lawrence, PNNL's associate laboratory director for energy science and technology.

Creating the smart energy network also will foster growth of a new energy technology systems industry that breaks down boundaries between electrical utilities, telecommunications, computers, software, building systems and electrical equipment.

"In the next few years, we could see a Microsoft or a Dell rise from this," notes technology analyst Jesse Berst of Redmond, Washington-based Athena Institute. "This is the Internet 1992, set to begin a steep upward climb."

THE THIRD ELECTRICAL SYSTEMS REVOLUTION

A dizzying array of new energy technologies are reaching or nearing the marketplace. Newer choices to generate electricity include fuel cells, wind turbines, solar cells and microturbines. Energy storage is approaching practicality, for example through reversible fuel cells. But remarkable as each of the new devices is on its own, their value is fully unleashed only when they are linked together in coherent systems. Information technology constitutes the connective tissue.

The originator of the first great electrical revolution knew that while innovative devices are important the key is creating systems that make them useful. Thomas Edison's decision to create a practical incandescent light bulb was only part of a larger scheme to supplant the gas light industry by piping electricity into people's houses. It came to fruition when he opened the first central power stations and grids in 1882.

Nicola Tesla believed he had a better idea. Instead of Edison's Direct Current (DC), which then could travel only short distances he would invent an Alternating Current (AC) system, which could move over longer distances. In 1895 George Westinghouse used Tesla's technology to harness Niagara Falls and transmit AC 22 miles to Buffalo. By multiplying electric generating potential the Tesla-Westinghouse system spurred the second electrical revolution.

The smart energy network is electricity's third and greatest revolution. Each of the earlier grids was centrally controlled. The smart network uses information technology to distribute control and generation of electricity to smart devices throughout the power network. Such distributed networks are complex on "a scale where we cannot manage things centrally," notes Ron Ambrosio of IBM Research. Instead each smart device optimizes operations in response to grid conditions. The cumulative outcome is collaborative direction of the energy network.

But will the system bog on its own complexity? The situation resembles an auditorium in which the entire audience wants to join in the conversation. The result would be pandemonium unless the crowd somehow sets up protocols for communication. As the grid moves from central to distributed control, this is exactly what must develop. But who will be accountable when the grid runs into problems? Can we trust the grid to "run itself?" Will difficulties in integrating many new energy technologies forestall or delay realization of their benefits? Can the system be worked by price gougers or hijacked by terrorists?

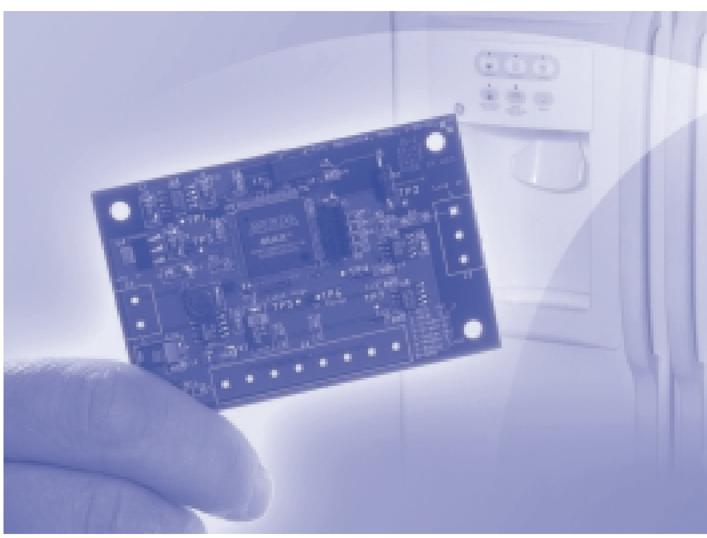
Such questions point up the critical need to explore how new technologies mesh together in systems. This is the point of PNNL's energy system transformation work. The Laboratory's ambitious overview includes developing basic architecture that enables smart energy devices to communicate, creating a virtual grid in a supercomputer to model new energy networks, and mounting real-world physical tests to see how energy devices work together.

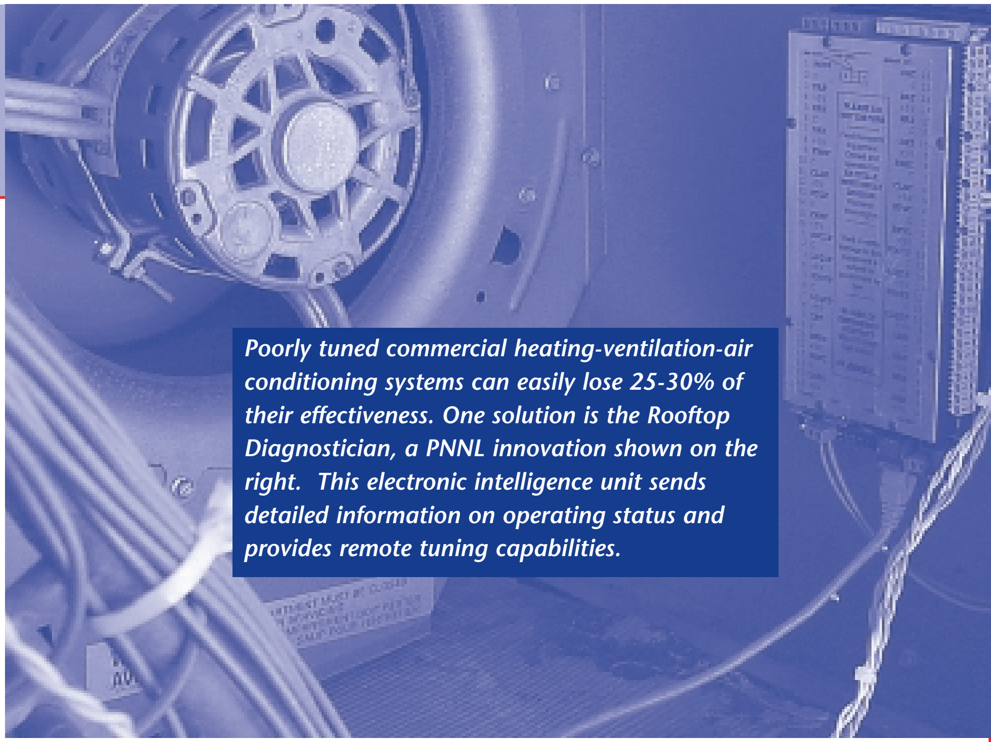
"We're putting together the whole story and creating a transformation – not just a business, not just a technology, not just science," PNNL Power Systems Program Director Steve Hauser says. "We need all those elements for success."

At the Tipping Point

A number of key players have the smart energy network in their sights. Bonneville Power Administration has envisaged the "Energy Web" and is planning Northwest demonstrations with utility and business partners. The U.S. Department of Energy, GridWise™ Program and PNNL are mounting tests of energy communications and control networks. Some of the world's biggest companies are pioneering the new energy landscape:

- IBM researchers are designing software and hardware for "Internet-scale integration" and real-time analysis of the massive amounts of data that will flow through networks of smart devices.
- Whirlpool, working with PNNL's "grid-friendly™ appliance concepts, is developing a web-based system that enables appliances to curtail demand, share energy with other devices and provide detailed energy consumption information.





Poorly tuned commercial heating-ventilation-air conditioning systems can easily lose 25-30% of their effectiveness. One solution is the Rooftop Diagnostician, a PNNL innovation shown on the right. This electronic intelligence unit sends detailed information on operating status and provides remote tuning capabilities.

- Siemens has created a Decentralized Energy Management System™ that acts as a virtual control room for distributed generator networks and optimization of electrical demand. Pilot tests are underway in Germany.

The Pacific Northwest hosts an emerging cluster of smart energy companies:

- ALSTOM, a major global company with a Bellevue, Washington software development division, provides a broad range of products to automate power plants, transmission networks and local distribution systems. For example, the e-terra™ system automates scheduling of power flows through transmission systems.
- Celerity Energy, Beaverton, Oregon employs information technology from Sixth Dimension to network distributed energy resources for Public Service of New Mexico and Xcel of Denver, Colorado, creating "virtual power plants" through which utilities can meet peak power demands.
- Portland General Electric has created its own "virtual power plant" by enlisting back-up generators owned by its customers. Since 2001 it has created its own electronic network to dispatch 10 megawatts of generators. It aims to sign up 120 megawatts.
- Serveron, Hillsboro, Oregon, provides web-based monitoring of transmission and distribution facilities. A dozen of its units were installed at John Day Dam in Oregon in 2002.
- Itron, Spokane, produces wireless, smart meters and software products for utilities ranging from load forecasting to workforce management.
- Alerton, Redmond, Washington, has installed building automation and controls in thousands of buildings globally.
- Schweitzer Engineering, Pullman, Washington, manufactures compact microprocessor-based power relays that replace bulky electromechanical systems.

"We're very near the tipping point on these technologies, when the ah-ha's about what they can really do start to break out," Hauser says.

Precision Power Management

While generating stations constitute the bulk of resources to meet electrical demand, managing that demand is an increasingly significant power resource.

Utilities for many years have operated programs to help customers improve their energy efficiency. These have targeted all customer classes. Smart technologies will yield further efficiency gains, first in larger commercial and industrial buildings, then in small businesses and homes. Building-level networks of sensors and microprocessors could shave $15 billion off power bills through 2020. Web-based management from remote locations already tunes commercial building systems for top performance. Buildings are starting to catch up with automobiles, which are now packed with computer chips that make them operate more economically.

A second major facet of demand management is control of loads. Utilities now strike agreements with larger customers to curtail demand when the grid is stressed. But it is not economical to make similar arrangements with small businesses and the residential sector that consumes 34% of U.S. electricity.[1] Information technology will make possible precision management of power demands in all customer classes.

Information technology will optimize grid operations much as it has manufacturing and retailing. "Just-in-time" inventory systems based on computers and telecommunications have tight-

[1] U.S. Department of Energy, *Core Data Book*, 1997

ened distribution chains and eliminated much warehousing. New precision power management capabilities will similarly optimize the electricity supply chain.

Today's power grid "warehouses" substantial excess capacity to cover peak demand and just-in-case contingencies. The U.S. operates around twice the power plants it would theoretically need if electrical use spread evenly across all hours of the year. But power loads peak daily and seasonally. Standard operating procedure also dictates that power plants online must maintain a reserve of 15% more generating capacity than needed to meet expected peak demands. Long-distance transmission systems typically maintain around 40% more capacity than expected peaks. In local distribution networks padding over peaks is typically over 50% and can range up to 90%, as utilities often overbuild in anticipation of growth.[2]

The smart network will eliminate much of this "warehousing." PNNL projects that flattening out peak demand could avoid or defer the need for 100 gigawatts of new generation and associated transmission and distribution capacity by 2020, equivalent to $50 billion or 200 large gas turbine power plants. Each dollar invested in smart, grid-friendly™ appliances will provide the same reserve capacity as $10 invested in new power plants, PNNL calculates.

A PNNL presentation on grid-friendly™ appliances drew an impromptu response from a utility engineer: "Given enough ants, you can move a mountain." The mountain is electrical power demand. Through smart technology a virtual "army of ants" could be mobilized to manage a huge portion of demand. Household refrigerators, freezers, water heaters and air conditioners represent 25% of U.S. power demand during summer daytime peaks while 5% drives commercial heating-cooling units.[3] When appliances and equipment are imbued with intelligence and linked in a network they can be jointly managed to reduce demands and carry the grid through trouble spots.

Smart appliance operations will in most cases have no noticeable impact on customers. For instance, smart water heaters will pre-heat water before peaks. Smart refrigerators will make sure their daily defrost cycle, which amounts to around 7% of their energy use, does not occur during peaks. Smart clothes dryers and dishwashers will wait until late night to turn on. When customers suffer slight inconveniences to help the grid through tight spots they may be recompensed on their power bills. When they are not willing to be inconvenienced consumers can override the devices and use appliances at will.

Customers will find incentives to participate in peak shaving through time-of-use pricing in which peak power costs more than non-peak. The nation's largest time-of-use pricing pilot, operated by Puget Sound Energy, was recently cancelled because many customers were actually paying more than under standard rates. The failure of this program makes a case for technologies PNNL is developing. The pilot relied on customers keeping in mind which hours to turn on and off appliances, For example the owner of a standard dishwasher had to remember to wait until after the peak to turn it on. A grid-friendly™ dishwasher is programmed to not run during peaks, so the owner can hit the on switch after dinner and forget about it. The dishwasher will not come on until after the peak unless the owner explicitly overrides the programming.

A likely pathway for the mass emergence of the demand management market is through aggregators, which directly sell power to customers and negotiate with power generators and deliverers for the best deals. By managing customer demand aggregators could earn significant amounts of money. They would have incentives to spread smart technologies to their customers and market demand-side services to the grid.

Distributed Energy Networking

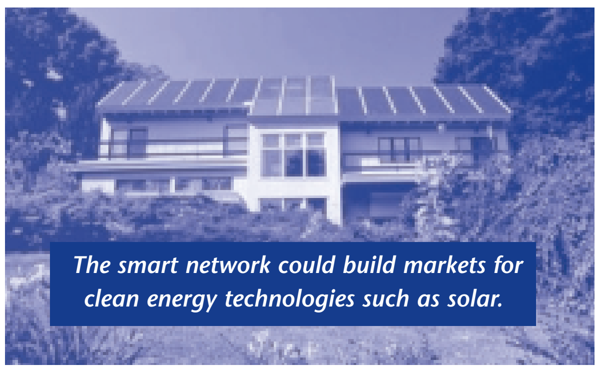
Approximately 60,000 megawatts (MW) of small-scale distributed generators, defined as under 10 MW, are on line in North America.[4] They are mostly diesel generators and reciprocating engines. Fuel cells, microturbines and solar arrays are growing. Distributed generation could be expanding by 2,500-5,000 MW annually by 2010, the Electric Power Research Institute projects.[5] The U.S. Department of Energy aims that by 2010 20% of new electrical generator additions are distributed. The distributed power market is driven primarily by the need for reliable back-up supplies and

[2] Capacity figures from PNNL economist Michael Warwick.
[3] U.S. Department of Energy, *Core Data Book*, 1997
[4] Electricity Innovation Institute, CEIDS Distributed Energy Resources Integration Element Program Plan, March 6, 2002, p1
[5] Borberly, Anne-Marie & Kreider, Jan F, *Distributed Generation: The Power Paradigm of the New Millennium*, CRC Press, Boca Raton, Fla., p18

information-technology quality electricity free of surges and "noise." Small generators are finding their way into hospitals, police stations, data centers, high-tech plants and other facilities which need high-quality, blackout-free electricity.

Distributed generation brings many potential values to the overall power network. A new Rocky Mountain Institute study identifies 207 distinct benefits of distributed energy, from lower financial risks to improved grid operations, that can make a kilowatt's worth of distributed power worth far more than the equivalent power from a large plant.[6]

But distributed energy's full benefits cannot be realized until it is integrated into the grid. Today, "very little (distributed generation) is connected to the power delivery infrastructure, and even less is integrated into the utility communication and control infrastructure," the Electricity Innovation Institute reports.[7] A distributed power network with thousands of small generators requires far more sophisticated communications and control systems than a radial grid focused on a few big plants. The smart energy network is key to integrating distributed resources.



The smart network could build markets for clean energy technologies such as solar.

The smart network will set up a virtuous cycle. It will open new niches where distributed energy is economically competitive, promoting economies of scale that decrease costs, thus making distributed energy economical in yet wider applications.

By making it easy to connect and coordinate distributed resources, the smart network will make it more practical to serve local needs with local generation. This will provide lower-cost alternatives to beefing up substations and power lines in high-growth areas. "Virtual power plants" could take demands off long-distance transmission lines. Distributed resources also cut costs by allaying siting problems that increasingly plague the electrical industry. Gaining approval for big transmission lines is notoriously difficult. Moving power generation closer to home reduces or eliminates need for new lines.

In a smart energy scenario, distribution and transmission system operators publicize upgrade needs and challenge the marketplace to meet them. That provides an incentive to bid packages of distributed resources, demand management and building efficiency improvements. But regulated utilities guaranteed a rate of return based on capital investment have little incentive to look for cheaper alternatives. Setting rates of return on the basis of services performed will motivate utilities to economize on capital investment.

One cost-cutting incentive for distributed resources is their ability to offer capacity increases that closely track demand growth. Meeting increasing demands by adding central plants and new lines inevitably brings large "lumps" of new capacity on line at once. So capacity typically moves in feast-and-famine cycles. Distributed resources come on line in smaller increments and far faster so they can match demand curves more accurately. Resulting reduced financial risks could yield big paybacks. Shaving just one percent off average interest rates would reduce the power infrastructure bill through 2020 by $11 billion.

The smart energy network will also make it easier for owners of distributed generators to sell surplus power. It will open the way to a range of potential customers including neighboring buildings and aggregators.

Environmental and Security Benefits

Smart energy will be cleaner energy because efficiency improvements cut electrical demand, thus reducing power plant emissions. Power customers could also order their devices to buy the cleanest power available within their budgets. Smart networks could respond collaboratively during smog alerts by purchasing power with the lowest emissions and shifting loads to hours when smog concerns have abated.

Smart energy will open new niches for distributed zero-emissions power sources such as solar and small-scale wind. It also will build the market for fossil-powered distributed generators such as reciprocating engines and today's fuel cells. Such

[6] Lovins, Amory B. et al, *Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*, Rocky Mountain Institute, Snowmass, Colo., 2002

[7] Electricity Innovation Institute, ibid

generators still can offer efficiencies that significantly beat central stations. Generating power near where it is used eliminates the standard 5-10% line loss. If waste heat is used to propel heating and cooling systems, efficiencies of fossil-powered distributed generation climb into the 80% area, far greater than what can be achieved with big power plants. Higher efficiency spells less pollution. As economics improve, engines and fuel cells could run on low-pollution biofuels such as ethanol and biodiesel. Ultimately they might run on zero-emissions hydrogen if production, distribution and storage hurdles are overcome.

One of the most compelling benefits of smart energy is a grid that can heal itself. With today's heightened focus on security, this has never been more relevant. No longer will protecting the grid be solely the purview of a small cadre of power system operators sitting in control rooms, who during crises can become overwhelmed by the grid's equivalent of the fog of war. Grid stability will become the task of millions of distributed software agents located throughout the system. "Cops on the beat" in grid watch posts will still monitor the overall system, but now they will have the aid of "eyes on the street" software agents on the lookout for trouble and ready to respond. Those agents will automatically check failures that otherwise might cascade through the system.

Information Technology to the Forefront

Information technology has catalytic potential to create a smart energy network that will:

- Dramatically reduce costs of upgrading electrical infrastructure
- Accelerate deployment of more efficient and cleaner energy technologies
- Foster growth of an advanced energy technology systems industry
- Bounce back quickly in the face of terrorist attack and natural disaster
- Reduce air pollution that damages human health and the global climate.

The electrical grid is moving into the information age. Distributing decisionmaking power and electrical generating potential to virtually everyone hooked up to the grid will create a smart energy network that supplies clean, secure, reliable and economical energy to meet the emerging needs of the 21st century economy. The more comprehensively the potentials of smart energy are addressed and developed, the more quickly and fully society will realize its many opportunities and benefits.

First National Bank of Omaha puts the cost of outages at its credit card processing center, seventh largest in the nation, at $100,000 per minute. Such high-stakes risks are driving the growth of distributed energy installations such as this fuel cell array at the Omaha center.
Photo credit: First National Bank of Omaha.

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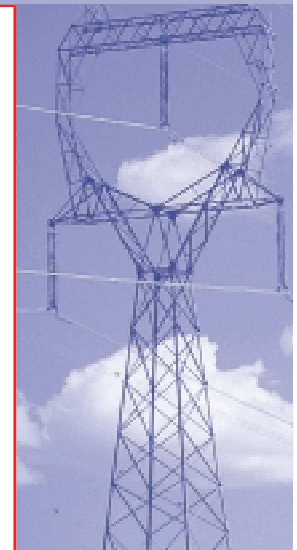
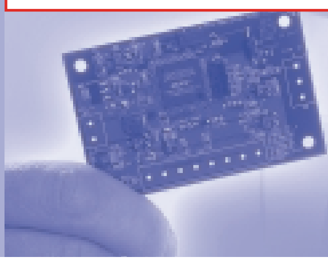
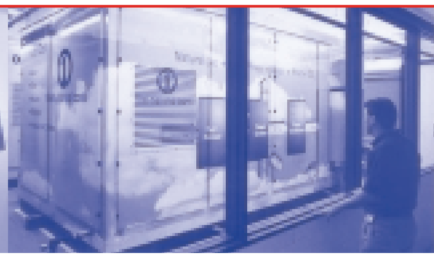


Action for Smart Energy

To fully realize smart energy's potentials, here are steps key players can take:

1. Utilities study how to implement smart energy concepts and undertake pilot tests.
2. Building and facilities managers become aware of smart energy concepts and begin to implement them.
3. Companies in telecommunications, controls, computers, software, power systems, building systems and electrical equipment explore smart energy potentials and build strategic alliances to offer comprehensive energy systems packages.
4. Technology investors investigate smart energy opportunities and invest in promising companies.
5. Policymakers identify and remove regulatory barriers, and incorporate smart energy into economic development strategies.
6. Energy and environmental activists advocate with utilities and policymakers to employ smart energy solutions.





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