Energy = innovation: 10 disruptive technologies

Innovation in energy technology is happening more quickly than expected—and it could accelerate economic growth and improve sustainability as early as 2015.

Matt Rogers

The world is approaching a tipping point in the development of energy technologies that could generate increases in energy productivity on a scale not seen since the Industrial Revolution.

Most of the technologies that could prove disruptive are familiar—including unconventional gas, electric vehicles, solar, and lighting from light-emitting diodes (LEDs)—yet many managers will be surprised when they arrive. That is because most organizations have been watching them develop for so many years that they find it difficult to believe that these technologies could reach scale any time soon. This view rests on a misunderstanding of the nature of technological change. The accelerating pace of energy innovation means that some technologies will achieve commercial viability much faster than most observers expect—in some cases, the shift could begin as early as 2015.

Technology may advance incrementally on the margins for long periods of time without substantially affecting established players. Indeed, developing technologies may remain uneconomical on average, even as leading innovators approach breakthroughs. But once a technology delivers cost and performance that is materially superior to the status quo, it

may well be adopted en masse. Such technologies can render existing ways of doing business untenable in less than a decade—the blink of an eye, in economic terms.

History shows that innovations in technology can cause dramatic increases in productivity, transforming industries and setting whole societies on new paths to growth. For example, the rise of wireless technology fundamentally altered telecommunications. PCs and smartphones, enabled by ever-smaller and faster chips, have revolutionized the consumer-electronics industry. And portable audio devices—starting with the Sony Walkman and continuing with the iPod—have radically transformed the way music is packaged and consumed.

Energy markets are on the verge of a similarly dramatic transformation. With prices for oil, steel, copper, aluminum, and other commodities soaring to historic highs, energy-technology innovators are taking advantage of developments in areas such as software and consumer electronics, semiconductors, and pharmaceuticals to greatly improve how the world produces and consumes energy.

The pace of change could be unprecedented. To succeed, companies must understand the major performance thresholds for each technology and the market shifts that breakthroughs will trigger. Those that are content merely to keep an eye on technological developments, betting on averages rather than positioning themselves to benefit from the cutting edge, may fail to survive in the new world these innovations create.

In the United States, five technologies have the potential to begin to affect energy productivity by 2015: unconventional natural-gas production, electric vehicles, advanced internal-combustion engines (ICE), solar, and LED lighting. Another five could do so in the period shortly after 2020: grid-scale storage, digital power conversion, compressor-less air-conditioning and electrochromic windows, clean coal, and biofuels and electrofuels. These technologies have broad applications, and they are mature enough to disrupt markets when their implementation costs drop below those of the technologies that currently dominate their industries.

The widespread adoption of any of these technologies could save customers hundreds of billions of dollars annually and help countries achieve economic growth without degrading the environment. Even if only a few of the technologies achieve breakthroughs, the world economy and the environment will benefit tremendously. These advances may also provide national-security benefits by reducing countries' reliance on fuel and other commodity imports.

While it is impossible to predict which of these technologies will thrive and to what degree, it is clear that some will. For many companies, survival will depend on the ability to navigate this "uncertain inevitability." A breakthrough in any of these technologies could mark the point of no return for an incumbent that is not prepared for it. As such, every company should take steps to ensure it is positioned to benefit if the following breakthrough scenarios come to pass.

Market impact could begin as early as 2015

Technologies that have rapidly declining cost curves and that save consumers money are developing much faster than technologies that rely on regulation to be economically viable. Each of the five technologies in this section benefits from software and consumer electronics to accelerate the rate of change, and each has six to eight competing pathways that could deliver breakthrough performance. Competition among countries introduces multiple forms of innovation to the market in parallel; Chinese low-cost engineering, Korean manufacturing scale and quality, German systems integration, and US product innovation are all important factors, and the intense competition benefits consumers. Competition among technologies (for example, solar versus wind versus natural gas and electric vehicles versus advanced ICE versus fuel cells) raises the bar and often accelerates innovation.

Unconventional gas. In the 1980s, massive unconventional natural-gas resources were identified in the United States, spurring advances in horizontal drilling, four-dimensional seismic imaging and software modeling, and hydraulic fracturing ("fracking") that enabled gas to be extracted from shale formations. The technology was implemented at scale for the first time in the early 2000s in response to significant tightening of supply in the US natural-gas market. Estimates of US natural-gas reserves were increased by 50 percent within five years, and prices fell rapidly, from more than $10 per thousand cubic feet in 2008 to about $4 per thousand cubic feet in 2011 and just over $2 per thousand cubic feet in 2012, as the market realized the new technologies could deliver low-cost gas reliably for decades. These new natural-gas supplies are already saving US consumers billions and enabling the country to reduce its emissions of greenhouse gases. The North American case is clear, and the technology has the potential to reshape global resource economics and politics as Europe, China, and India begin to evaluate and tap their unconventional natural-gas resources. While those harnessing the technology must address significant water and land-use challenges, it could still be the most important energy-technology innovation of the last 100 years.

Electric vehicles. The cost of advanced batteries is dropping precipitously. In 2009, advanced batteries cost about $1,000 per kilowatt hour. New battery-manufacturing facilities were able to deliver batteries at just over $500 per kilowatt hour in 2010, and the price could drop to $350 per kilowatt hour when these facilities reach full-scale production over the next few years. The cost of batteries could reach total-cost-of-ownership parity with ICE when the price drops to $250 per kilowatt hour, at which point the global market could increase to 15 million to 20 million sold per year, from 1 million to 2 million sold per year today. Of course, it could take three to five years from the time batteries become cheap until automakers can integrate these new designs into standard automotive platforms, pushing back consumer-benefit time-lines. Nevertheless, once these vehicles are available on the market, the resulting improved fuel economy could save consumers more than $500 billion annually in the near term, replacing high-cost, mostly imported oil with lower-cost domestic electricity. Moreover, customers are discovering that electric vehicles often deliver better acceleration, safety, and comfort and may be able to support new vehicle-design innovations better than traditional technologies.

Advanced ICE. US corporate average fuel economy (CAFE) standards remained flat for nearly three decades, at 27.5 miles per gallon, while vehicle technology continued to improve. New CAFE standards will require automakers to achieve 35.5 miles per gallon in 2016 and 54.5 miles per gallon in 2025. Even then, US standards will remain below the European and Chinese standards that define automotive requirements in the rest of the world. Consumers are demanding vehicles that are more fuel efficient, and the material science and software controls are now in place to deliver them. Consumers stand to save almost as much from improvements made to the internal-combustion engine as they do from breakthroughs in electric vehicles—the competition among technologies is likely to create more attractive high-efficiency, low-cost alternatives for consumers.

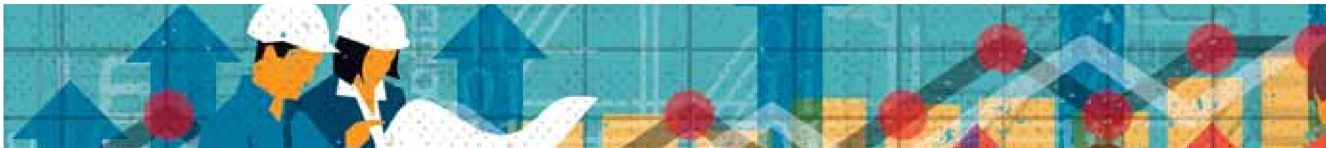
Solar photovoltaics (PV). The installed cost of solar power has fallen to about $2.50 per watt in 2012, down from $4 per watt in 2011, and from about $7 to $8 per watt as recently as 2009. The US solar market grew by about 40 percent due to the US stimulus program in 2009 and 2010, mirroring the global rate of growth driven by similar incentives provided in Germany, Italy, Spain, and China. Subsidies are likely to dry up, but the momentum could continue, supported by significant innovations in manufacturing scale, quality yield, and "balance of system" costs, potentially driving solar prices down to $1.50 per watt by 2015 and to less than $1 per watt by 2020. At these prices, solar PV will be preferable to retail electric prices for most new homes and big-box commercial businesses in sunny markets, providing an alternative to traditional power sources.

LED lighting. Lighting accounts for almost 15 percent of US electricity demand. LEDs, which rely on semiconductors, benefit from rates of improvement dictated by Moore's Law. Software increases the value in LEDs by adjusting their energy use based on needed lighting levels. A 100-lumen LED bulb cost $20 in 2011, down from $50 in 2009. The price should drop to between $8 and $10 for a 170-lumen bulb by 2015, which would render incandescent and compact-fluorescent bulbs obsolete. LED lighting currently accounts for approximately 2 percent of the global lighting market, but it could represent 30 percent by 2015 and 80 percent by 2020. If LED lighting reaches these levels, global consumers could save more than $50 billion annually by 2015 and more than $100 billion annually by 2020, which could enable a 1.5 percent decline in US electricity demand per year, the equivalent of more than 30 base-load power plants.

Market impact after 2020

Scientific and engineering innovations will be required for a subsequent wave of energy technologies to reach commercial scale at viable costs. These technologies will also likely depend on regulations to expand available markets. Not all of these technologies will succeed in the market—they will only earn a place if they can outdo top performers from the earlier wave. If successful, however, these technologies could render some of the earlier innovations obsolete.

Grid-scale storage. A variety of technologies, including batteries, flywheels, and ultracapacitors,



are being developed to enable large-scale storage of electricity within electric power grids, many of which are following an innovation pattern similar to auto batteries. Today, grid storage costs about $600 to $1,000 per kilowatt hour and can be used only when local geology supports pumped hydro or compressed-air storage systems. Innovations that make use of flow batteries, liquid-metal batteries, and other technologies could reduce costs to between $150 and $200 per kilowatt hour by 2020 and make it possible to provide grid storage in every major metropolitan market. At these prices, the United States alone would want to build more than 100 gigawatts of storage over a decade (the capacity equivalent of the current US nuclear generation fleet), significantly improving reliability and making solar, wind, nuclear, and coal much cheaper to deliver. Power companies can also use storage to smooth variability in power supply, which is more extreme for renewable technologies than for traditional generation technologies; doing so would significantly reduce distribution capital requirements.

Digital power conversion. Edison and Westinghouse invented large-scale, high-voltage transformers in 1885, setting the stage for widespread development of the electrical grid. The technology in use today remains virtually unchanged. A typical transformer costs $20,000, weighs 10,000 pounds, and takes up 250 cubic feet. High-speed, very reliable digital switches made of silicon carbide and gallium nitride have been developed for high-frequency power management in military contexts. They use 90 percent less energy, take up only about 1 percent as much space, and are more reliable and flexible than existing transformers. These digital transformers could begin to replace conventional technology at less than one-tenth the cost by 2020. China is particularly well positioned to benefit from adopting digital power electronics due to the scale of grid expansion it has planned.

Compressor-less air-conditioning and electrochromic windows. Today, it costs about $3,000 to $4,000 per year to run a high-efficiency air conditioner in a hot region, and the efficient windows now in common use allow 50 percent of this cooling energy to escape. New compressor-less air conditioners and electrochromic window technologies offer the potential to cut home heating and cooling bills in half. Today, these technologies are expensive, but by 2020, they could begin to cost only about half as much to install as current state-of-the-art cooling and window technologies.

Clean coal. Carbon capture and sequestration currently costs $8,000 to $10,000 per kilowatt. Innovative processes now under development could help coal-fired generators in the United States capture more than 90 percent of their carbon dioxide, enabling them to meet stringent new Environmental Protection Agency pollution-control requirements. Generators should be able to retrofit their existing plants with new clean-coal technology for less than $2,000 per kilowatt. About 200 US coal plants are currently slated for closure by 2020 due to their high cost relative to natural gas and their pollution output. New clean-coal technologies could enable many of these plants and similar plants in Europe and China to remain open for decades. However, clean-coal technologies are unlikely to be deployed at scale unless supportive carbon regulations are put in place.

Biofuels and electrofuels. With crude-oil prices reaching $100 per barrel, biofuels such as cane and corn ethanol have already rapidly increased their market share. But the supply of biofuels is limited by demand for food and the declining quality of available land, which drives costs up and minimizes the potential for growth. Genetic innovations that enable the use of cellulosic and algae-based biofuels can free producers from these constraints. The most innovative start-ups in this area are creating high-margin specialty chemicals and blend stocks, generating cash now and providing a pathway to begin to deliver biofuels at $2 per gallon or less by 2020. At the same time, biopharmaceutical researchers are developing electrofuels pathways that feed carbon dioxide, water, and energy to enzymes to create long-chain carbon molecules that function like fossil fuels at one-tenth the cost of current biofuels. The key question is whether these new technologies can scale.

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Not every technology we have discussed will come to fruition, but some will—and those that do will change energy markets dramatically and for good. Companies must understand cutting-edge technology if they want to succeed in the energy markets of the future. In particular, they must develop the ability to understand the technology road maps coming out of the software and consumer-electronics sectors and track innovators in key markets. They must know what particular countries are doing in their areas of competitive advantage, including understanding balance-of-system costs in China, consumer electronics in Japan and Korea, and the impact of software on product economics in Germany and the United States. Finally, companies must be aware of the price and performance thresholds that will trigger massive shifts in demand for each relevant technology. Those that neglect what is happening on the margins today put themselves at risk of being pushed to the margins themselves in the not-too-distant future.

Matt Rogers is a director in McKinsey's San Francisco office.