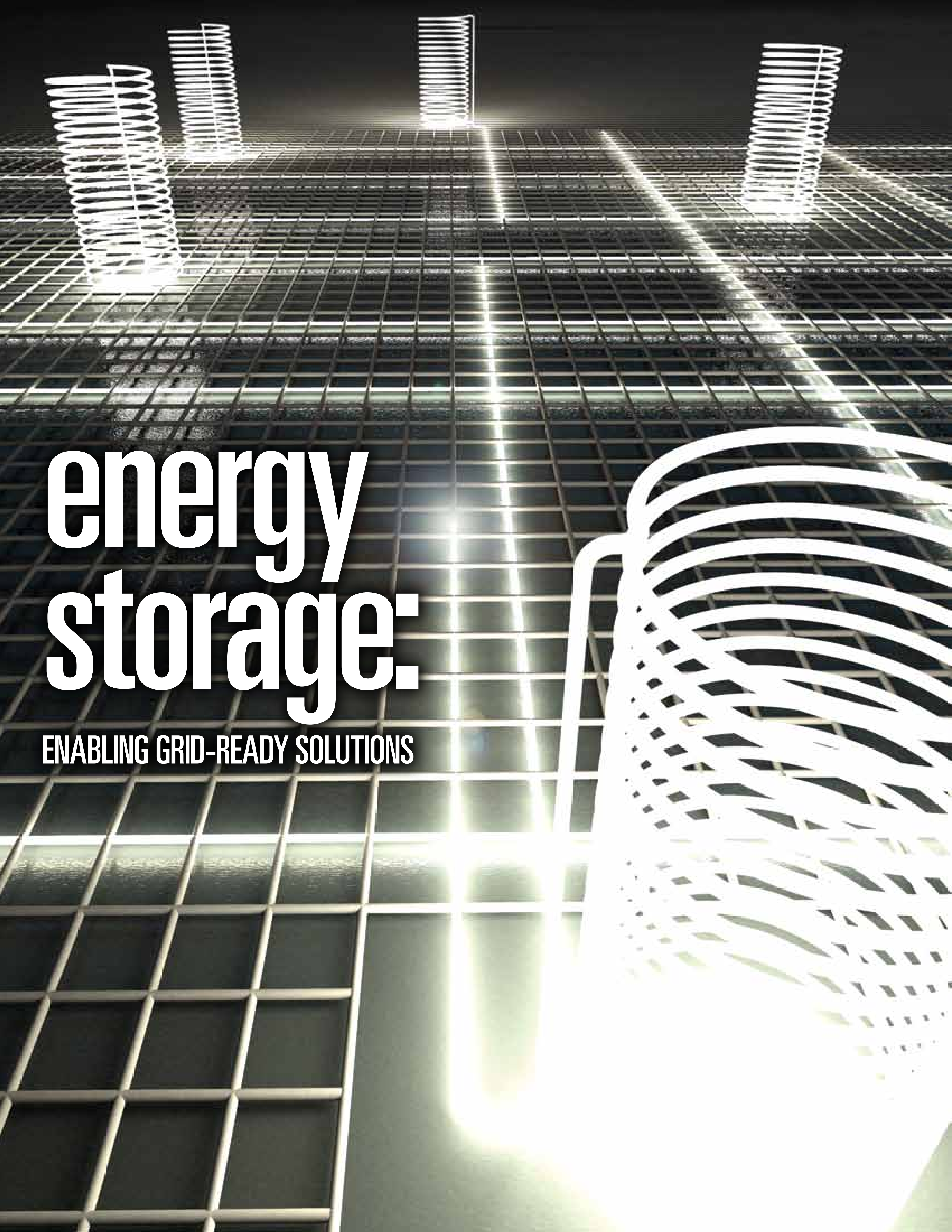

energy storage:

ENABLING GRID-READY SOLUTIONS

THE STORY IN BRIEF

Energy storage technologies could perform two essential roles in the evolving low-carbon, smart power grid: balance variable renewable generation and increase grid reliability. EPRI energy storage researchers aim to provide proven, grid-ready storage technologies within five years while pursuing longer-term efforts to develop advanced storage technologies with higher performance and lower costs.

Energy storage has played a relatively minor role in the power system, but as intermittent renewable resources, distributed generation, and advanced technologies transform the traditional power grid, storage may become a key enabler of the low-carbon, smart power grid of the future.

Moving Electricity Through Time

"Transmission and distribution systems deliver electricity where it's needed, but energy storage systems deliver electricity *when* it's needed," said Daniel Rastler, EPRI's program manager for energy storage and distributed energy resources. "By moving electricity through time, energy storage provides benefits along the entire electricity value chain."

Although there are numerous applications for energy storage, they can be grouped into two basic categories, according to Haresh Kamath, strategic program manager in EPRI's Technology Innovation organization. "The first role is balancing variable renewable generation. The second is increasing the reliability and asset utilization of the grid. Both of these roles are becoming more important because the power grid, as we know it, is changing."

In today's grid, electricity flows in one direction from central generating stations through the transmission and distribution systems to serve industrial, commercial, and residential customers. Generation is always balanced with load. But the traditional grid is undergoing fundamental changes. The addition of wind and solar resources on a large scale introduces variable generation controlled by forces of nature as much as by grid operators. Distributed generation, such as rooftop photovoltaic systems, can cause power to flow upstream in localized areas, creating voltage stability issues. Further accelerating the transformation are possible changes in energy markets and the coming smart grid, which will give consumers and utilities more control over how energy is used.

"As a result of these changes," said Kamath, "energy storage may soon be playing a more prominent role throughout the grid." Extended drop-offs in wind energy can affect operational scheduling, and clouds passing over photovoltaic systems can cause abrupt drops in power that can affect local system stability. Energy storage systems at the transmission level represent one way to increase the operational flexibility of the bulk power system to accommodate the greater penetration of renewables. Meanwhile, smaller storage systems can give utilities more control over power flows at the distribution level, increasing reliability and allowing the deferral of capacity expansion.

Energy Storage at EPRI

EPRI's energy storage strategy includes near-term and long-term goals. The near-term goal is to achieve grid-ready energy storage solutions by 2015 in three areas:

- Large-scale bulk storage as a balancing resource for renewables (providing more than 50 MW for 6 to 10 hours);
- Substation storage to allow upgrades in transmission and distribution assets to be deferred (1 to 10 MW for 2 to 6 hours); and
- Distributed energy storage systems at the neighborhood level (15 to 25 kW for 2 to 4 hours).

Grid-ready in this context means cost-effective, safe, and reliable and refers to products with proven track records. EPRI, in collaboration with utilities and technology developers, is producing a set of functional specifications that will serve as a target for energy storage products in these three areas.

"Cost has been the biggest barrier to energy storage deployment," said Rastler. To quantify the barrier, the EPRI energy storage program performed detailed application and value analyses of storage systems in 10 different applications to better estimate the total value and thus the allowable installed costs for storage systems. Findings are presented in an EPRI report, *Energy Storage Market Opportunities: Application Value Analysis and Technology Gap Assessment* (1017813), and a white paper, *Electric Energy Storage Options* (1020676), to support business case assessment for energy storage investments (see "Assessing the Cost and Value of Energy Storage," page 22).

Near-Term Focus: CAES and Lithium-Ion Batteries

From the analysis, EPRI researchers identified two leading energy storage candidates for near-term demonstrations: compressed-air energy storage (CAES), which is considered the most cost-effective bulk storage technology for long discharge durations, and lithium-ion batteries, potentially the most cost-effective option

Assessing the Cost and Value of Energy Storage

A new EPRI analysis offers the latest information on the applications, benefits, and value of energy storage technologies, from large utility-scale systems providing bulk storage for wholesale energy services to small systems providing backup power for home offices. Findings are presented in the report *Electric Energy Storage Options* (1020676), which informs industry stakeholders about available and emerging storage technologies and their status and provides cost and application value information to support business case assessment for energy storage investments.

EPRI researchers identified the top 10 key applications for energy storage in order to estimate their value and market potential. The analysis compared the present value of benefits for each application with the total costs of installing an energy storage system. These estimates are analogous to the Total Resource Cost test, which compares costs and benefits for a region as a whole, regardless of who actually pays the cost or receives the benefits.

"Each of the 10 applications is centered on a specific operational objective but provides multiple benefits," said Dan Rastler, EPRI's program manager for energy storage and distributed energy resources. "Because of the current high installed capital costs of most energy storage systems, applications—for either utilities or end users—must be able to realize multiple operational uses across the energy value chain."

According to EPRI modeling analyses, the highest-value applications are the following:

- Wholesale services with regulation;
- Commercial and industrial power quality and reliability; and
- Stationary and transportable systems for grid support and T&D capital expansion deferral.

Key customer applications are commercial, industrial, and home energy management. Most of the larger markets have estimated application values of less than $500 per kilowatt-hour of storage.

The results imply that the total energy storage market opportunity might be on the order of 17 gigawatts if energy storage systems could be installed for a capital cost of about $700–$750/kWh and the benefits estimated could all be monetized. Actual installed costs would have to be lower to accommodate life-cycle and maintenance costs. Niche high-value market sizes were estimated to total approximately 5 GW if energy storage systems could be installed for $1,400/kWh and all benefits could be monetized.

for short durations.

"Many storage technologies are relying solely on utility customers to achieve scale," said Kamath. "But it's hard to see how these technologies will achieve adoption at intermediate price points. Lithium-ion batteries and CAES technologies each have a clear, broad path to scale based on other markets—and that will bring down costs. EPRI is leading demonstration efforts with the objective of having products using these two technologies ready by 2015."

CAES plants use off-peak power to pump air into a storage reservoir, which may be an underground salt cavern, rock formation, or depleted gas field or an above-ground vessel. When power is needed, the air is withdrawn, heated, and run through a turbine to generate electricity. Two CAES plants are in operation today, a 110-MW 26-hour plant in Alabama and a 290-MW 4-hour plant in Germany. The Alabama plant, constructed as an EPRI collaborative demonstration project, has operated reliably since 1991. CAES plants respond rapidly to load fluctuations and can perform ramping duty to smooth the intermittent output of wind power as well as provide spinning reserve and frequency regulation to improve overall grid operations and stability.

In late 2009, the U.S. Department of Energy (DOE) awarded Smart Grid grants for the construction of 150-MW 10-hour and 300-MW 10-hour advanced second-generation CAES units to New York State Electric & Gas (NYSEG) and Pacific Gas and Electric (PG&E), respectively. NYSEG plans to use an underground salt cavern for the air storage system, and PG&E hopes to use underground porous rock or a depleted gas field for air storage. EPRI and utilities are planning to participate in these two projects to help build, perform technology transfer, and demonstrate these advanced, second-generation CAES systems.

Lithium-ion batteries are commonly used in consumer electronic products, which make up most of the worldwide production volume of 10 to 12 gigawatt-hours per year. Lithium-ion also is positioned as the leading technology platform for plug-in hybrid and all-electric vehicles. Compact and highly efficient, lithium-ion batteries also are prime candidates for stationary energy storage markets, such as community energy storage, commercial peak shaving, home backup energy management, frequency regulation, and smoothing the variable output of wind and solar generation.

The huge investment in lithium-ion battery fabrication facilities to serve the budding electric vehicle market presents opportunities for the electric utility and electric transportation industries to increase production volume to reduce

EPRI tested this 6-kW/20-kWh lithium-ion battery system at its Knoxville laboratory and is planning to evaluate a 25-kW/50-kWh scale-up by the end of the year. (Photo courtesy Greensmith Energy Management Systems)

Battery modules configured from lithium-ion cells are being considered for neighborhood grid support, outage mitigation, and peak management. Larger modules may provide substation support on the megawatt scale. (Photo courtesy International Battery)

costs. To that end, EPRI is evaluating a demonstration project building on the synergies between electric transportation and stationary storage applications. The project is intended to demonstrate several high-value applications for lithium-ion energy storage systems with electric utilities and evaluate the performance of technology exposed to various operating conditions. The project may involve 15 to 20 MW of lithium-ion storage systems in applications including grid support, distributed storage, energy management, renewables integration, and frequency regulation.

Long Term: Moving the Dial

Looking beyond 2015, EPRI aims to support and accelerate the development of advanced energy storage technology options with superior performance and lower costs, as well as strategic tools to improve the value of storage.

"There are gaps in our applications matrix that aren't served by our present storage technologies," said Kamath. "For example, we don't have a good solution yet that provides four to six hours of discharge in the 1-MW range. And while the costs of CAES and lithium-ion are promising for utility application, we'd like to see costs fall even further."

Among the promising advanced energy storage technologies are zinc-air batteries, a next-generation technology that offers the potential for higher energy densities and lower costs than lithium-ion. Zinc-air shares the same path to scale as lithium-ion—with initial application in portable electronics, where cost is barely an issue, followed by electric vehicles and then stationary storage. Ultimately, volume production will bring costs down. EPRI is supporting zinc-air technology as a developer-partner, providing seed funding and cost sharing to developers of fundamental technologies.

EPRI is taking a more active leadership role in the development of a no-fuel (pure adiabatic) CAES technology. Existing CAES plants require a fuel input during the generation cycle and so are not carbon-neutral. Adiabatic CAES plants store the heat of compression in thermal energy storage systems and heat the air from the thermal store during the plant's generation cycle to eliminate the fuel requirement. EPRI is developing adiabatic CAES technology in-house, with the goal of establishing proof of concept.

One Vital Part of the Solution

"No single energy storage option meets every need," said Rastler. "Instead, a portfolio of storage options that meet cost, performance, and durability requirements will be needed. But much more research is required in order to understand how storage can best be deployed in different sections of the electricity value and supply chain, and ultimately how the benefits of the various applications can be monetized."

In the low-carbon power system of the future, energy storage may play a significant role in balancing renewables, increasing grid reliability, and enabling smart grid capabilities, along with facilitating demand response, transmission expansion, and efficient use of the power delivery system.

"The only real solution is a combination of technologies and approaches," said Kamath. "And storage is a vital part of the mix. That's why we'll need grid-ready storage by 2015."

This article was written by David Boutacoff. For more information, contact Dan Rastler, drastler@epri.com, 650.855.2034, or Haresh Kamath, hkamath@epri.com, 650.855.2268.

Daniel Rastler is the program manager for energy storage and distributed energy resources in EPRI's Power Delivery and Utilization Sector. He also has managed projects in technology assessment, market analysis, and electrical integration. Before joining EPRI in 1981, he spent five years in General Electric's nuclear power business. Rastler received a B.S. in chemical engineering from the University of California at Davis and an M.S. in mechanical engineering from the University of California at Berkeley.

Haresh Kamath is a strategic program manager in EPRI's Technology Innovation program and a senior project manager in the Power Delivery and Utilization Sector, where his current research activities focus on the development, assessment, and application of energy storage technologies for both transportation and grid storage applications. Before joining EPRI in 2002, he worked at Lockheed Martin Space Systems as a product engineer responsible for spacecraft batteries. Kamath holds B.S. and M.S. degrees in chemical engineering from Stanford University.