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

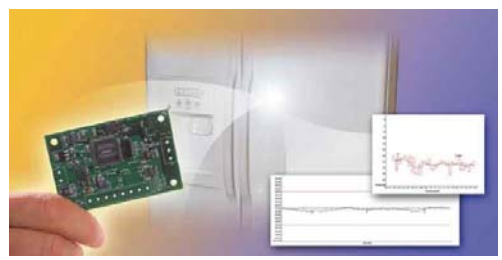
**By Patrick Mazza**

## *The Smart Energy Network*

### Introduction: Information Technology Meets Electrical Power

Electrical power is entering its greatest revolution in a century, one that compares to Thomas Edison's creation of the world's first electrical grids and George Westinghouse's origination of long-distance power transmission. In prospect are profound changes in the ways electrical power is produced, delivered and used.

The source of this revolution has already made over economic sectors from manufacturing to retailing -- electronic intelligence. Information technology, employed in electrical grid command centers since it has been available, is starting to infuse electronic intelligence throughout the grid. Driven by the recent emergence of cheap computing power and low-cost bandwidth, the traditional grid is in the early stages of transformation to a smart energy network.



Electronic intelligence such as this smart chip for refrigerators will become part of virtually every device hooked to the grid, from power plants to substations to home appliances. The continual communication and interplay of smart devices will optimize the grid for economical rates, reliable service and environmentally clean operations.

"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."

For electrical power providers, the infusion of information will translate into economical, smart technologies that provide alternatives to traditional power plant and line upgrades. For electrical power ratepayers, that spells savings on power bills. They also will save with smart technologies that sharply increase energy efficiency in homes and businesses. For everyone concerned about power reliability, the smart network will offer greater capacity to bounce back from troubles, making for fewer blackouts and brownouts. For the environment, smart energy promises reduced air pollution and greenhouse gas emissions.

The key to smart energy is information technology's capacity to optimize grid operations. Electrical devices will be operated by their own intelligent software agents that communicate information on operating status and needs to the network, collect information on prices and grid conditions, and respond in ways that most benefit their owners and the grid. Constant interactions and transactions of millions of smart agents will move the grid beyond central control to a collaborative network nearly as complex as biological systems. Momentum toward this smart energy network is starting to pick up speed, and will reach critical mass over the next decade.

The information technology base of the smart energy network is communications and control systems that create two fundamentally new capabilities:

1. The ability to precisely manage electrical power demand down to the residential level.
2. The ability to network vast numbers of small-scale distributed energy generation and storage devices.

From those two basic capabilities emerge a host of other new and enhanced capacities, opening a tremendous flow of new electrical power devices, services, markets and players. This promises to bring sweeping changes to the power grid along with tremendous benefits and potential instabilities. A comprehensive approach is crucial if society is to navigate through this emerging information-technology-rich electrical network, avoid pitfalls and realize the full range of benefits in the earliest timeframe possible.

Generating this "big picture" overview is the goal of the Energy Systems Transformation Initiative (ESTI), an effort of Pacific Northwest National Laboratory based in Richland, Washington. With so many revolutionary energy technologies arriving at once, ESTI's multidisciplinary team of scientists, engineers and economists is starting with a "blank sheet of paper" to chart the outlines of a profoundly new electrical network. The team is 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 is based on the work, vision and analysis emerging from this broad ranging collaboration.

## A Roadmap to the Smart Energy Revolution

The infusion of information technology throughout the grid will change fundamental assumptions about electricity; about what is a power resource and who is a power producer.  As this transition takes place, a number of issues will be at play.  This paper covers key issues and developments 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 some 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 natural and human-caused disasters.

## At the Crux: How Best to Use $450 Billion

Today's power grid is suffering from a backlog in capital investment. While electrical power demand surged over recent years, electrical industry restructuring left utilities in a state of suspended animation.  It is unclear who is responsible to make sure power infrastructure keeps up with demand, and who will benefit.  This has left a grid in a state of slow-moving crisis and subject to disruption. The California power crisis offers a case study. While market manipulation drove much of the crisis, power transmission bottlenecks between the state's north and south provided means and opportunity.

The electrical power grid suffers from underinvestment and will have to be substantially rebuilt over the next 20 years to replace outworn equipment and keep up with growth.  Rebuilding with intelligent systems could yield $78 billion in economic benefits to the U.S. over that period.

"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," Pacific Northwest National Laboratory (PNNL) economist Mike Warwick says.

The power infrastructure challenge is a fine example of why the Chinese chose the same character for danger and opportunity.  While inertia might propel the electrical industry toward investment in traditional plant and line infrastructure, the need to rebuild represents an opportunity to accelerate development of a 21st century-technology smart energy network.

Based on U.S. Energy Information Administration projections, PNNL calculates that to keep up with expected growth in electrical demand, the traditional infrastructure route would require investing $450 billion between now and 2020. The nation has been coasting on a legacy of cheap, 1950s vintage systems. When the time comes to switch them out, simply replicating existing systems will be far more expensive and produce power bill-sticker shock. On the other hand, a scenario for rapid adoption of smart energy technologies envisioned by PNNL could provide $78 billion in economic benefits by 2020, significantly lessening the impact on ratepayers.

"With the old cheap stuff wearing out, threatening a really serious escalation in prices, we have a system here that's going to significantly lessen the impact," Rob Pratt says. Taking the intelligent systems route, PNNL projects that within the next two decades 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 – amounting to 200 large gas turbine power plants and infrastructure needed to serve them.

"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.

The nation can put in place a 21st century power system capable of meeting intensified demands for reliability and environmental quality, and in the process save itself a great deal of money. Creating the smart energy network also will foster growth of a new energy technology systems industry that removes boundaries between electrical utilities, telecommunications, microelectronics, software, controls, building systems and electrical equipment, and creates untold numbers of new businesses and jobs.

"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 and flywheels. Under development are smart home appliances that can sense and adjust to grid conditions and commercial heating-ventilation-air conditioning systems that allow remote diagnosis and control.

In the background is the most powerful energy technology of all, the microprocessor. Virtually all new energy technologies come with embedded electronic intelligence that controls their operations and enables them to link with other devices, buildings and the overall grid. Perhaps the most important message about the energy technology revolution is that, 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 represents the connective tissue.

The originator of the first great electrical revolution knew that innovative devices are important, but 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. Electrical power was already finding niche applications such as arc lighting powered on-site. Edison's vision was to pipe electricity into people's houses to supplant the gas light industry. So he mimicked its systems as he plotted out the first power grids. When he opened the first central power stations and grids in 1882, Edison's new power system vastly increased the usefulness of electrical devices, setting off an explosion in their use.

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 a system of Alternating Current (AC), which by cycling back and forth could move over longer distances. In 1895 George Westinghouse used Tesla's technology to harness Niagara Falls and transmit AC power 22 miles to Buffalo. The Tesla-Westinghouse system created the second great revolution in electricity's usefulness by multiplying electric generating potential. The grid of today, with large central power plants and thousand-mile-plus transmission lines, is more a child of Westinghouse and Tesla than Edison. Edison is having some revenge on his great rivals, though. The smart energy network represents a partial swing back to Edison's original idea of localized DC power distribution.

The concept of the smart energy network is the third and greatest revolution of electricity. The infusion of ubiquitous information technology throughout the grid makes it a far different and even more useful animal than either Edison's or Tesla's creations. Each of the earlier grids was oriented around central power plants and central control. The smart energy network will distribute the control and generation of electricity throughout the power network, producing a system that operates in fundamentally different and unprecedented ways.

One driver toward this new system is electrical industry restructuring. A grid composed of relatively few regulated utility monopolies is evolving into a network of many competitive power producers and other new players. This trend itself was kick-started by technology, the rise of competitive natural gas turbine electricity. Large power customers demanding access to this cheap power spurred the opening of wholesale power markets to competition a decade ago, beginning the restructuring process. Restructuring ran into roadblocks after the 2001 western states power crisis. But the trend toward competitive power markets is unlikely to abate, particularly with the emergence of economical, small-scale, distributed energy generation.

Put the new energy technologies and economics together, and the picture that emerges is a shift from top-down control to bottom-up management. Spontaneous patterns of organization described as complex adaptive systems emerge from the bottom. In the smart energy network every software agent is an actor capable of optimizing power operations in its own venue. The cumulative outcome is a complex adaptive system that collaboratively directs the energy network.

Networks of smart devices take complexity to "a scale where we cannot manage things centrally," notes Ron Ambrosio of IBM Research. Smart software agents within each device must be able to assess conditions of their operating environment and respond independently.

Those assessments and responses produce an environment with far more complex interactions that today's power grid. On the traditional grid energy flows outward to customers, while information concentrates in command centers and money flows from customers to billing departments. In the smart energy network, software agents conduct transactions on their owners' behalf, and information, energy and money stream in all directions.

But will a system of millions of linked smart devices work without boggling on its own complexity? How will traditional energy providers relate to all the new players? The situation resembles an auditorium with one speaker on stage, but where the entire audience suddenly wants to join in the conversation. The result will be pandemonium unless the crowd somehow organizes itself and sets up protocols for communication. As the grid moves from central to distributed control, this is exactly what must develop. The speaker up on stage may still facilitate the discussion but much of the action will move to the floor.

Talk of moving from centralized to distributed systems raises other concerns. 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? Will interactions and transactions of smart devices produce instabilities? Can the system be worked by price gougers or hijacked by terrorists?

Such questions indicate why it is absolutely critical to comprehensively explore how the new technologies mesh together in systems. Developing this comprehensive approach is the point of PNNL's work related to energy system transformation. 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. PNNL researchers aim to ground the emergence of the smart energy network by creating a framework for all its aspects from fuels and power generation through transmission and delivery to end-use.

"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."

## The Transactive Network

On a wall in a PNNL office is a motto paraphrasing a former president: "Ask not what the grid can do for you…Ask what you can do for the grid (and get paid for it!)."

The subtext of this saying is that there are many potential ways to generate value for the grid. But market niches "in between" the grid's major elements – generation, transmission, distribution and end use -- are falling through the cracks. In a smart energy network linked by a new transactive network, such niches could be discovered and filled with new technologies and new opportunities.

Transactive networks are characterized by free communication of information between parties that enables exchanges and transactions. In a transactive energy network, price signals embedded throughout the energy system enable a kind of electronic commerce for energy. The universal language of price bridges all kinds of devices and institutional boundaries, making possible distributed decisionmaking that optimizes use of resources.

The distributed software agents at the center of the transformed system create the possibility for a theoretically perfect marketplace, in which each actor has complete information and bases decisions upon rational criteria. At the same time, the malfunctioning of a very imperfect western states power marketplace in 2001, with its blackouts and price gouging, raised red flags over further opening of power markets.

The transactive network could help resolve uncertainties, putting some needed structure in restructuring by deploying technologies that let consumers control their own power use and guard against manipulation. By making information on power availability and prices transparent, the information network could shine the light on areas where gougers and manipulators might try to hide. Customers could also band together to undercut gougers in the marketplace.

For instance, a fleet of smart appliances could have protected California from price explosions in 2001. California made itself vulnerable by allowing reserve generating capacity, needed to meet unexpected spikes in demand, to drop from the standard level of 15% to around 7%. So on days when capacity was stretched, the owners of reserve plants could charge an arm and a leg and get away with it. Several million smart home appliances could have bid to reduce their demands at critical hours, in effect competing to supply the same capacity.

The smart energy network is not predicated on restructuring.  While it could make restructuring far more practical and politically feasible, it would also add value in a regulated scenario.  The distributed software agents that can transact the optimal deals in a competitive marketplace can also identify and verify the most economical investments in a regulated context, using the same universal language of price.

## Mass Customization

The transactive network could bring "mass customization" to the power market.

"The premise of mass customization is simple," says *Wired* Magazine Editor-at-large Kevin Kelly. "Technology allows us to target the specifications of a product to smaller and smaller groups of people." Customers are "given tools with which they can complete a product to their own picky specifications."

Information technology creates the potential for customers to build their own smart energy products. For example:

- Fletcher manages a computer-intensive graphic design agency. He buys premium-grade, super-reliability power to protect valuable data and equipment.
- Brian is concerned about the environment and particularly wants to support the growth of solar power, so instructs his smart meter to seek out economical solar offerings on the network.
- Mary tells her smart dishwasher and clothes dryer to turn on only during late night cut-rate power hours so she can control her power bills.
- Gayle orders all her major appliances to do as little as possible during peak cost hours, and lets her energy company occasionally turn them off in exchange for credits on her bill.

## At the Tipping Point

A number of key players have the smart energy network in their sights. The Electric Power Research Institute foresees an "intellectric network." Bonneville Power Administration has envisaged the "Energy Web" and is planning Northwest demonstrations with a series of utility and business partners. The U.S. Department of Energy GridWise™ Program and PNNL, working in conjunction with many industry players, are slating tests of energy communications and control networks. Numerous companies 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. “That makes available intellectual activities you couldn’t do before because it would take days or months to gather the data,” notes Nicholas Noecker, worldwide energy industry executive with IBM Software Group. As the ability to conduct such analysis translates into dollars,”We’re placing a lot of bets on this.”
- Whirlpool, working with PNNL's concepts for "grid-friendly™ appliances," is looking to a web-based system that enables appliances to curtail energy use on demand, share energy with other devices and provide detailed energy consumption information for owners.
- Siemens has created a Decentralized Energy Management System™ that acts as a virtual control room for distributed generator networks and optimization of electrical demand. Several pilot tests are underway in Germany.
- EnerG, a British company, manages 700 combined heat and power generators using its Distributed Intellect Monitoring System™, which provides real-time data to pre-empt and diagnose problems.
- Commonwealth Edison has automated its power delivery system by placing radio-controlled smart switches atop power poles throughout its Northern Illinois network. When the network has a problem, the

switches confer with each other and quickly isolate the trouble spot, so power can flow on the rest of the lines.

The Pacific Northwest is home to 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, uses 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, and aims to sign up 120 megawatts. The power costs less than one-third what PGE might pay on the open market for peaking energy.
- 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.

"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.

"The tipping point is when ideas start to generate ideas," chimes in PNNL scientist Dave Chassin. PNNL "used to be in the pushing mode on ideas, but now they are starting to come back to us faster than we can put them out."

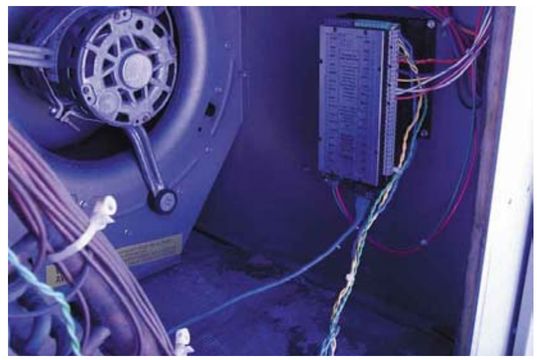
# ***Precision Power Management***

## Power Demand as a Power Resource

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. PNNL is working on a "Rooftop Diagnostician" that provides remote troubleshooting and control of heating-ventilation-air conditioning (HVAC) systems, making sure that they operate at maximum efficiency. 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. For instance, the Bonneville Power Administration announces a day in advance when it needs to reduce loads, and large customers bid back to the utility in return for favorable treatment on their bills. 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.



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. Within homes, offices, stores and factories, internal networks of sensors and microprocessors will produce tremendous energy efficiency gains that could shave $15 billion off power bills through 2020.

To understand the impact of ubiquitous information technology on the grid, consider that it is parallel to just-in-time delivery in manufacturing and retailing. Sophisticated real-time inventory systems based on computers and telecommunications have tightened distribution chains and deeply cut costs by eliminating much warehousing. New precision management capabilities offered by information technology 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 that it would theoretically need if electrical use were spread evenly over all hours of the year. But power loads peak during the day and drop at night. Standard operating procedure dictates that the number of power plants online must generate about 15% more energy than is expected to be needed to meet peak demands. Long-distance transmission systems typically

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

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 energy network will eliminate much of this "just-in-case" and peaking capacity "warehousing." New technologies will enable quicker, smaller additions of capacity that more accurately track growth. And customers will be able to make "just-in-time" responses to grid conditions that shift demand out of peaks. 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, which is 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.

## "An Army of Ants"

A PNNL presentation on grid-friendly (TM) 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. The potential number of recruits is massive. An estimated 500 million major appliances and pieces of equipment are tied to the Western U.S. grid alone. Household refrigerators, freezers, water heaters and air conditioners draw 25% of U.S. power demand during summer daytime peaks, while 5% drives HVAC units.[3] Whirlpool Advanced Electronic Applications Director Marco Monacchi calculates that the average home can move 850 watts out of peaks, much from appliances.

Electrical power managers seeking to control power loads have worked with larger customers because it has been impractical to coordinate millions of appliances. But when appliances are made grid-friendly™ -- imbued with intelligence and linked in a network -- they can be jointly managed to reduce their peak demands and help carry the grid through trouble spots. PNNL has developed prototype grid-friendly™ appliances and is working with major manufacturers to adopt this technology on a mass scale.

Smart appliance operations will in most cases have no noticeable impact on customers. For instance, smart water heaters will pre-heat water before peaks.

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[2] Capacity figures from PNNL economist Michael Warwick.
[3] U.S. Department of Energy, *Core Data Book*, 1997

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. At the same time, in instances when they aren't 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 electricity at other times of the day. The nation's largest pilot for time-of-use pricing, operated by Puget Sound Energy, was recently cancelled because many customers were actually paying more than under standard rates. So they were leaving the program in droves. The failure of this program actually makes a case for the grid-friendly™ technologies PNNL is developing, Rob Pratt says.

The Puget pilot relied on customers keeping in mind which hours to turn on and off appliances, Pratt notes. "But unless there is a technical way to lock in people's good intentions, you will lose their time and attention. Behavior change is short term." For example the owner of a standard dishwasher must remember to wait until after the peak before turning 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.

Networks of grid-friendly™ devices open the way for power customers to sell "ancillary services" to the grid. Because the pressure of electricity on the grid must be kept constant at a frequency of 60-cycles per second, electricity is used by the grid itself to preserve balance and stability. Today, generators sell electricity for these and similar ancillary services. By electronically controlling their power demand, customers could also supply these services.

While customers might opt individually to sell demand management to the power network, it would require smart meters that most will not have for some time. Even then, the money that individuals might earn will be relatively small and might not provide great incentives to purchase smart equipment. The more likely pathway for the mass emergence of the demand management market is through aggregators. These are companies that will directly sell power to customers and negotiate with power generators and deliverers for the best deals. By managing customer demand, aggregators could keep their own costs under control and earn significant amounts of money. They would have incentives to market services to the grid and help spread smart technologies to their customers.

It is important to note that shifting demand out of peaks could cause some slight increases in overall power use. When appliances are ordered to pre-heat or pre-cool before peaks, or must re-heat or re-cool after shutting down during peaks, they can require more power than if they had run at a steady rate. The prime benefit of peak shaving is economic, not environmental. By changing the shape of the daily load curve it reduces the need for peaking infrastructure. However, the environmental impacts avoided by not building 200 power plants and lines needed to transmit their production are not inconsiderable. And deploying the information backbone that makes it possible to shave peaks also creates new incentives to reduce power use through energy efficiency investments and to deploy clean distributed generation. This is detailed in the "Distributed Energy Network" section below.

## A Sample "Conversation"

So how will the smart energy network really operate? Here is one scenario.

As morning gets under way, a generator software agent tells the network, "I have X megawatts of production capacity available today at Y price." The transmission system software agent responds, "I can carry those megawatts today for Z dollars until midafternoon when extremely hot temperatures are forecast. At that time, I expect to cut loads then to protect my lines."

Meanwhile down at the distribution level, smart appliances and equipment are projecting the day's power use to smart meters, which then report expected demands to distribution software agents at substations. The aggregated information indicates heavy afternoon load from air conditioners. That information goes back to the transmission agent, which then can foresee a midafternoon pinch. In response, the transmission agent posts an offering price for demand reductions.

Distribution software agents communicate the offer to reduce demand to smart meters, which then confer with their appliances and equipment and report back. The distribution agents determine they can shut down enough water heaters during high stress hours to meet the transmission system's need. So they post demand reduction offers and the transmission agent accepts. Transmission lines reduce loads and comfortably ride out the afternoon.

By the time people arrive home to take their after-work showers, most water heaters will be back on, no one will be without hot water, and everyone involved in the deal will receive a small credit on power bills. Through a real-time conversation, the energy network has self-optimized a low-cost solution without brownouts, blackouts or costly overbuilding of transmission lines.

# *Distributed Energy Networking*

## The Big Benefits of Small-Scale Power

Bigger isn't always better. The trend in power generation today is moving toward the small, a reversal of a curve that peaked in the early '70s when utilities were building thousand-megawatt-plus plants each capable of serving a large city on its own. The big plants hit imposing economic, physical and regulatory barriers, so by 2000 the average new plant was around 100 megawatts (MW).[4] Movement toward even smaller-scale generation is accelerating. Approximately 60,000 MW of small-scale distributed generators, defined as under 10 MW, are online in North America.[5] They are mostly diesel generators and reciprocating engines, while fuel cells, microturbines and solar arrays are finding increasing markets. Distributed generation could be growing by 2,500-5,000 MW annually by 2010, the Electric Power Research Institute projects.[6] The U.S. Department of Energy aims that 20% of new electrical generator additions will be in the distributed category by 2010.

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

The distributed power market is driven primarily by the need for super-reliable, high-quality power. Small generators are finding their way into sites such as hospitals, police stations, data centers and high-tech plants which cannot afford blackouts, and which in many cases need computer-friendly power that is reliable 99.999999% of the time. The grid can only guarantee around 99.99% reliability, and millisecond outages that merely cause lights to flicker will cause costly computer crashes. 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.[7] Such high-stakes risks make it economical to

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[4] Lovins, Amory B. Et al, *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Sources the Right Size*, Rocky Mountain Institute, 2002, p35
[5] Electricity Innovation Institute, CEIDS Distributed Energy Resources Integration Element Program Plan, March 6, 2002, p1
[6] Borberly, Anne-Marie & Kreider, Jan F, *Distributed Generation: The Power Paradigm of the New Millennium*, CRC Press, Boca Raton, Fla., p18
[7] Wald, Matthew L., "Energy to Count On: Fuel Cells Tapped as Power Source for Computer Systems," *New York Times*, Aug. 17, 1999

install on-site power units even if their production costs substantially exceed grid rates. So First National powers its center with a fuel cell array.

Distributed generation brings many potential values for the overall power network as well. 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.[8]
But distributed energy's full range of values cannot be realized until it is integrated into the larger power network. That is a big sticking point. 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.[9] 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. Deploying the smart energy network is key to gaining the full benefits of distributed generation.

The Department of Energy and its labs including PNNL, as well as other research organizations, have devoted tremendous time and energy to developing innovative energy technologies, notes Steve Hauser. But these technologies have faced logjams on their way to the marketplace. The smart energy network can play a critical role in breaking those logjams by enabling "plug&play" integration that reduces the costs of installing new energy technologies, and by opening markets in which their economic value can be quickly and fully realized.

"What you want is a sustainable marketplace that will drive the use of these technologies over 20 years," Hauser says.

## Driving Distributed Energy with Smart Networks

The smart network will set up a virtuous cycle for distributed generators and energy storage devices. It will grow the market by opening up more niches where distributed energy is economically competitive. This growth will lead to economies of scale that decrease costs, making distributed energy economical in yet wider applications. A rule of thumb is that every time production quantities double the cost per unit decreases by around 20%. Thus the smart energy network will help reduce costs and break down market barriers for generation technologies such as solar photovoltaics, fuel cells and

[8] Lovins
[9] Electricity Innovation Institute, ibid

microturbines, and new energy storage technologies such as reversible fuel cells.

The market for upgrades to the power delivery system is one of the largest niches the smart network will open for distributed energy. By making it easy to connect and coordinate distributed energy 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. Large "virtual power plants" composed of many networked small generators could take demands off long-distance transmission lines.

Utilities including Pacific Gas & Electric and Ontario Hydro have uncovered a major savings potential resulting from distributed energy and its ability to avoid traditional grid investments. But turning this innovative concept into standard business practice will require changes in business cultures and regulatory frameworks. A new marketplace for grid upgrades must be created.

By making it easier to interconnect distributed energy resources to the grid, the smart network could cut installation costs and build markets for clean energy technologies such as solar.

Today utilities make long-range plans to upgrade delivery networks and then execute those plans, often with little systematic exploration of potentially cheaper alternatives. In a smart energy scenario, distribution and transmission system operators publicize upgrade plans and budgets. They challenge the marketplace to meet those needs through less expensive means. That provides an incentive for aggregators to bid packages of distributed resources, demand management and building efficiency improvements. The smart energy network's capacity to seamlessly integrate technologies reduces the costs of assembling such packages, making this new marketplace feasible.

Regulatory reforms will provide investor-owned utilities with incentives to promote innovative alternatives to traditional upgrades. Utilities guaranteed a rate of return based on capital investment have less incentive to reduce infrastructure investments or have the need met by third parties. Setting rates of return on the basis of services performed motivates 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. This system typically moves in boom-and-bust fashion from starvation to surfeit and back to starvation. Distributed resources come on line in smaller increments and far faster than large plants, so they can match demand curves more accurately. Because they come in small pieces, distributed resources entail less commitment to technologies that might later be outcompeted in the marketplace. By reducing financial risks of big investments, distributed resources also can lead to big financial paybacks. Shaving just one percent off average interest rates would reduce the power infrastructure bill $11 billion by 2020.

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. Small-scale power plants also require less environmental review and are far less likely to arouse not-in-my-backyard resistance.

The smart energy network could make it easier for owners of distributed generators to sell surplus power. While 36 states have enacted net metering laws that require utilities to take surplus power from small generators, in most cases the amount is capped well below 1 MW.[10] Utilities generally are the market for surplus production, and many have set up institutional barriers. With the smart network in place, small generator operators would have a range of potential buyers for surplus, including neighboring buildings and aggregators.

## *Environmental and Security Benefits*

### Clearing the Air

Electricity generation is the leading source of U.S. greenhouse gas emissions, with 34% of the total, the Environmental Protection Administration reports.[11] As well, it is the top sulfur dioxide emitter and near the top for emissions of mercury and oxides of nitrogen. Smart energy will be cleaner energy because improved efficiency reduces electrical demand and thus reduces power plant emissions. Building-level control systems will improve energy efficiency, while energy efficiency retrofits will find new markets as alternatives to transmission and distribution system upgrades.

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[10] Union of Concerned Scientists, State Clean Energy Policy Maps and Graphs - Net Metering, www.ucsusa.org

[11] *Inventory of U.S. Greenhouse Emissions and Sinks: 1990-2000*, U.S. Environmental Protection Administration

Another component of the smart energy network, smart software agents, can be programmed to seek power from the cleanest source. Agents representing each generating source could report current air emissions. Power customers interested in reducing environmental impacts could order their agents to buy the cleanest power available within their budgets. Smart networks also could respond collaboratively during smog alerts. Agents would be notified of air advisories, kicking in programming that has them purchase power with the lowest emission profiles. On the demand side, loads could be reduced and shifted 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 generators still can offer efficiencies that significantly beat central stations. Generating power near where it is used eliminates the standard 5-10% “line loss” leakage of power from lines. 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. And 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.

## From Brittle to Resilient Power

One of the most compelling benefits of smart energy is that the grid can heal itself. With today’s heightened focus on security, this has never been more relevant.

In 1982, Admiral Thomas Moorer, former Chair of the Joint Chiefs of Staff, and James Woolsey, later to head the Central Intelligence Agency, pointed to "one of our society's most troubling vulnerabilities -- the extremely fragile nature of the way it acquires, transmits and uses energy . . . the vulnerabilities are so numerous -- to the weather, to accidents rising from complexity, to a handful of terrorists, to the detonation of even a single nuclear weapon -- that denying the plausibility of such threats is unlikely to prove persuasive."[12]

Yet in the intervening years, energy security concerns were shoved to the backburner. Worries over energy system brittleness returned with a vengeance, however, with the terrorist attacks of Sept. 11, 2001. Not only are thousands of miles of power lines exposed and vulnerable -- attacks on a few control centers

[12] Lovins, Amory B. & Lovins, L. Hunter, *Brittle Power: Energy Strategy for National Security*, Brick House, Andover, Mass., 1982, p.iv

could effectively destabilize the grid across wide stretches of the U.S. And grounds for concern are growing.  A power grid starved for investment and increasingly stressed to meet demands is more liable to crack.

It hardly takes an Al Quaeda cell to wreak havoc in the energy network. A few days after 9-11, a wayward drunk shut down the Alaska oil pipeline for days with a single rifle bullet. On August 10, 1996, a tree branch shorted out a Bonneville Power Administration transmission line in Oregon, setting off a cascade of blackouts that darkened the Southwest from the Pacific Ocean to West Texas. California's economic losses alone were $1 billion.[13]

The smart energy network would be a system resilient in the face of troubles, capable of rapid recovery from natural and human-made disasters. Webbed with a new, information-technology nervous system, the smart energy network will exhibit adaptiveness that parallels that of biological life. 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.

PNNL is developing scenarios for how the smart energy network bounces back from troubles:

- A storm with high winds sweeps through, downing lines and blacking out power in a number of areas. Distribution-level software agents quickly detect the troubles and report the location of broken lines to repair crews. That enables linemen to more quickly restore service.   As juice begins to flow again, smart appliances turn back on in a staggered fashion rather than all at once. This avoids demand surges that could shut down power all over again.
- A power plant unexpectedly trips off, leaving a regional grid dangerously short of power to serve a large city. All residential water heaters in the city automatically shut down. While this will cause some customer inconvenience, everybody pretty much agrees this beats the rolling blackouts and brownouts that would have been the only option a few years back.
- On a scorcher day in the middle of summer, transmission lines from one region to another lose much of their carrying capacity.   This is another case where blackouts and brownouts would have once resulted.  But now the

[13] Electric Power Research Institute, *Electricity Technology Roadmap*, 1999, p21

smart energy network allocates power on a customer-by-customer basis, using "virtual" circuit breakers. So everyone will have electricity, even if it's not all they want.

- A terrorist group bombs a transmission line serving a major American metropolitan area, causing an immediate drop in available power. The smart network automatically reduces loads by turning off grid-friendly™ appliances and equipment, avoiding an area-wide outage.

Of course, realizing the energy security benefits of the smart network necessitates good electronic security. Systems must be protected against hackers and crackers (people who invade computers with the intent to destroy) with authentication procedures, encryption and intrusion detection.

## *Information Technology to the Forefront*

A team of scientists led by New York University physicist Martin Hoffert in 1998 assessed needs for stabilizing climate-disrupting greenhouse gases and the technologies needed to accomplish that stabilization. Developing technologies and deploying them at the necessary levels could require large-scale, high-priority agendas "pursued with the urgency of the Manhattan Project or the Apollo space program," they wrote.[14] A recent Hoffert-led assessment of climate-stabilizing technologies firmed that conclusion: "...a broad range of intensive research and development is urgently needed to produce technological options that can allow both climate stabilization and economic development."

Energy security concerns that came to the fore in the wake of the Sept. 11 attacks also are spurring calls for bold new energy initiatives. In a column entitled, "Let's Roll," the *New York Times'* Thomas Friedman recalled the initiative of the passengers who brought down the suicide plane in Pennsylvania. With the same spirit the nation should roll on a "version of the race to the moon," Friedman wrote, "for energy independence, based on developing renewable resources, domestic production and energy efficiency."[15]

This paper has emphasized the catalytic potential of information technology 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

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[14] Hoffert, Martin I. Et al, "Energy Implications of future stabilization of atmospheric CO2 content," *Nature*, Oct. 29, 1998, p881-4

[15] Friedman, Thomas, "Let's Roll," *New York Times*, Jan. 2, 2001

- Reduce air pollution that damages human health and the global climate.

The implications are clear – building a new Apollo program or Manhattan Project for energy technology on an information technology platform makes tremendous sense. Creating the smart network that links innovative energy technologies into a coherent system is crucial to the deployment of these new technologies.

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.

## 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, microelectronics, 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.