ARGUMENT

The End of OPEC

Forty years after the Arab oil embargo, new technologies are dramatically reshaping the geopolitics of the Middle East

BY AMY MYERS JAFFE, ED MORSE

Forty years have passed since the Arab oil embargo went into effect on Oct. 16, 1973, triggering a period of incredible change and turmoil. After the United States provided

support to Israel during the Yom Kippur War, a cartel of developing-world countries (via the Organization of the Petroleum Exporting Countries, or OPEC) banned the sale of their oil to Israel's allies and thereby set in motion geopolitical circumstances that eventually allowed them to wrest control over global oil production and pricing from the giant international oil companies -- ushering in an era of significantly higher oil prices. The event was hailed at the time as the first major victory of "Third World" powers to bring the West to its knees. Designed in part to bring Arab populations their due after decades of colonialism, the embargo opened the floodgates for an unprecedented transfer of wealth out of America and Europe to the Middle East. Overnight, the largest segment of the global economy, the oil market, became politicized as never before in history.

But four decades later, the shoe may finally be on the other foot. Now, on the 40th anniversary of the 1973 embargo, the United States has a historic opportunity to lead a counterrevolution against the energy world created by OPEC as innovation in the U.S. energy industry looks poised to end the decades-long, precarious "dependence on foreign oil." Washington should seize the opportunity and push to democratize energy globally, just as its Silicon Valley giants have democratized information.

In the run-up to 1973, two-thirds of global ownership of oil moved from the private sector of American and European companies to public-sector national oil companies. Rather than let the forces of supply and demand determine prices, post-1973, the lowest-cost oil producers, such as Saudi Arabia, Iraq, and Iran, artificially shut production and discouraged capital investment, creating a lasting wedge of rents or financial profitability that market conditions never warranted. (Today, oil prices in real terms are more than four times higher than in 1972.) A massive industrial restructuring occurred over the course of a half-decade, as state-owned enterprises, with limited project-management skills and bloated workforces, surpassed the oil majors like Chevron and Shell in both capitalization and size.

The 1970s witnessed a profound and unprecedented transfer of wealth to the Middle East that continues to have significant repercussions today -- from democracy movements to terrorism to civil wars**.** The region's leaders failed to set up long-term mechanisms to distribute the benefits of that wealth transfer broadly to their populations and to establish an equitable stake in governance of resource proceeds that would have brought a newfound stability to the region. Instead, they bought lavishly, gilding their palaces and buying fleets of luxury autos. For decades, they squandered the opportunity to use oil wealth to modernize their societies and train their populations for future global economic competition. The result -- unfolding not just in the Middle East but in other oil-producing countries as well -- is a crisis of governance that is itself triggering a round of oil-supply disruptions.

Massive petrodollar inflows brought with them a new political paradigm of "rentier" patronage, characterized by financial excesses, corruption, repression, and billions of dollars in accumulated weapons purchases. Populations of oil-producing states, for the most part, are little better off today than in 1973. Many of the countries have been war-ravaged or riven by sectarian hatreds. And, even with decades of relatively high oil prices and associated worker remittances, most countries of the Middle East still see modest GDP per capita, below $30,000 person on a purchasing-power-parity basis.

Deep income inequality means that much of the region's population is in fact still living in poverty, even in places like Saudi Arabia. So it should be no surprise that 40 years after the 1973 embargo, citizens of the region are rising up against those who squandered their futures. Tired of waiting for the day when rising oil revenues would somehow magically bring back the promise of prosperity, youth are taking to the streets; port and oil workers are mounting strikes; and jihadists are taking up arms to end the oil curse once and for all. Their frustrations do not unfold in a vacuum. High oil prices associated with all this unrest is propelling energy investment elsewhere to great success. Energy efficiency is also getting a boost, shrinking the long-term market for Middle East oil. The upshot will be that it will be

harder and harder over time for Arab rulers to count on oil money to keep them in power. And that has a trickle-down effect to the populations they've been keeping quiescent with handouts for decades.

Ironically, just when political revolutions were gaining momentum across the Middle East, a different kind of revolution was emerging that looks likely to bring a new epoch of dislocation and distortion to prevailing oil and gas structures. This second energy revolution is also ameliorating the impact of the first.

Since January 2011, at the dawn of the rebellions against dictatorial governments in North Africa, the amount of oil "offline" or being blocked from production by either domestic turmoil (in Iraq, Nigeria, Sudan, Syria, Yemen) or international sanctions (in Iran) has generally been above 2 million barrels per day (m b/d), four times the average level of supply outages before the so-called Arab Spring. Then Libya erupted once again this past summer, taking another 1.2 m b/d, or more, offline. But the impact of these disruptions has been relatively mild, given that over the same period, production in North America, the heartland of the three revolutionary changes in unconventional hydrocarbon production (shale, deep water, and oil sands), has grown by more than 2.5 m b/d. And more is on the way.

Growth in renewable energy has also been significant in recent years in the United States and beyond, and rising fossil fuel costs and strong government intervention have created new market opportunities. World biofuels production has doubled to over 1.2 m b/d since 2006, but wind power has grown in oil-equivalent terms from 1 m b/d to 2 m b/d since 2008 (and is accelerating at about a 20 percent annualized clip). Solar power, meanwhile, grew from 20,000 b/d of oil-equivalent energy in 2008 to 400,000 b/d last year.

But the impact of all this change in the energy world will go far beyond just replacing continuing Arab Spring outages. Unconventional oil and gas and the clean-tech booms are spawning a host of new, smaller oil and gas exploration companies committed to innovation

and willing to take on risk. They have no stake in the multibillion-dollar megaproject world of the international majors and national oil companies, and as such, they have fewer concerns about sustaining high profits from giant assets found decades ago. They are enabling the United States the opportunity to take a lead in changing the way energy is bought and sold -- not just in the United States, but globally.

Energy innovation is taking many forms in the United States, creating major export opportunities and giving Washington the tools it needs to ensure that the conditions of a 1973-style oil embargo will not repeat themselves. The oil embargo was so devastating because strong economic growth throughout the 1960s had taken up the margin of spare oil-productive capacity in the United States and across the world, leaving the Middle East's oil producers with undue monopoly power. Similar razor-thin extra productive capacity left markets highly vulnerable in 2006 and 2007, when OPEC made contraseasonal cuts in output to increase prices, instead of considering the risks to global economic growth. But as oil and gas production from U.S. and Canadian shale formations rises, the ability of oil producers like Russia to use an "energy weapon" to gain extra benefits from consuming countries is diminishing.

U.S.-led innovation in alternative fuels (including natural gas-vehicle fueling technology and electric vehicles), energy-efficiency technologies, battery storage, and smart-grid solutions, working together with and complementing the supply surge in unconventional oil and gas, should also change the face of demand, giving consumers around the world more freedom of choice. And as the United States becomes an energy exporter -- at competitive prices -- that should seal the deal. By providing ready alternatives to politicized energy supplies, the United States can use its influence to democratize global energy markets, much the way smartphone and social media technologies have ended the lock on information and communications by repressive governments and large multinational or state-run corporations.

Abundant U.S. natural gas is just the first step. Booming domestic natural gas supplies have already displaced and defanged Russia's and Iran's grip on natural gas buyers. By significantly reducing American domestic requirements for imported liquefied natural gas (LNG), rising U.S. shale gas production has had the knock-on effect of increasing alternative LNG supplies to Europe, breaking down fixed pricing from entrenched monopolies. But this is just the beginning: Over the coming decade, the United States looks likely to overtake Russia and rival Qatar as a leading supplier of natural gas to international markets.

The geopolitical role of U.S. natural gas surpluses in constraining Russia's ability to use its energy as a wedge between the United States and its European and Asian allies should strengthen over time, to the extent that Barack Obama's administration stays the course with approving the construction of LNG export terminals. American unconventional oil and gas plays from Texas to Pennsylvania are also generating new surpluses of natural gas liquids, which are increasingly exported as transportation fuel or petrochemical feedstock to Europe, Asia, and elsewhere -- reducing demand growth for oil from the Middle East. And U.S. crude oil exports might also be possible some day, strengthening America's lead in market-related pricing for kingpin crude oil, much the way rising North Sea production did in the 1980s.

As an increasing number of companies and investors flock to North America to develop prolific unconventional resources, Middle East heavyweights like Saudi Arabia, Kuwait, and Iran are losing their lock on remaining exploitable reserves, reducing their ability to band together and create artificial shortages. Already, Mexico and Argentina are reading the tea leaves and reversing protectionist resource nationalism policies, instead pushing through reforms to attract capital investment to their doorsteps.

Abundant U.S. natural gas is also spawning new American-designed engine and modular fueling station technologies to readily use natural gas as a fuel in trucks, trains, and ships, ending oil's monopoly in transport. Some 40 m b/d of the global 85 m b/d oil market is open for competition from natural gas -- in the form of compressed natural gas for cars and buses,

and LNG for heavy-duty vehicles and marine transportation. We conservatively expect at least 2 m b/d of currently projected oil demand to cede to natural gas by 2020, further weakening perspectives on future global oil-demand growth and once again chipping away at Middle Eastern influence.

American innovation and exports of energy supply and technology will open global energy markets to competitive investments and consumer choice. But Washington needs to embrace this choice by resisting the call to continue to ban energy exports to protect vested business interests or for resource nationalistic reasons. Indeed, we need to reverse the mindset of the oil embargo years -- a mindset of supply shortages and husbanding of resources -- and move back to a more traditional promotion of free markets. The energy sector has done this in the trade of petroleum products, where the United States is simultaneously the world's largest importer and exporter. The United States is heading in this same direction for trade in natural gas, whether by pipeline to Mexico and eastern Canada or the export of LNG. And it should move in the same direction with crude oil exports as pressures mount from growing surpluses midcontinent and on the U.S. Gulf Coast.

The expanding wind and solar businesses in California and Texas are encouraging new complementary battery-storage options and smarter networks, laying the groundwork for greater consumer choice and control. The move to distributed energy, right now focused mainly on affluent customers who can afford private backup generation, may spread to broader applications. Some day soon, it will enable increased remote energy solutions for villages in sub-Saharan Africa or Southeast Asia.

The U.S. government needs to support the reform of the electricity utilities to enable this transition, which will entail more-efficient technologies, locally produced and distributed generation, time-of-day pricing and peak-demand shaving. Such reforms are critical to the integration of renewable energy whose output varies widely over the course of a day. By leading the charge to these new energy technologies, the United States can fashion a global

energy world more to its liking, where petropowers can no longer hold car owners hostage or turn off the heat and lights to millions of consumers to further geopolitical ends.

Just as it was difficult to predict the impact of Apple computers on future global social trends, it may now seem hard to depict the exact time and place that America's unconventional resources and smart-grid innovation will democratize energy markets. But Apple did reset the way we think about computing and changed the world. Similarly, the dislocations currently unfolding in the energy sector are pointing to markets taking back pride of place over government control and consumer choice winning over supplier monopolies. The pace of change may be slow in coming at first, but eventually it will be no less stunning than Oct. 16, 1973, a day that sent shock waves into the global economy, the ripples of which are still visible today.

MARK RALSTON/AFP/Getty Images

http://www.foreignpolicy.com/articles/2013/10/16/the_end_of_opec_america_energy_oil

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Are you ready for the resource revolution?

Stefan Heck and Matt Rogers

Meeting increasing global demand requires dramatically improving resource productivity. Yet technological advances mean companies have an extraordinary opportunity not only to meet that challenge but to spark the next industrial revolution as well.

Most cars spend more than 95 percent of their time sitting in garages or parking lots. When in use, the average occupancy per vehicle is well below two people, even though most cars have five seats. Roads are likewise extremely inefficient. Freeways can operate at peak throughput (around 2,000 cars a lane per hour) only when they are less than 10 percent covered by cars. Add more, and congestion lowers speeds and reduces throughput. Most roads reach anything like peak usage only once a day and typically in only one direction. For a visualization of these dynamics, see Exhibit 1.

The story is similar for utilities. Just 20 to 40 percent of the transmission and distribution capacity in the United States is in use at a given time, and only about 40 percent of the capacity of power plants. The heat-rate efficiency of the average coal-fired power plant has not significantly improved in more than 50 years—an extreme version of conditions in many industries over the past century. Automotive fuel-efficiency improvement, for example, has consistently lagged behind economy-wide productivity growth.

Underutilization and chronic inefficiency cannot be solved by financial engineering or offshoring labor. Something more fundamental is required. We see such challenges as emblematic of an unprecedented opportunity to produce and use resources far more imaginatively

and efficiently, revolutionizing business and management in the process. Indeed, rather than facing a crisis of resource scarcity, the world economy will be revitalized by an array of business opportunities that will create trillions of dollars in profits.

To put this new era in context, think back to Adam Smith's *The Wealth of Nations* (1776), which identified three primary business inputs: labor, capital, and land (defined broadly as any resource that can be produced or mined from land or disposed of as waste on it). The two industrial revolutions the world has thus far seen focused primarily on labor and capital. The first gave us factories and limited-liability corporations to drive growth at scale. The second, from the late 1800s to the early 1900s, added petroleum, the electric grid, the assembly line, cars, and skyscrapers with elevators and air-conditioning, and it created scientific management, thus enabling corporate globalization. But neither revolution focused on Smith's third input: land and natural resources.

Our argument is relatively simple:

- Combining information technology, nanoscale-materials science, and biology with industrial technology yields substantial productivity increases.

- Achieving high-productivity economic growth in the developing world to support the 2.5 billion new members of the middle class presents the largest wealth-creation opportunity in a century.

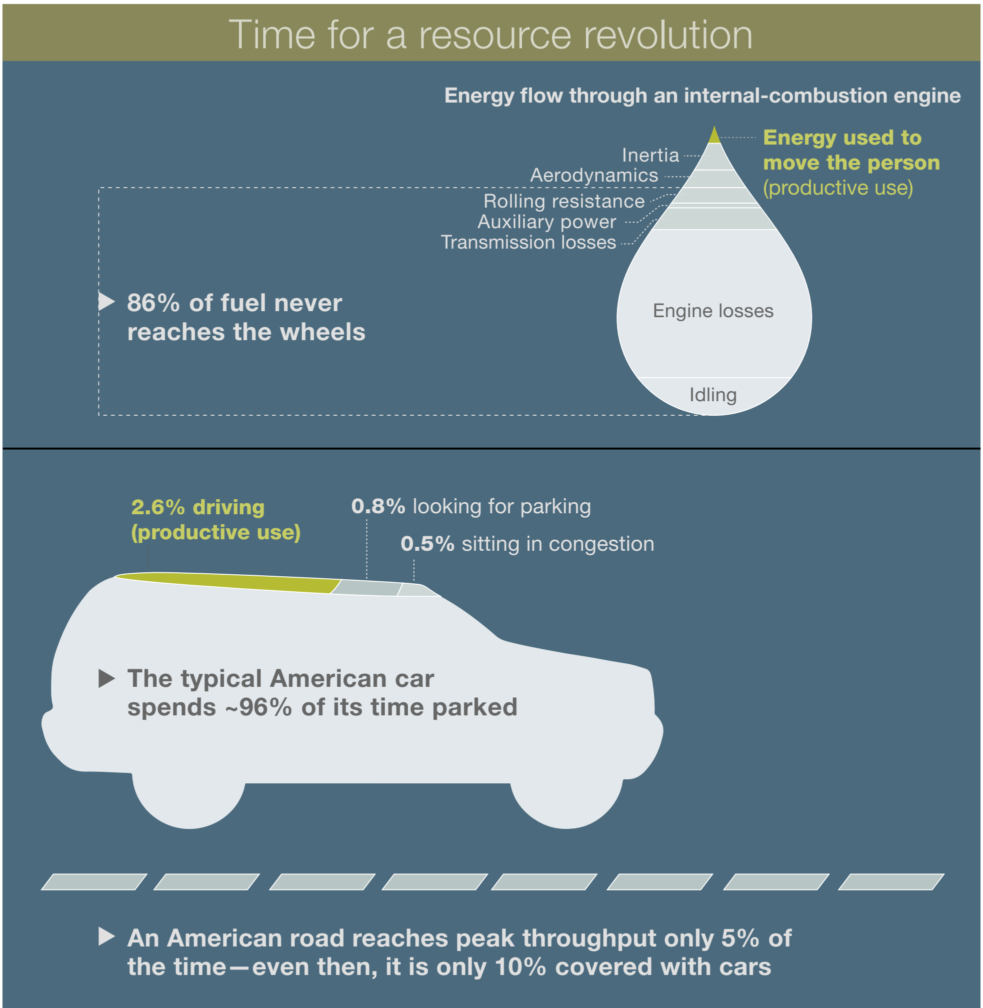
- Capturing these opportunities will require new management approaches.

Rather than settling for historic resource-productivity improvement rates of one to two percentage points a year, leaders must deliver productivity gains of 50 percent or so every few years (Exhibit 2).

The outlines of this next industrial revolution are starting to come into sharper focus: resource productivity is the right area of emphasis, and the opportunities for companies are extraordinary. In this article, we'll explore the business approaches most likely to unlock the potential and then highlight ways senior managers can integrate tomorrow's new technologies, customers, and ways of working with the realities of today's legacy business environment.

Exhibit 1

Stuck in neutral: cars are notoriously underutilized and inefficient.



Source: Amory B. Lovins and the Rocky Mountain Institute, *Reinventing Fire: Bold Energy Solutions for the New Energy Era*, 2011; Wolfgang S. Homburger, James H. Kell, and David D. Perkins, *Fundamentals of Traffic Engineering*, 1992

Winning the revolution

We believe the businesses that capitalize most successfully on the resource revolution will employ five distinct approaches, either individually or in some combination. We explore all five of them in our new book, *Resource Revolution*, but focus here on three: substitution (the replacing of costly, clunky, or scarce materials with

less scarce, cheaper, and higher-performing ones); optimization (embedding software in resource-intensive industries to improve, dramatically, how companies produce and use scarce resources); and virtualization (moving processes out of the physical world). The remaining two are circularity (finding value in products after their initial use)[1] and waste elimination (greater efficiency, achieved by means including the redesign of products and services). For more on the waste-elimination approach, see "Bringing lean thinking to energy," on mckinsey.com.

Businesses that have harnessed these five models include Tesla Motors, Uber, and Zipcar (now owned by Avis) in transportation; C3 Energy, Opower, and SolarCity in power; Hampton Creek Foods and Kaiima in agriculture; and Cree, DIRTT, and Nest Labs in buildings. As we show in our book, these companies have the potential to upend traditional competitors and create previously unimagined business models. For examples of what this might look like at scale, see the sidebar, "Twelve companies of tomorrow."

Substitution

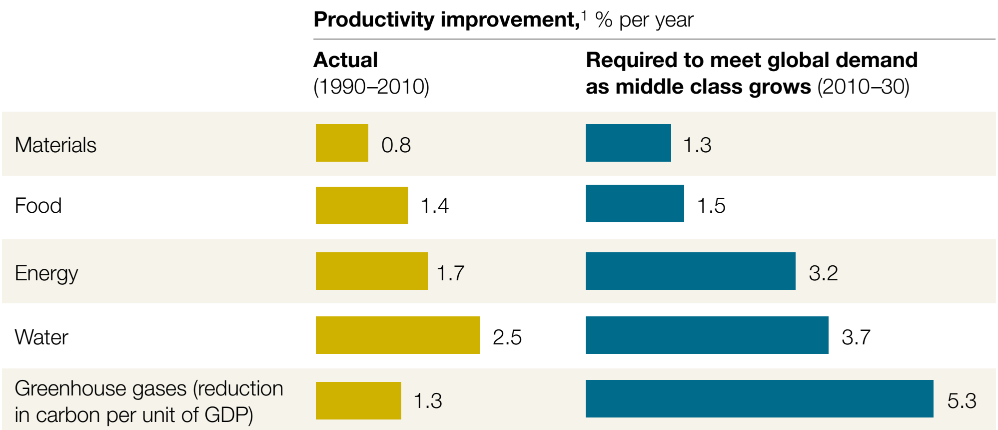
The guiding principle for substitution is to consider every resource a company uses in its core products and every resource customers use or consume and then to look for higher-performing and less expensive, less risky, or less scarce materials that might work as substitutes. But don't think of the new resources as replacements for the current bill of materials. Look instead at how substitution might deliver superior overall performance, much as electric motors are more efficient and provide better safety and acceleration than traditional internal-combustion ones. Carbon fiber, for instance, not only saves weight but allows companies to build quieter, better-performing, more efficient, more comfortable, and more beautiful cars (Tesla) or airplanes (Boeing's Dreamliner).

These opportunities are extraordinary because many new materials have begun to reshape industrial and consumer products. A much richer understanding of materials science at the nanoscale level, combined with advanced computer-processing power, has catalyzed a broad revolution in surface properties, absorption characteristics, and optical and electrical properties.

[1] Our McKinsey colleagues Hanh Nguyen and Martin Stuchtey, along with McKinsey alumnus Markus Zils, discuss the circularity approach in "Remaking the industrial economy," *McKinsey Quarterly*, February 2014, on mckinsey.com.

Exhibit 2

A step-change improvement in resource productivity is required to sustain GDP growth.



[1] Productivity improvement in energy measured in GDP/Btu (British thermal unit); materials, GDP/metric ton; water, GDP/cubic meter; food, yield/hectare; and greenhouse gases, GDP/ton of carbon-dioxide equivalent.

Source: *Resource Revolution: Meeting the world's energy, materials, food, and water needs*, McKinsey Global Institute report, 2011

For example, activated carbon, typically made of nanoparticles with custom-engineered pore sizes, is dramatically improving the efficiency of water filters, electrodes in batteries, and potentially even power-plant exhaust scrubbers. For the first time since the development of leaded crystal, centuries ago, glass is being reinvented—from high-bandwidth optical-networking fiber to Corning's Gorilla Glass, which allows touch screens to capture the imagination in portable devices and, soon, on larger interactive screens. A company called View is even creating "dynamic glass," which changes its visible- and infrared-light transmission characteristics so that windows can be programmed to block the sun on hot days but to capture sunlight in the depths of winter. That would reduce the need for heating and air-conditioning in Mediterranean climates, where cool nights mix with hot days.

Substitution extends even to food production. Hampton Creek Foods, for instance, has developed a plant-based egg substitute for baked and processed foods. Called Beyond Eggs, it uses peas, sorghum, beans, and other plants to make a product that tastes like eggs and has the same nutritional properties. The company says its process is already

nearly 20 percent less expensive than the production of eggs, and costs will fall as scale increases. Hampton Creek also says its product will suffer less from drought. At the moment, about 70 percent of an egg's cost comes from corn, a crop susceptible to drought and increasingly linked to the price of oil, while Hampton Creek uses hardier crops and therefore does not compete with biofuels (or risk salmonella infections). So, Hampton Creek's egg substitute may cut costs and risks for major food producers.

Spotting substitution opportunities takes hard work. Apple and GE have gone through the periodic table element by element, assessing which ones pose the biggest risks for supply, costs, and regulation. These companies have developed substitution opportunities for each risky element. Similarly, we recently completed a review for a major oil company, looking at the resource risk in its supply chain, and found that the lack of available water would probably cut its growth sharply below expectations over the next decade. Looking a decade ahead gives companies a time advantage over competitors in responding to potential constraints.

Optimization

Another way for companies to boost the productivity of existing resources is to optimize their use—for instance, by integrating software into traditional industrial equipment or providing heavy equipment as a service, something most businesses can do at every level of activity.

GE, for example, outfits its jet engines with advanced software and sensors that yield important real-time maintenance data midflight. As a result, planes can radio ahead with spare parts and servicing requirements before they land. GE often prices its maintenance per hour of flight, so anticipating and streamlining maintenance activities is critical to business profitability.

Komatsu, the industrial-equipment manufacturer, goes even further, optimizing the use of its equipment essentially by creating a market that lets customers rent to and from each other. Need a $300,000 earth mover for just a few days? Komatsu will help find one that would otherwise be sitting idle. Have unused equipment? Komatsu will help find a company to rent it.

Some methods of optimization are surprisingly straightforward. UPS reduced fuel consumption and improved safety and speed by rerouting its trucks to avoid left turns. We helped a large utility shave 30 percent off its meter-reading costs just by restructuring service routes to reflect new traffic conditions and customer-use patterns. And the US Air Force is optimizing fuel consumption by having some of its planes fly in convoys. The new patterns, which copy the way geese “vortex surf” in V-formation, save up to 20 percent on fuel—a huge amount for one of the world’s largest fuel consumers. Implementing the new configuration was not expensive. Maintaining the precise separations between planes required nothing more than changing a few lines of code in the autopilot. Pilots also needed some training not to override it manually.

As companies consider which opportunities have the most potential, the guiding principles should be these: What expensive assets could be integrated with software and sensors? Which pieces of equipment are used only for a small portion of the time? What energy-intensive equipment is active without performing a function? This could be construction equipment, shipping containers that go back empty, or simply planes circling airports waiting for congestion to clear. All lend themselves to IT solutions that optimize routing, timing, loading, or sharing.

Virtualization

As a thought experiment, create a list of physical objects or products that you no longer own or use, even though they were an everyday part of your life just five or ten years ago. For many people, that list might well include traditional calculators, paper calendars, cameras, alarm clocks, or photo albums. All of these have been rendered virtual by smartphone technology.

Virtualization means moving activities out of the physical world or simply not doing things, because they’ve been automated—and both challenge business models. Companies struggle to embrace virtualization because they don’t want people to stop doing things that generate revenue, which always seems to drop more than costs do when activities move into the virtual realm. Look at newspapers, which get from a digital ad just 16 percent of the revenues they got from a comparable print ad.

Likewise, car companies don't want people to drive less, but that's what's happening in developed countries. Miles driven per capita peaked in 2004 in the United States and have declined steadily since. The reasons aren't entirely clear yet: the decline started before the recent recession and has continued even as the economy rebounded. Higher gas prices are surely a factor, but probably more important is the fact that many people are doing things virtually that they used to do by hopping into cars. For example, the recent holiday shopping season demonstrated how much Americans now rely on online purchases. Even US teenagers have shown a declining interest in driving, according to statistics on the age when Americans get their first license (the ability to connect via social media being a possible reason). Skype and other video-chat applications further reduce the need to drive somewhere to see someone. Work, too, is becoming more virtual as people increasingly use online media and virtual private networks to connect productively without needing an office. Virtualization will happen whether companies want it or not, so they need to prepare themselves.

Nest Labs, a start-up purchased by Google, has already shown what's possible. The company took a traditional, boring, analog piece of equipment—the thermostat—and turned it into a digital platform that provides dynamic energy and security services (and could one day deliver entertainment, health care, security, and communication services to homes). Several years ago, it would have been hard to imagine ordinary alarm clocks going virtual.

What's next? Could everyday items like eyeglasses, keys, money, and wallets soon disappear in the same way? Do cars and trucks need drivers? Should drones deliver packages? Can IBM's Watson and other expert systems provide better and safer maintenance advice in industrial settings?

The integration challenge

Making the most of any of these models represents a huge change to the way companies operate, organize, and behave. The influence of big technological changes, among them the rise of big data and

the Internet of Things,[2] guarantees that for most companies, the biggest initial challenge will be systems integration: embedding software in traditional industrial equipment. Building and running these systems represents one of the biggest managerial challenges of the 21st century.

Going far beyond the current networks of phones, roads, and the like, the most complicated and powerful network yet is now being built. In it, devices embedded in power lines, household appliances, industrial equipment, and vehicles will increasingly talk to one another without the need for any human involvement. For example, by the end of the decade, cars will communicate directly with each other about speeds, direction, and road conditions.

The reach of these integration capabilities will go far beyond infrastructure and manufacturing. Today, for example, clinicians diagnose depression through a lengthy assessment. But simply matching call patterns and GPS signals on a phone to determine whether someone has become a hermit is a more accurate diagnostic approach, not to mention a better early-warning signal.[3] To make the most of such opportunities, health-care companies must figure out how to integrate systems far beyond the hospital.

Systems integration has been a discipline for a long time, but, frankly, most companies aren't very good at it. This is especially true in resource-intensive areas where technologies have been in place for decades or longer (the electric transformer outside your house, for example, was invented in the 1880s). One reason is that the problems are intrinsically hard, often involving billions more data permutations and combinations. Systems integration is more like trying to manage an ever-evolving ecosystem than solving the sort of finance problem one encounters in business school.

Despite the challenges, companies can do three things to increase the odds of success greatly: create simple software building

[2] Markus Löffler and Andreas Tschiesner, "The Internet of Things and the future of manufacturing," June 2013, mckinsey.com.

[3] Devon Brewer, Tracy Heibeck, David Lazer, and Alex Pentland, "Using reality mining to improve public health and medicine," Robert Wood Johnson Foundation, February 2009.

blocks, expand frontline analytical talent, and apply computational-modeling techniques whenever possible—then test, test, test to learn and refine.

Recognize the scope

Simply realizing that systems are subtle and that lots of variables are interacting simultaneously will give any company a head start. Starting with a few simple software building blocks lays the foundation for success. The case of US power distribution is instructive.

The build-out of the US electric grid has been called the 20th century's greatest engineering achievement, but the grid's basic technology has changed little since the time of Edison and Westinghouse. The average circuit is 40 years old, and some have been around for more than a century. The grid is showing its age.

This translates into declining reliability and increasing costs and risks for utilities and their customers. The average utility generally learns about problems with its power lines when customers call in to complain rather than by receiving information on the problems directly. Issues at substations often have to be addressed by sending maintenance workers into the field to flip a switch, not by having someone in a central control room make the change—or, better yet, having the grid sense the problem and either fix it automatically or route electricity around it.

Utilities have to overcome their own inefficiencies and adapt to the rapidly shifting contemporary environment. Homeowners, for instance, are putting solar panels on their roofs, depriving utilities of many of their most profitable customers. Utilities will now have to figure out how to integrate into the grid the power these homes sometimes make available.

Once electric vehicles are deployed in large numbers, utilities will have to get used to the power equivalent of a commercial building unplugging, moving, and plugging back in somewhere else. Utilities must develop capabilities for integrating—in real time—not only what they are doing but also what all the related interconnected players are doing.

The era of big data will also have a huge effect. At the moment, the average utility collects about 60 million data points each year—five million customers and a dozen monthly bills. When smart meters, distributed generation, and electric vehicles come into widespread use, the average utility may have to handle five billion data points each day. The grid will almost need to be redesigned from scratch to get the full benefit of the new types of solid-state transformers, as well as the ability to sense problems and solve them automatically and, essentially, to have little power plants on millions of rooftops as solar prices keep coming down.

Expand frontline analytical capabilities

Mastering the building blocks of the resource revolution will also require intelligent organizational design and excellent talent management. In some cases, the specialized knowledge and know-how won't be at hand, because companies are dealing with new problems, but each manager will need to find any expertise available. Software skills, specialized engineering, nanotechnology, and ultralow-cost manufacturing are just four of the many areas where talent will be scarce. In some instances, it will make sense for companies to form partnerships with businesses in other industries to gain access to specialized expertise.

In other cases, companies will have to develop new management skills from scratch. Some of the need will occur at the top of organizations, among leaders. The leadership skills required to deliver 10 to 15 percent annual productivity gains for a decade or more are a far cry from the incremental-improvement skills that marked the generation of leaders after World War II. Business-model innovation will no longer be just for start-ups or technology companies.

Frontline workers too will have to learn how to use massive amounts of analytical data to perform heavy industrial tasks. These front-line workers will need to be educated, whether by schools, the government, or employers, to undertake this technical work. For example, resource productivity requires frontline gas-leak detection teams to make sophisticated decisions based on big data and advanced analytics, leveraging technology to find and fix leaks rather than just walking the block with the technological equivalent of a divining rod. Many traditional blue-collar workers need a knowledge worker's skills, such as the ability to analyze data, evaluate statistics, identify

the root causes of problems, set parameters on machines, update algorithms, and collaborate globally.

The good news is that while the search for new organizational models and new talent in new places will be extraordinarily taxing, just about all of the competition will face the same problems. The sooner management starts confronting the gaps a company is facing, the sooner it is likely to close them—and gain an edge on the ones that don't.

Model, then test

Because systems are so complex, the only way to know for sure whether a process works is to test it. But, these days, a company can do an awful lot of that testing through computer models. For instance, the US national labs—notably Lawrence Livermore, Los Alamos, and Sandia—have maintained the nation's nuclear capabilities without testing live warheads for decades, by using advanced computational methods. Now companies can deploy these same techniques to accelerate product development. One defense contractor used computer modeling to test thousands of potential new materials at the atomic level to find a few superlight, high-performance, and very reliable composites for next-generation jet engines. The best manufacturers of batteries can test their performance for thousands of hours, across an extremely broad range of operating conditions, in the Argonne National Laboratory battery-testing facility outside Chicago, dramatically accelerating product innovation.

For example, when ATMI, a materials-technology company, went looking for a better way to extract gold from electronic waste than traditional smelting methods or baths of toxic acids, it resorted to computational modeling of combinatorial chemistries. The resulting eVOLV process uses a water-based solution that's safe to drink and is dramatically cheaper than the traditional methods. Moreover, the process allows the collected computer chips to be reused, since they are never exposed to high temperatures or acids (the toxic solder is collected as a by-product). The equipment can even be placed on a truck for processing e-waste at collection sites. This is what we mean when we say a resource revolution will open up solutions that are not only cheaper and more efficient but also better.

The resource revolution represents the biggest business opportunity in a century. However, success requires new approaches to management. Companies that try to stick to the old "2 percent solution" (just improve performance by 2 percent annually and you will be fine) are going to become obsolete quickly. Businesses that can deliver dramatic resource-productivity improvements at scale will become the great companies of the 21st century.

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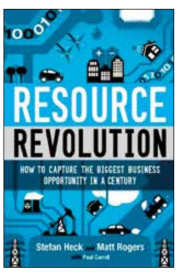

This article is based in part on the authors' book, *Resource Revolution: How to Capture the Biggest Business Opportunity in a Century* (New Harvest, April 2014).

Twelve companies of tomorrow

While we possess no crystal ball, we can imagine the next 20 years giving rise to global companies that exploit the new resource-productivity fundamentals and look different from today's leaders. Here are 12 possibilities:

1 **Maximum Oil Recovery Enterprise (MORE)** companies would get more oil from wells. They would use advanced sensor networks and operating techniques to recover 60 to 70 percent of the oil in every field, up from the traditional 20 to 30 percent—reducing risk and reducing the need to drill in remote, difficult areas.

2 **Efficient Resilient Grid Operator (ERGO)** businesses would capitalize on the shift from an analog, hub-and-spoke power grid toward an integrated digital network. The new grid would connect many distributed-power generators. It would also incorporate storage so power can be generated at more efficient times, rerouted to handle shortages, and flow in both directions. Digital transformers sharply reduce power losses in transit.

3 **HOme Unified SErvices (HOUSE)** firms would reach into homes more completely than security, utility, and media companies do today, using data from mobile devices to provide services enhancing comfort and convenience. For example, this technology would not only anticipate and recognize your preferences for lighting, temperature, health services, news, education, and music but also use them as you move from place to place.

4 **Convenient Organizer Service for Travel (COST)** companies would efficiently handle travel details, such as rides, rooms, and tickets to events. COST companies would optimize routing and inventory—users would type in where and when they wanted to go and COST handles the rest, choosing among shared, electric, or autonomous cars, trains, and planes.

5 **Global Recovery of Waste (GROW)** companies would be the most profitable miners, using microfluidic technologies to recover high-value products in waste streams: gold and silver from consumer electronics, lithium from geothermal effluent, and high-value rare-earth metals from electronics, for instance. GROW miners would also provide heat, power, and fertilizer from organic waste.

6 **WAter DElight (WADE)** firms would use nonchemical-purification techniques and mineralization technologies to provide high-quality water for agriculture and the world's best drinking water. Through partnerships that reduced waste, increased recycling, and provided networkwide leak detection and management in cities, such businesses would ensure that water systems needed new water for only 20 percent of their total annual requirement. The health benefits from expanded fresh-water access would more than pay for the infrastructure.

7 **Fresh Organic Opportunities Delivered (FOOD)** companies would be global, integrated organizations that locally produced high-quality, nutritious food using one-tenth of the water and energy of existing methods.

8 **Lightweight Innovation Technology Engineering (LITE)** enterprises would make carbon fiber cheaper than aluminum. Cars, trucks, ships, planes, and buildings will become safer and more efficient (and more pleasing, aerodynamic, and comfortable). Additive manufacturing allows for the quick replacement of parts anywhere. Carbon-fiber recycling helps close the loop and promotes a “circular economy.”

9 **Government Operations Verified (GOV)** firms would be low-cost service providers that let governments use standardized technology platforms to deliver personalized services—for example, passports and drivers’ licenses, health and retirement plans, and tailored career training and advice. Many private companies would deliver efficient, innovative services over the GOV platforms, like apps on mobile platforms today.

10 **SEnsor Network SOlutions (SENSO)** companies would give businesses trillion-point, integrated sensor networks and access to a marketplace of algorithmic analyses of sensor data. Much as Google search terms created a new field of research, these companies would give small ones access to big data and the tools to make business decisions using it.

11 **Equipment As Service for You (EASY)** enterprises would expand the experience many companies have with software as a service by developing businesses based on equipment as a service, but on a larger scale than today’s rental companies. Small businesses could get access to the most advanced heavy equipment, with remote-operations capabilities to handle high-value local requirements.

12 **Basics All Supplied in Container (BASIC)** firms would serve emerging markets and offer companies access to some of the least advantaged people in these regions by delivering essential infrastructure in rugged containers. This infrastructure might include solar power, electrical storage, cell-phone towers, phone charging and service, water pumping and purification, LED lamps, and Internet access (with dedicated channels for information and services). BASIC firms would bring low-cost energy, water, and communications to the next billion consumers in developing markets.