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BEYOND THE SUPERCYCLE: HOW TECHNOLOGY IS RESHAPING RESOURCES

FEBRUARY 2017

IN COLLABORATION WITH
MCKINSEY'S GLOBAL ENERGY & MATERIALS PRACTICE

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BEYOND THE SUPERCYCLE: HOW TECHNOLOGY IS RESHAPING RESOURCES

FEBRUARY 2017

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IN BRIEF

BEYOND THE SUPERCYCLE: HOW TECHNOLOGY IS RESHAPING RESOURCES

During the 2003–15 commodity supercycle, spending on resources including oil, natural gas, thermal coal, iron ore, and copper rose above 6 percent of global GDP for only the second time in a century before abruptly reversing course. Less noticed than these price gyrations have been fundamental changes in supply and demand for resources brought about by expected macroeconomic trends and less predictable technological innovation. Our analysis shows that these developments will have major effects on resource production and consumption over the next two decades, potentially delivering significant benefits to the global economy and bringing change to the resource sector.

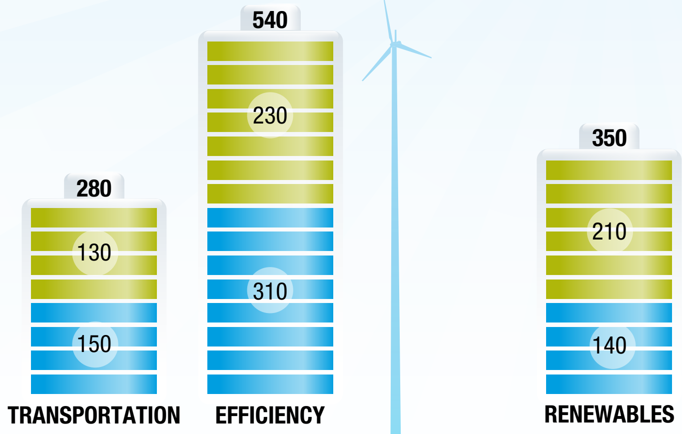
- Rapid advances in automation technologies such as artificial intelligence, robotics, analytics, and the Internet of Things are beginning to transform the way resources are produced and consumed. The advent of electric and self-driving vehicles and ride sharing, greater use of energy-efficient technologies in factories, businesses, and homes, and the growth of renewable energy sources are changing demand for resources. For producers, technology-driven transformations including underwater robots that repair pipelines, drones that conduct preventive maintenance on utility lines, and the use of data analytics to identify new fields could raise productivity.
- Scenarios we modeled show that adoption of these technologies could unlock cost savings of between $900 billion and $1.6 trillion in 2035, equivalent to the GDP of Indonesia or, at the upper end, Canada. Total primary energy demand growth will slow or peak by 2035, despite growing GDP, according to our analysis. Reduced energy demand from transportation, the proliferation of energy efficiency measures, and increased substitution of fossil fuels enabled by cost reductions in renewables could account for as much as $1.2 trillion of the total savings in an accelerated technology adoption scenario. The potential supply-side savings for producers of the five commodities we focus on—oil, natural gas, thermal coal, iron ore, and copper—could amount to $300 billion to $400 billion annually in 2035.
- The price correlation that was evident during the supercycle is unraveling, and a divergence in prospects between growth commodities and declining ones may become more significant. Demand for oil, thermal coal, and iron ore could peak and potentially decline in the next two decades while copper's prospects remain buoyant, according to our analysis, although there may be regional differences. Advanced economies could experience a faster decline in demand for oil with rapid technological adoption, for example, while emerging economies may experience demand growth, regardless of the rate of technological change. However, the resource intensity of GDP growth is continuing to decline globally.
- Policy makers could capture the productivity benefits of this resource revolution by embracing technological change and allowing a nation's energy mix to shift freely, even as they address the disruptive effects of the transition on employment and demand. Resource exporting regions whose public finances rely on resource endowments will need to find alternative sources of revenue. Importers could stock up strategic reserves of commodities while prices are low, to safeguard against supply or price disruptions, and use the savings from avoided resource spending to invest in other areas.
- For resource companies, particularly incumbents, navigating a future with more uncertainty and fewer sources of growth will require a focus on agility. Harnessing digital and other technologies will be essential for unlocking productivity gains, but not sufficient. Companies that focus on the fundamentals—driving up throughput, driving down capital costs, spending, and labor costs—and look for opportunities in technology-driven areas may have an advantage. In the new commodity landscape, incumbents and attackers, including digitally enabled outsiders, will race to develop viable business models.

THE TECHNOLOGY REVOLUTION IN RESOURCES

Technological advances will change supply and demand dynamics in the resource sector, raising productivity, increasing energy efficiency, **and unlocking value to the global economy in 2035**

$900 billion to $1.6 trillion

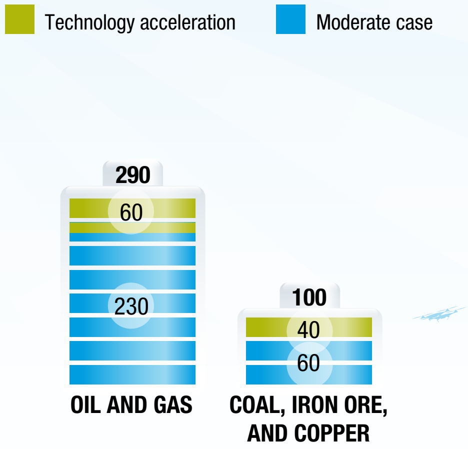
2035 run rate savings opportunity
$ billion 2015



Consumption of energy will become less intense as people use energy more efficiently in homes, businesses, and transportation.

Technological advances will help bring down the cost of renewable energies, such as solar and wind energy, partially displacing fossil fuels.

2035 increased productivity
$ billion 2015



Resource producers will be able to deploy a range of technologies including robotics, Internet of Things, and data analytics in their operations to raise productivity.

The impact of technology on 5 major commodities

OIL
Peak demand for oil could be in sight, as changes in transportation including electric and autonomous cars cut the energy intensity of transport fuel consumption.

NATURAL GAS
Demand could grow in the near term as economies decarbonize, but in the longer term, gas could face competition from renewables.

THERMAL COAL
Peak demand for coal is possible by 2020 as China pushes renewables to displace it in the power sector and natural gas advances with cost reduction and supply increases.

IRON ORE
Growth in demand for iron ore will decline as steel demand growth weakens and recycling gains ground.

COPPER
Copper's future looks buoyant, with a strong demand outlook including from the electronics industry, despite progress in efficiency in demand and supply.

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Autonomous haulage trucks at Rio Tinto's Pilbara mines in Australia.
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EXECUTIVE SUMMARY

First came the "fly-up," the price spike on world markets for oil, gas, and a broad range of natural resources that began in 2003. Then came the abrupt bust, as prices tumbled and global spending on natural resources dropped by half in the course of 2015 alone. Now, even as resource companies and exporting countries pick up the pieces after this commodity "supercycle," the sector is facing a new wave of disruption.[1] Shifts taking place in the way resources are consumed as well as produced—less noticed than the roller-coaster commodity price ride but no less significant—will have major first- and second-order effects on both the sector and the global economy. These shifts are the result of technological innovation, including the adoption of robotics, Internet of Things technology, and data analytics, along with macroeconomic trends and changing consumer behavior. We see three principal effects of this technological revolution:

- Consumption of energy will become less intense as people use energy more efficiently thanks to smart thermostats and other energy-saving devices in homes and offices, and the use of analytics and automation to optimize factory usage. Transportation, the largest user of oil, will be especially affected, by more fuel-efficient engines and by the burgeoning use of autonomous and electric vehicles and ride sharing.

- Technological advances will continue to bring down the cost of renewable energies such as solar and wind energy, as well as the cost of storing them. This will hand renewables a greater role in the global economy's energy mix, with significant first- and second-order effects on producers and consumers of fossil fuels.

- Resource producers will be able to deploy a range of technologies in their operations, putting mines and wells that were once inaccessible within reach, raising the efficiency of extraction techniques, shifting to predictive maintenance, and using sophisticated data analysis to identify, extract, and manage resources.

Scenarios we have modeled suggest that these developments have the potential to unlock $900 billion to $1.6 trillion in incremental cost savings throughout the global economy in 2035, an amount equivalent to the current GDP of Indonesia or, at the top end, Canada.[2] As a result of lower energy intensity and technological advances that improve efficiency, energy productivity in the global economy could increase by 40 to 70 percent in 2035. We believe these changes will have profound implications not just for companies in the resource sector and for countries that export resources, but also for businesses and consumers everywhere.

RESOURCE PRODUCERS EMERGED WEAKENED FROM THE SUPERCYCLE, AND LONGER-TERM RESOURCE CONSUMPTION TRENDS ARE SHIFTING

Resource spending during the supercyle exceeded

6%

of global GDP

Driven by seemingly insatiable demand from China, the commodities boom between 2003 and 2015 both galvanized and jolted the global economy. For only the second time in a century, spending on the five commodities that are the focus of this report—oil, natural gas, thermal coal, iron ore, and copper—rose above 6 percent of global GDP, more than triple the long-run average, and unlike the previous fly-up in the 1970s, some of the biggest demand

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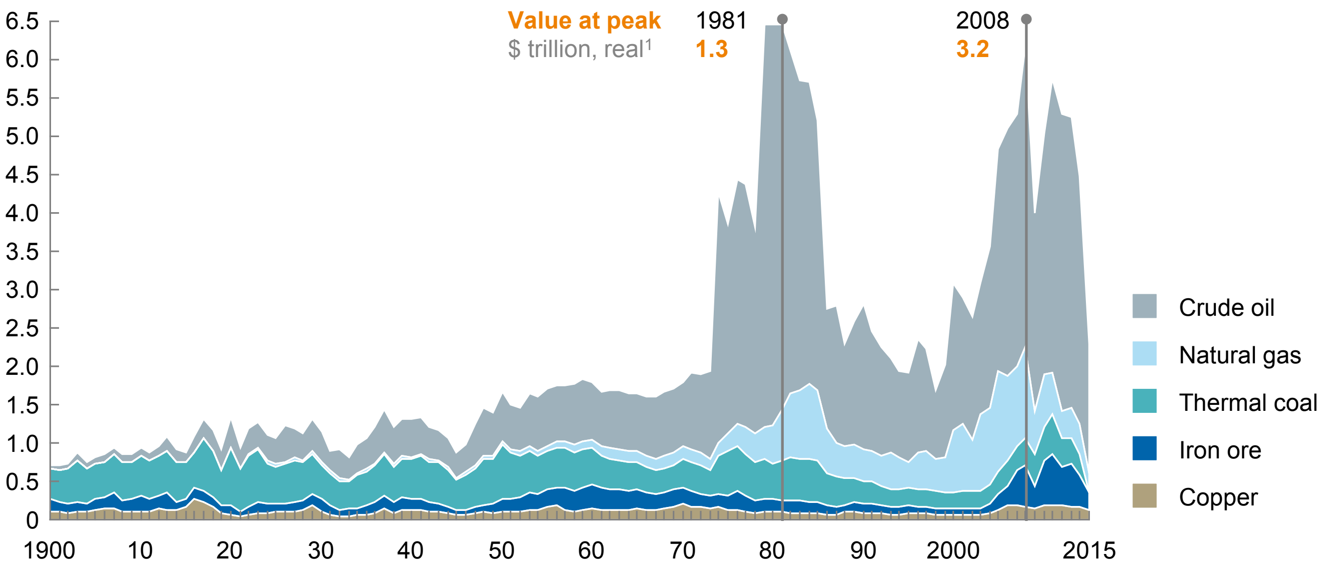
1. A supercycle is a lengthy, above-trend movement in a wide range of commodity prices, although precise definitions differ. See Bilge Erten and José Antonio Ocampo, "Super cycles of commodity prices since the mid-nineteenth century," *World Development*, volume 44, April 2013.
2. This report is an update of our research published during the price upswing. See *Resource Revolution: Meeting the world's energy, materials, food, and water needs*, McKinsey Global Institute, November 2011.

growth was in metals, not only in fossil fuels (Exhibit E1). Then came the wrenching decline in prices, which began in 2008, reversed briefly, and resumed in 2014–15, propelled by the twin forces of slowing demand and increased supply. The resource sector lost $2 trillion in cumulative shareholder value as global spending on commodities fell by 50 percent in 2015 alone.[3] Many producers—both companies and countries—are struggling to deal with the aftermath. At the same time, the outlook for the global economy has changed, and its resource intensity is waning. This will likely have a major impact on resource consumption in the years ahead.

Exhibit E1

Spending on resources during the 2003–15 supercycle exceeded 6 percent of global GDP for only the second time in a century

Resource expenditures as share of global GDP
%



1 Indexed to 1990 dollar values.

SOURCE: Rystad Energy; *BP statistical review of world energy*, 2015; World Bank; The Madison Project; USGS; McKinsey Global Institute analysis

The upswing masked declining productivity and rising costs among producers

The downturn in financial performance for producers began while prices were still rising. Their gains from the up cycle masked declining productivity and rising costs, which continue to take a heavy toll. The resource industry emerged from the supercycle severely weakened and facing significant productivity and investment challenges.

This declining performance came about as a result of growing difficulty in accessing resources, rising costs, a willingness to sacrifice productivity in return for growth, and increasing competition among producers for both assets and services. The return on invested capital for oil companies fell by about 50 percent between 2005 and 2011 (during the up cycle) and further deteriorated to the end of 2015. For the oil majors, the lifting cost per barrel increased from about $8 per barrel of oil equivalent in 2004 to more than $28 in 2014, which amounts to a 12 percent annual decline in lifting productivity.[4] Mining

3 Analysis based on data from Rystad Energy; United States Geological Survey data, January 2015; *World energy outlook 2016*, International Energy Agency; World Bank; and *BP statistical review of world energy*, BP, June 2015.

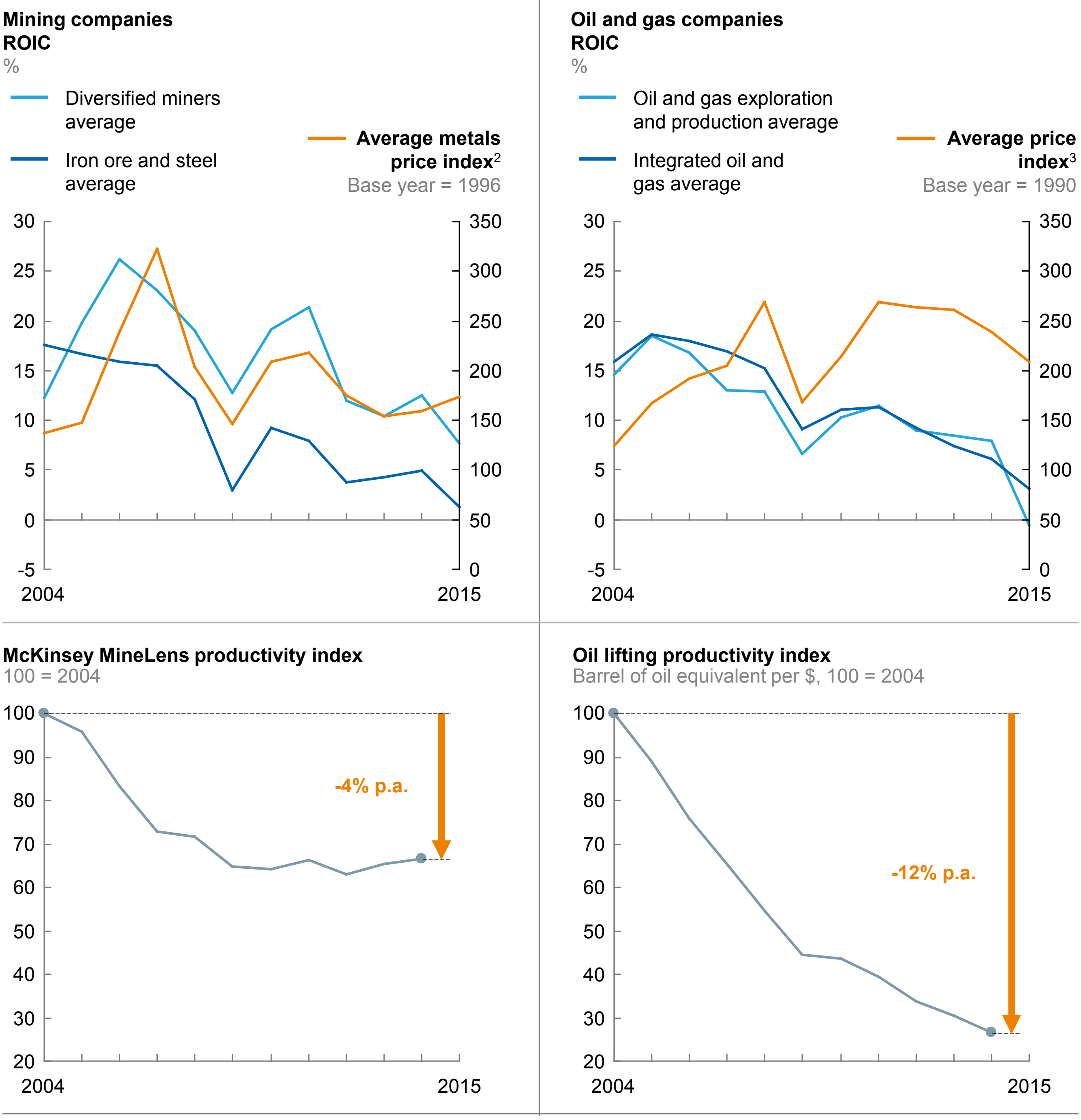
4 Data on lifting cost is the production-weighted average of costs per barrel of oil equivalent from five companies (BP, Chevron, ExxonMobil, Royal Dutch Shell, and Total) as specified in their annual reports.

productivity has likewise been declining, by about 4 percent annually, and is at a 30-year low (Exhibit E2).[5]

Exhibit E2

Return on invested capital in the resource sector has declined along with productivity[1]

Mining | **Oil and gas**



1 Based on companies with >$5 billion market cap and >$1 billion revenue for oil and gas; >$1 billion market cap and >$0.5 billion revenue for metals.
2 Average of aluminum, thermal coal, copper, iron ore, lead, nickel, and zinc.
3 Average of WTI and Brent.

SOURCE: McGraw-Hill Companies' S&P Capital IQ; MGI Commodity Price Index; McKinsey Global Institute analysis

5 McKinsey & Company MineLens Productivity Index.

At the same time, new energy supplies became available through technological advances such as hydraulic fracturing and through a surge of new investment, both in conventional sources, including megamines, and in alternatives such as wind and solar power, which continue to make inroads in the global energy mix. This new investment reached $1 trillion per year at its height, in 2014.[6]

China's changing growth model and global demographic and energy consumption trends will affect future resource demand

China's rapid industrialization, its urbanization on a massive scale, and its surging economic growth were the primary factors that drove up prices of metals during the supercycle; by 2015, China was consuming more than half of the global supply of iron ore and thermal coal and about 40 percent of the world's copper. However, the end of the supercycle coincided with a shift within China, as it began transitioning from an investment-driven economic model to a services- and consumption-led one, and reduced its appetite for additional resources. This will affect resource demand going forward.

The abrupt fall of commodity prices has not been the boon to the global economy that many economists had expected. Lower commodity prices could in theory act as a stimulus to consumption and growth, but the shock of the downturn exacerbated prevailing trends of weak investment and job creation, slowing trade and economic growth, and increasing deflationary risks.[7]

The outlook for projected global GDP growth over the next two decades is more subdued than it was in the years before and during the supercycle.[8] This is due in part to global demographic trends, including the declining share of working-age population in countries from Japan to Germany. China's working-age population has been in decline since 2012 and could fall by more than 20 percent by 2050.[9] Productivity will need to compensate for employment declines in order for GDP growth to accelerate—but measured productivity growth has been weakening in the past decade.[10]

70%
decline in China's resource intensity per unit of GDP in 1980-2010

Could there be another China, one or several large emerging economies with voracious appetites for resources which unleash another supercycle? Several factors suggest that could be unlikely. In addition to a slower pace of GDP growth than we have seen historically, the resource intensity of this growth will be lower, continuing a declining trend that dates to the 1970s. Emerging economies will continue to drive demand for resources as infrastructure is built out and citizens consume more goods. However, no other emerging economy, including India, is likely to replicate the scale or the investment intensity and resource intensity of China's industrialization. That is because much of this economic growth will benefit from technology-enabled improvements in resource productivity that are the focus of this report. China itself is illustrative of this trend: while its economy increased 18-fold from 1980 to 2010, energy consumption increased only fivefold. Energy intensity per unit of Chinese GDP declined by about 70 percent during the same period.[11] In advanced

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6 Rystad Energy; World Bank; *BP statistical review of world energy*, BP, June 2015.

7 Maurice Obstfeld, Gian Maria Milesi-Ferretti, and Rabah Arezki, *Oil prices and the global economy: It's complicated*, IMFdirect, March 24, 2016; John Baffes et al., *The great plunge in oil prices: Causes, consequences, and policy responses*, World Bank Group Policy Research note number 15/01, June 2015; Rabah Arezki and Olivier Blanchard, *Seven questions about the recent oil price slump*, IMFdirect, December 22, 2014; Aasim M. Husain et al., *Global implications of lower oil prices*, IMF staff discussion note number 15/15, July 2015.

8 In this report we assume an average annual global GDP growth rate of 2.7 percent to 2035. This is a projection from McKinsey & Company's proprietary Global Growth Model, which provides complete time-series data for more than 150 concepts and 110 countries over 30 years. See the technical appendix for details.

9 Joe Myers, *China's working-age population will fall 23% by 2050*, World Economic Forum, July 25, 2016.

10 For a detailed discussion of the global economy's slowing growth and productivity challenge, see *Global growth: Can productivity save the day in an aging world?* McKinsey Global Institute, January 2015.

11 *Bringing China's energy efficiency experience to the world: Knowledge exchange with Asian countries*, World Bank, June 27, 2014.

economies, meanwhile, peak consumption of many mineral resources could become a reality as technology makes economic activity more productive and as these economies continue their shift to more consumer-driven, service-centric growth.

THE $1 TRILLION TECHNOLOGY OPPORTUNITY FROM RESOURCES

In the past, changes in the resource sector have often come about as a result of regulation. Over the next two decades, however, we expect technology and its effect on costs will be the main drivers of change and bring significant disruption to the sector, although policies and regulations could still have a substantial impact. We model two scenarios for resource supply and resource demand. The first is a "moderate" technology adoption case, which assumes improved energy productivity from the greater deployment of technology to support energy efficiency and reduce the cost of renewables, as well as increased productivity for resource producers. The second scenario, which we call a "tech acceleration" case, assumes a faster rate of adoption of technologies and therefore greater energy and resource productivity.[12] For both of these scenarios, we assume that the productivity of resource extraction for our five focus commodities will improve as oil and gas and mining companies deploy robotics, data analytics, Internet of Things, and other technologies.[13] The main difference between the two scenarios is the pace and extent of technological adoption by both producers and consumers.

We find that the incremental savings to the economy from technology-driven changes in 2035 could amount to between $900 billion and $1.6 trillion, depending on the scenario, from a combination of demand reduction, substitution, and increased productivity by resource producers. These figures reflect the opportunity to reduce spending on resources and redeploy the savings to other, more productive parts of the economy.

At least two-thirds of this saving is derived from reduced demand for energy as a result of greater energy productivity and from growing use of renewables (Exhibit E3).[14] The technology payoff from resources will have far-reaching benefits for the global economy. In the United States, for example, while resources make up only 5 percent of GDP and 8 percent of employment, the sector accounts for one-third of total capital expenditure and 40 percent of input costs in housing, transportation, and food—the three largest items in the median household budget.[15]

By 2035, annual fossil fuel consumption could drop by at least

140M

terajoules

The combination of increased efficiency in energy use and a shift to renewable energies could mean that primary energy demand peaks in 2025 in a tech acceleration scenario. Even in a moderate case scenario, without accelerated deployment of technology, total primary energy demand growth would slow by 2035, despite growing GDP. Moderate technology adoption could reduce fossil fuel consumption annually by more than 140 million terajoules in 2035 compared with a scenario in which there is no improvement in energy productivity. The tech acceleration scenario would cut annual consumption of fossil fuels by a further 100 million terajoules. At today's prices, this represents a reduction of 13 percent in resource expenditure by 2035 in the moderate case and of 26 percent in the tech acceleration scenario.

The projected reduction in fossil fuel consumption will have an impact on greenhouse gas emissions; in our moderate technology adoption case, emissions will continue to increase through 2035 but at a slower pace of growth, while in the tech acceleration scenario,

[12] We developed our models with help from our colleagues at McKinsey & Company Energy Insights and the McKinsey Basic Materials Institute. See the technical appendix for details of our methodology.

[13] We calculated the increased productivity as compared to a reference case that used the same macroeconomic assumptions but assumed no further technology adoption beyond today's levels. See technical appendix.

[14] Energy productivity is defined as the terajoules of energy required to generate a unit of GDP.

[15] *The US economy: An agenda for inclusive growth*, McKinsey Global Institute, November 2016.

emissions will peak in 2025 and then start to decline. However, even under this latter scenario, the decline in CO_2 emissions will not on its own be sufficient to meet international targets agreed at the Paris climate change conference in December 2015.

Exhibit E3

Technology will create opportunities for increased productivity

Moderate case | Technology acceleration

		Run rate savings opportunity, 2035 ($ billion, 2015): Moderate case	Technology acceleration	Total	Cost reduction vs. reference case[1] (%): Moderate case	Technology acceleration	Description of opportunity
Reduced energy demand	Transportation	150	130	280	13	24	Disruption in the transportation sector from electric and autonomous vehicles and ride sharing reduce energy demand, particularly fossil fuels
	Efficiency	310	230	540	12	21	Increased energy productivity of the economy due to shifts away from manufacturing, smart thermostats and other devices in homes and offices, and technology-optimized energy in factories
Substitution	Renewables	140	210	350	16	40	Substitution of fossil fuels for power by renewables as costs decline, resulting in increased energy conversion efficiency
Increased productivity of resource producers	Oil and gas	230	60	290	19	25	Adoption of automation, Internet of Things, data analytics, and other sector-specific innovations enable improvements in productivity for resource producers
	Coal, iron ore, and copper	60	40	100	14	22	
Total		**890**	**1,570**				

1 The reference case used the same macroeconomic assumptions but assumed no further technology adoption beyond current levels

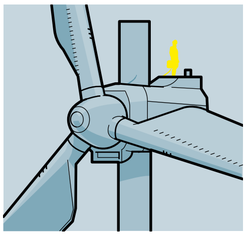
NOTE: Numbers may not sum due to rounding

SOURCE: Energy demand based on demand scenarios from *Global energy perspective*, McKinsey Energy Insights; resource productivity based on McKinsey Basic Materials Institute; additional analysis by McKinsey Global Institute.

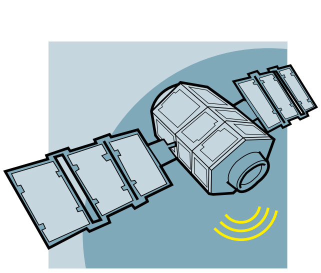
Technology can improve the efficiency of resource use and reduce consumption

A significant increase in the energy productivity of the global economy will come from changes in the transportation sector, increased energy efficiency in industrial, residential, and power usage, and greater substitution by renewables (see illustration, “Technology will change the ways consumers live and reduce resource consumption”). We estimate that this combination of reduced demand and substitution could amount to a total annual savings opportunity in 2035 of between $600 billion in a moderate case and almost $1.2 trillion in a tech acceleration case.

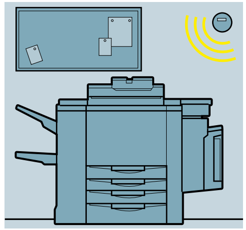
Technology will change the ways consumers live and reduce resource consumption



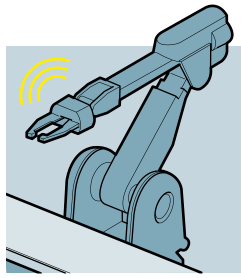
1. Renewable energy may become the cheapest form of power, used in a combination of decentralized and centralized sources.



2. Long-haul transportation adopts greater levels of autonomy as **telematics of travel patterns**, platooning, and analytics enable greater fuel economy.

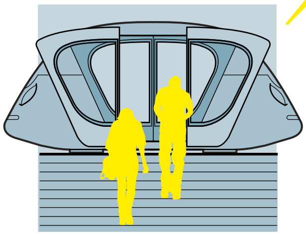


3. Electrical sensors in the office and home enable optimization of heat and light based on usage, weather, and occupancy data.

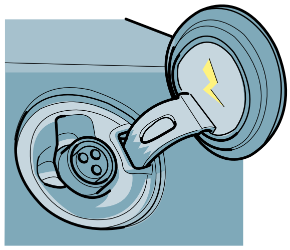


4. Industrial sites capture efficiency improvements with sensors, analytics, and automation, improving overall productivity and safety.

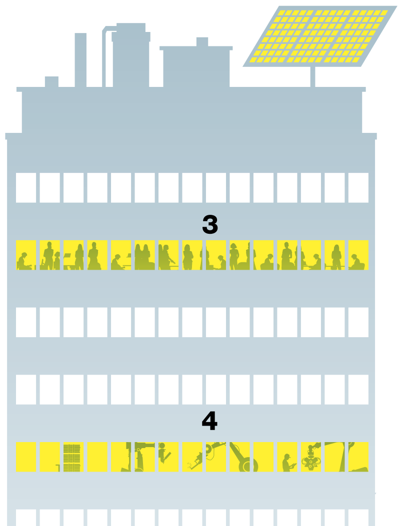
5. Utilities communicate with users and devices to identify optimization opportunities like retrofits or upgrades to new appliances.



6. Autonomous ride sharing services collect passengers at their homes, optimizing route and picking up other commuters to carpool, reducing number of vehicles on the roads.



7. Electric vehicles may account for the majority of new car sales, taking advantage of their lower total cost of ownership.



15%
of new cars sold in 2030 could be fully autonomous

Transportation, which accounts for more than half of total primary oil demand, may experience significant shifts in the future as improved engine performance and fuel efficiency, and innovation in technology-enabled mobility such as self-driving and electric vehicles, come to the fore. McKinsey has estimated that 15 percent of new cars sold in 2030 could be fully autonomous.[16] Autonomous vehicles will be more fuel efficient. Electric vehicles will replace oil with electricity, and ride sharing will reduce the number of cars on the road. Together they will end up reducing oil demand. Such trends will affect global consumption of oil. The net effect is that in our moderate scenario, oil demand in the light vehicle segment peaks and starts to decline slightly between 2015 and 2035.[17] In the tech acceleration case, we forecast demand for new vehicles could be roughly 13 percent lower than the moderate case, resulting in lower oil demand for light vehicles of about 4.5 million barrels per day by 2035.[18]

Changing demand for vehicles and shifting usage of them will have second-order effects on resource demand, including for metals. Reduced sales of cars and use of more lightweight materials could lower demand for steel and therefore for iron ore. Car sharing, which would lower the volume of vehicles on the roads, could reduce the need for construction of new roads, potentially reducing demand for steel, cement, and other infrastructure materials. At the same time, a trend toward lighter vehicles could enhance the role of plastics as a structural material.

Beyond transportation, technology will improve energy efficiency for consumers and industry. In residential and commercial buildings and in factories, the combination of advanced sensors, control systems, and analytics could substantially reduce energy demand. Already, many manufacturing plants have significantly reduced energy demand through retrofit efforts. In the moderate case scenario, we see potential for a 12 percent reduction in fossil fuel costs due to greater energy efficiency. In the technology acceleration scenario, increased efficiency could generate a further 9 percent, or $240 billion, opportunity.

In assessing the potential benefit from further deployment of technology, we consider that adoption rates for these technologies are likely to vary from region to region and country to country, depending on factors including government policy, the cost of deployment including hardware and software costs, and the level and rate of economic development.

36%
Potential share of power generation by renewables in 2035, up from 4% today

Technology advances in renewables will displace fossil fuels

Renewable energy usage has been rising rapidly as costs have fallen. Since 2001, total solar generation worldwide has grown by 50 percent annually, while wind power generation has been growing at an annual rate of 24 percent.[19] Costs have been falling sharply with widespread deployment of the technology; new solar power plants being contracted today are being bid at below $0.03 per kilowatt hour (kWh)—about one-tenth of the cost of solar plants just six years ago.[20] If that trend continues at the current pace, solar and wind energy could be competitive by 2025, without subsidies, with the marginal cost of thermal coal or natural gas generation in most regions globally. Renewables could grow from 4 percent of power generation today to as much as 36 percent of global electricity supply

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16 Paul Gao, Hans-Werner Kaas, Detlev Mohr, and Dominik Wee, "Disruptive trends that will transform the auto industry," *McKinsey Quarterly*, January 2016.

17 *Global energy perspective 2016*, McKinsey & Company Energy Insights.

18 These projections are constructed on modeling of aggressive assumptions about the total cost of ownership and its impact on adoption rates of technology, estimates of impact from proven deployments or pilots of technology, and current policy initiatives. See technical appendix for details.

19 Electricity power and generation data from GlobalData, 2016.

20 Anna Hirtenstein, *New record set for world's cheapest solar, now undercutting coal*, Bloomberg, May 2016; Stephen Lacey, "Jinko and Marubeni bid 2.4 cents to supply solar in Abu Dhabi. How low can solar prices go?" *Greentech Media*, September 20, 2016; *Renewable energy technologies: cost analysis series,* International Renewable Energy Agency, 2012.

by 2035 in a tech acceleration scenario. This would represent avoiding up to $350 billion in resource expenditure.

85
planned coal-fired power plants scrapped by Chinese authorities

Renewable energies already today are competitive without subsidies in some locations. The speed with which they substitute for some fossil fuels will depend on their ability to overcome obstacles including integration, scaling, and storage issues. Continued investment in technological innovation will help solve many of these challenges, and in the right policy environment, it is possible that even greater adoption will occur in the next 20 years. China's National Energy Administration, for example, in January 2017 announced it is scrapping construction of 85 planned coal plants and will invest $350 billion in renewable energy sources.[21] In India, as much as 40 percent of power could come from non-fossil fuel sources by 2030.[22]

A significant shift to renewables would help meet rapidly growing demand for electricity, which is set to outpace overall energy demand in the coming 20 years. Renewables are not only substitutes for fossil fuels, but also reduce overall demand for energy, as they do not incur the heat losses associated with fossil fuel power generation. Even as primary energy demand slows, electricity demand will grow as the developing world seeks access to energy and can leverage renewables as opposed to fossil fuels. Increased electrification in the developed world, including higher needs for electric vehicles, data centers, and cloud computing, and greater access to electricity in the developing world are major drivers of growing electricity demand. Renewable energies could also enable accelerated "sector coupling," the combination of power, heat, and mobility, as the energy used to supply homes and offices is also used to power cars and other transportation.[23]

Technology will enable resource producers to raise productivity and unlock substantial value

The resource sector as a whole, and mining companies in particular, have tended to be relatively slow to adopt new technology.[24] This is partly due to risk asymmetry: the downside for technological failure is very large in such a capital-intensive industry. However, productivity-enhancing technology is increasingly being deployed. Automated haul trucks and drilling machines are being tested in numerous mines across the world. Rio Tinto's mines using automation technology in Australia's Pilbara are seeing 40 percent increases in utilization of haul trucks, and automated drills are seeing 10 to 15 percent improvements in utilization—alongside improved safety, better maintenance, lower energy use, and greater operational precision.[25] For energy producers, horizontal drilling and hydraulic fracturing have become an economically viable extraction technique for hydrocarbons trapped in shale deposits.

Technologies including automation, data collection, mobile computing, and analytics can transform resource exploration and extraction and improve yields across different commodities. Innovations include sensors at the tips of drill bits that are able to measure ore grade in real time and crawling drill rigs that move between drill pads autonomously. Technology can also improve operational efficiency, by enabling predictive maintenance and yield and energy efficiency optimization—areas where resource companies have been

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[21] Lucy Pasha-Robinson, "China scraps construction of 85 planned coal power plants," *Independent*, January 17, 2017.

[22] *Transforming energy to transform India*, McKinsey & Company, December 2016.

[23] Kurt Rohrig and Dietrich Schmidt, *Coupling the electricity and heat sectors: The key to transformation of the energy system*, Presentation to workshop on renewables and energy systems integration, Golden, Colorado, September 2014.

[24] For example, the mining sector ranks near the bottom of the MGI Industry Digitization Index, which measures the state of digitization in sectors of the US economy. Oil and gas companies and utilities rank higher but still below digital leaders including banking, media, tech, and business services. See *Digital America: A tale of the haves and have-mores*, McKinsey Global Institute, December 2015.

[25] Michael Gollschewski, *Productivity improvements in a changing world,* presented at Australasian Institute of Mining and Metallurgy iron ore conference in Perth, July 13, 2015.

slower to move. Data analytics is a potentially key competency, which can prove highly effective in finding new deposits. One example is a gold mine in Red Lake, Ontario, operated by Goldcorp. Goldcorp's CEO sought to find new deposits of gold in the mine through an unusual crowdsourcing exercise, by publishing megabytes of geological data about the 55,000-acre site on the company's website with a cash reward for the best answers. The exercise helped the company identify 110 deposits, half of which its own geologists had not known.[26] Overall, we estimate that the deployment of data analytics, robotics, and other technologies can boost productivity across resource-producing sectors, with the gains in terms of cost reduction in our accelerated technology adoption scenario reaching close to 30 percent for oil and 40 percent for iron ore. Overall, the productivity increases could potentially unlock between $290 billion and $390 billion in annual savings for producers of our five focus commodities in 2035.

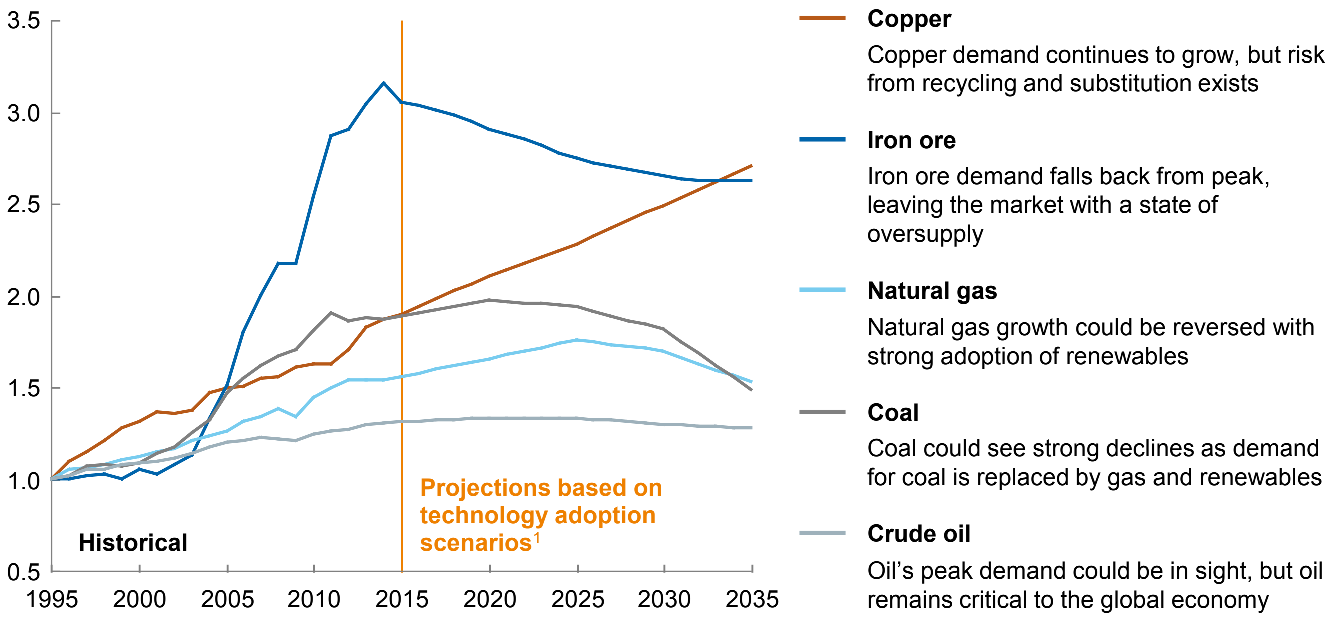
THE CORRELATION BETWEEN MARKETS FOR KEY COMMODITIES IS UNRAVELING

One of the striking characteristics of the down phase of the supercycle was the unraveling of what had been a close correlation between the markets for coal, copper, iron ore, and other commodities and those for oil and gas. While these markets rose in unison, seemingly as a monolithic group, during the upswing, divergences in supply and demand fundamentals for each commodity have meant that the correlation no longer holds. We expect this divergence to continue over the next 20 years, with ongoing shifts in demand and supply for oil, natural gas, thermal coal, iron ore, and copper, as well as for niche resources such as lithium and rare earth metals (Exhibit E4). Regional demand for commodities will also change. By 2035, according to our moderate case, China could account for 28 percent of the world's primary energy demand, up from 23 percent today, and India for 10 percent, up from 6 percent today, while the figure for the United States falls to 12 percent from 16 percent.

Exhibit E4

Demand growth for resources could be muted, with declines a possibility for some commodities

Commodity demand indexes
1 = 1995 demand level



1 Accelerated technology scenario for oil, gas, and thermal coal. Moderate adoption scenario for iron ore and copper. See technical appendix for details.

SOURCE: McKinsey Global Institute analysis

[26] *Open innovation: Goldcorp challenge*, Ideaconnection, October 22, 2009.

Investors, producers, and buyers will need to understand the unique characteristics of each commodity type, including these regional demand patterns, to anticipate the potential trajectory of demand and supply.

2% decline in oil demand in 2035 vs 2013, in our tech acceleration scenario

- **Demand for oil will peak under our tech acceleration scenario, although the global economy will remain dependent on oil.** By far the biggest consumer of oil is the transportation industry, accounting for about 56 percent of total primary oil demand. From a regional perspective, the United States, China, Japan, India, and Russia are the major consumers, but trends in demand differ among them. For example, in China and India, demand is growing strongly due to a rapidly emerging middle class that is increasing its demand for mobility as well as for plastics and other chemical-derived goods. Our two scenarios for technology adoption have divergent outcomes. In the moderate adoption scenario, demand for oil increases by about 11 percent between 2013 and 2035. In our tech acceleration scenario, however, demand for oil peaks around 2025 and then drops back. By 2035, under this scenario, oil demand would be 2 percent below its 2013 levels. Declining demand for oil in the transportation sector accounts for most of this decline. Oil supply could become more elastic, as technological innovation gives producers the ability to meet changing demand more rapidly; this is especially the case in North America, where hydraulic fracturing and horizontal drilling techniques have given producers the ability to add incremental capacity in a relatively short development cycle. Despite the longer-term outlook, the industry will need to continue investing in development of new fields to replace mature fields as they decline.

- **Growth of natural gas will ultimately be limited by renewables.** The biggest user of natural gas is the power sector, accounting for about 40 percent of total primary natural gas demand. In the United States, natural gas has already replaced coal as the largest source of electric power generation due to low gas prices and more stringent environmental policies that have reduced generation from coal. Some countries are looking to increase natural gas to help decarbonize their economies by promoting domestic upstream development or importing it via pipeline or in the form of liquefied natural gas (LNG) from neighboring regions. For example, China wants to increase natural gas to 10 percent of its energy mix by 2020 from 6 percent today.[27] In other countries, including India, investment is limited because of the high cost of imported natural gas compared with local fuel options such as coal. In Europe, meanwhile, efficiency efforts, the expansion of renewables in electric power generation, and sluggish economic growth are limiting the demand for natural gas. In the near term, we expect natural gas demand to grow, but in the longer term, it could face increasingly competitive challenges from renewable energies, and possibly also cheaper coal. In our moderate case scenario, demand for gas continues to grow rapidly until 2035. In our tech acceleration scenario, which includes greater growth of renewable power generation and improved end-use efficiency, natural gas demand is likely to grow through to 2025 but then decline. Under this scenario, demand in 2035 will be just 1 percent above 2013 levels.

Coal demand could peak by **2020**

- **Thermal coal may be headed for long-term decline as cleaner and cheaper substitutes penetrate the market.** Although coal has been the dominant fuel for generating electricity in the global economy, its role is under attack, and peak demand for thermal coal is a possibility in the next five years. In our moderate technology adoption scenario, thermal coal demand globally would peak in 2020 and by 2035 it would fall back to 2013 levels. In a scenario based on aggressive technology adoption, thermal coal demand would similarly peak in 2020, but then decline by 24 percent by 2035 compared with its 2013 level. Not all regions will be affected equally. While thermal

[27] Gabriel Nelson, Michael Ratner, and Susan Lawrence, *China's natural gas: Uncertainty for markets*, Congressional Research Service, May 2016.

coal demand will fall substantially in Organisation for Economic Co-operation and Development (OECD) countries, dropping to around 3 percent of total primary energy demand in 2035 compared with 14 percent today, demand will likely remain robust in some non-OECD countries. In India, for example, thermal coal demand could expand further as the economy continues its rapid expansion. Coal prices spiked unexpectedly in late 2016. However, even these forces are unlikely to fix the medium-term challenges the industry faces.

- **Iron ore producers must contend with oversupply for the foreseeable future.** By far the biggest demand for iron ore comes from the construction industry, accounting for almost half of the total, followed by machinery and equipment (17 percent). Supply expanded rapidly during the supercycle as investment poured in on the expectation of continued strong price growth. However, with the outlook for steel demand growth weakening, and recycling and scrap rates potentially increasing, especially in China, iron ore demand could fall. Under our moderate technology adoption scenario, demand would decline by 14 percent in 2035 compared with its 2015 level. Absent a repeat of China's massive industrialization, even strong economic growth in India and other emerging markets will be unlikely to focus on infrastructure investment in the same way. Current supply could be sufficient to meet global needs over the next 20 years, and major investment may not be needed to meet declining demand.

43%
potential increase in copper demand by 2035 vs today

- **Copper could see sustained growth as demand for consumer products accelerates, but recycling and substitution pose risks.** Copper has a wide range of uses in the modern economy, with far more consumer applications than iron ore. Just under half of copper demand today is from the electronics industry, with about one-quarter going to building and construction. The remainder feeds a range of industrial machinery, vehicles, and consumer products. Barring large-scale substitution by aluminum and other materials or a significant increase in recycling, primary copper demand could potentially grow to 31 million tonnes by 2035, a 2 percent annual increase. This corresponds to a 43 percent increase over today's demand of 22 million tonnes. We expect a majority of future demand growth to come from China; its per capita consumption of copper, which reached 7.2 kilograms per capita in 2015, could gradually rise to 11 to 12 kg per person by 2035, on a par with the figures for other developed Asian nations. At the same time, the supply outlook is challenging. Declining ore grades and increasingly difficult mining environments could result in supply constraints as ongoing investment becomes more expensive.

Beyond the core mineral resources, the impact of the technological and macroeconomic changes on other, smaller sectors could be significant. Lithium, for example, is already experiencing rapid growth, based on its usage in electric vehicle batteries, which is also driving growing demand for cobalt and nickel. Other resources to watch may include uranium, rare earth metals, and water, which is becoming scarcer around the world because of growing urbanization and economic development.

CAPTURING OPPORTUNITIES IN A NEW ERA OF TECHNOLOGY DISRUPTION

The more subdued outlook for demand and growth in the resource sector, together with a divergence in the prices of commodities and pressure for a substantial increase in the productivity of the resource sector itself, is creating a complex and competitive environment both for resource companies and for countries that depend on resource exports. Policy makers in resource-producing nations face pressure to diversify their economies and capture new growth opportunities, including from domestic demand rather than traditional exports. For resource-consuming nations, the challenge is to lock in the benefits a low-price commodities era has to offer households, industry, and society at large. In the resource sector, incumbent resource producers are under pressure to reverse the trend of declining productivity, while fending off possible attacks from more agile technology-enabled entrants. The prospect of more productive supply combined with potentially reduced demand will influence the decisions of both governments and companies about whether to devote tax dollars or shareholder capital to the development of new resources.[28]

Policy makers: Fostering the resource revolution payoff

Capturing the potential savings and productivity gains of the technological transformation of the resource sector will likely require some trade-offs. Policy makers will need to allow a nation's energy mix to shift and enable rapid technological changes throughout the economy, even as they recognize and account for the social and economic impact of these changes. Regardless of their resource exposure, all nations share the opportunity to invest savings from avoided resource spending into productive parts of the economy. We see three main priorities:

- **Taking a portfolio approach to national energy policy.** Policy makers could support market mechanisms that allow capital to flow in ways that enable resource productivity, while addressing market failures. They could also help companies develop their digital capacity by addressing digital infrastructure and interoperability issues. At a city and regional level, governments will need to ensure that energy-related infrastructure and regulatory choices work together, for example to support changing mobility trends that can reduce traffic congestion and pollution as well as energy demand.[29]

- **Developing the skills needed for the future.** To capture the benefits of the resource revolution, policy makers will need to invest in upgrading the skills of the workforce. Mining and oil and gas operations have a high technical potential for automation, especially occupations that involve sometimes dangerous physical activities.[30] Demand for new job classes such as data scientists, statisticians, and machine-learning specialists is already on the rise among resource producers. Within ten years, oil and gas companies could employ more PhD-level data scientists than geologists.[31] Wind-turbine service technician is the fastest-growing job category in the United States, according to the US Bureau of Labor Statistics.[32] Meanwhile, existing roles will be redefined. To meet the growing demand for skilled workers, policy makers should start by ensuring that education is well funded, retraining programs are effective, more students enter science, engineering, and other technical fields, and secondary and vocational training is upgraded to reflect changing skill requirements.[33]

- **Managing transitions efficiently and effectively.** All countries, regardless of where they are on the spectrum of exporting or importing resources, will have to manage transitions. For nations whose governments are highly dependent on resources as a source of government revenue, economic diversification is a pressing priority. Yet wherever core markets decline, policy makers may need to find ways to mitigate the externalities of shutdowns that arise. This includes addressing the long-term liability and remediation costs of resource assets and putting displaced people back to work. This reality is already playing out in the US coal market, where total coal demand could decline by 2020 by almost 40 percent from 2008 levels. According to McKinsey analysis,

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[28] In this report we focus primarily on the impact on resource industries. We looked more extensively at users of resources in previous research. See, *Resource Revolution: Meeting the world's energy, materials, food, and water needs*, McKinsey Global Institute, November 2011.

[29] *Game changes in the energy system: Emerging themes reshaping the energy landscape*, World Economic Forum, January 2017.

[30] See Michael Chui, James Manyika, and Mehdi Miremadi, "Four fundamentals of workplace automation," *McKinsey Quarterly*, November 2015, and *A future that works: Automation, employment, and productivity*, McKinsey Global Institute, January 2017.

[31] Christopher Handscomb, Scott Sharabura, and Jannik Woxhol, "The oil and gas organization of the future," *McKinsey Quarterly*, September 2016.

[32] Jennifer Oldham, "Nation's fastest growing job—only for those who like to get high," *Bloomberg*, May 12, 2016.

[33] *The world at work: Jobs, pay, and skills for 3.5 billion people*, McKinsey Global Institute, June 2012.

the entire US coal industry had liabilities of close to $100 billion in 2014, which will need to be addressed.[34]

Resource companies: Making the transformation from dig and deliver to technology-enabled productivity

As they adapt to the new realities of changing supply and demand, resource producers, especially incumbents, may need to become leaner and more agile by revisiting their strategy, improving capital allocation practices, and more fundamentally by infusing technology throughout the business.[35] By harnessing new technology, tomorrow's resource leader could derive its advantage from doing more with less, moving faster, thinking differently, and incorporating the best practices from other industries like manufacturing, services, venture capital, and consumer products. Possible steps could include:

- **Developing a more active approach to strategy and growth.** In order to embrace a future with greater uncertainty and fewer sources of growth, resource producers may need to think of themselves more like nimble portfolio managers and less like asset-heavy, "dig and deliver" businesses. As growth opportunities are harder to come by, companies may need to search and find resource-related business opportunities outside their core business and consider joint ventures, as well as mergers and acquisitions, which can lower risk, especially when entering an unfamiliar market. Harnessing technologies including data analytics and robotics can help producers identify and extract resources from areas that are especially remote and inaccessible.

- **Focusing on productivity to create value.** By incorporating technology, resource producers can build a more comprehensive understanding of the resource base, optimize material and equipment flow, improve anticipation of failures, increase safety, and monitor performance in real time. Alone, each of these opportunities has real potential; together, they will go a long way in reversing the trend of declining productivity. They will not be enough, however. By focusing on the fundamentals—driving up throughput and driving down capital costs, spending, and labor costs—resource producers can become productivity leaders. Innovative capital project design and delivery can reduce capital spending by 40 percent.[36] Reshaping workflows and improving collaboration with suppliers can cut operating costs and boost productivity. Those companies able to drive out the most waste from their operations and create a culture that prioritizes continuous improvement stand a better chance of success.

- **Adopting a digital mindset.** Barriers to technology adoption are not only physical, financial, and legal—they can also be cultural. Companies may need to address their own willingness to embrace change, akin to the mindset shifts that were needed in the early days of lean manufacturing, and embrace digitization and automation in a holistic manner, restructuring their organization and providing incentives to maximize adoption of these technologies. Fundamentally, resource producers need to develop the capability and talent of their workforce. This requires recruiting new talent and training existing talent but also putting in place systems for ongoing skills development. A significant challenge for resource producers will be to attract the next generation of talent.

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[34] *Downsizing the US coal industry: Can a slow-motion train wreck be avoided?* McKinsey Metals and Mining Practice, November 2015.

[35] *Mining's next performance horizon: Capturing productivity gains from innovation*, McKinsey & Company, September 2015.

[36] *The oil company of the future: From survive to thrive in "the new normal,"* McKinsey & Company, December 2016.

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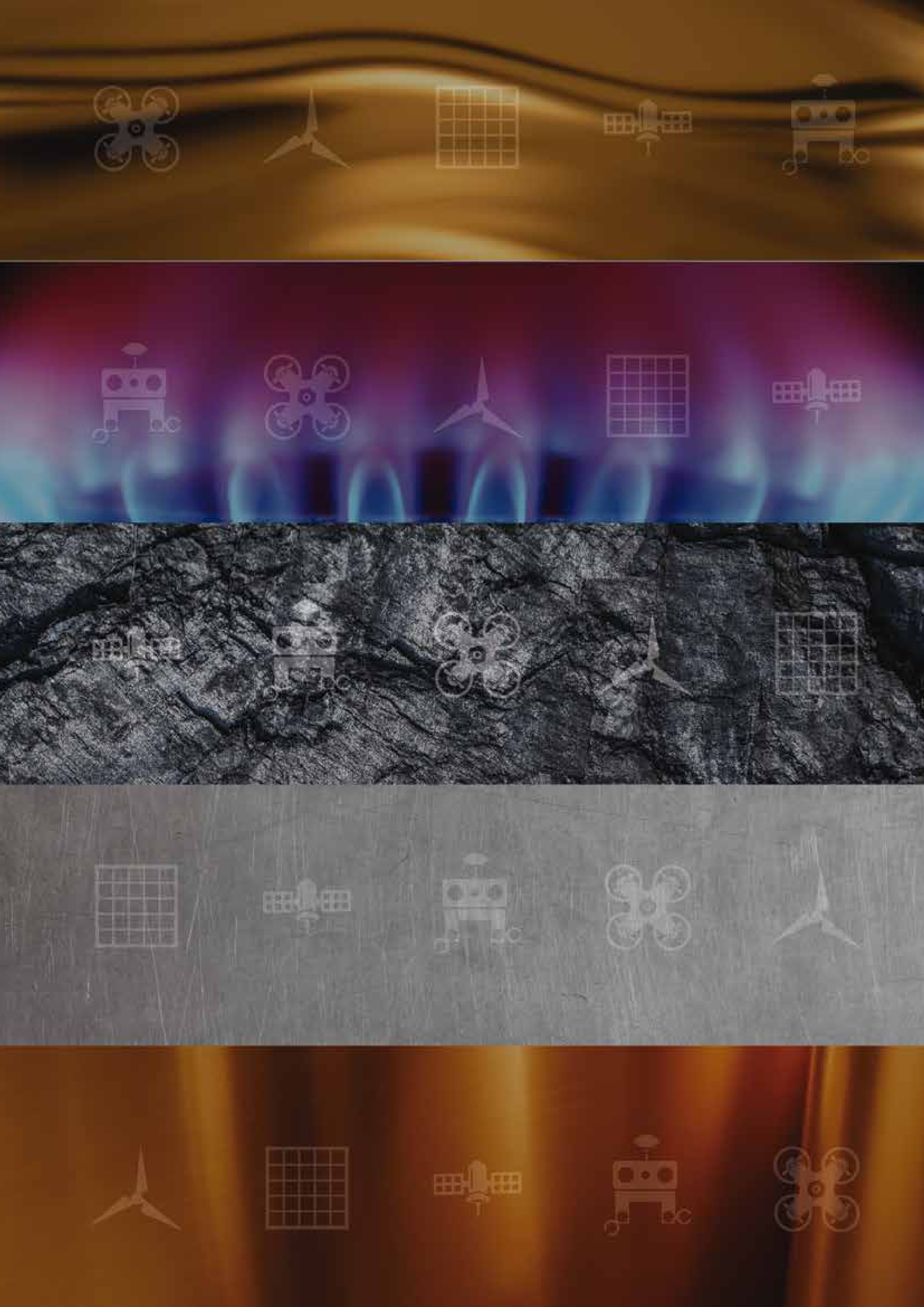
For resource producers, it may not be easy to capture the full value of advances in technologies from artificial intelligence to robotics. They may face a world with permanent overcapacity, in which competition is driven by productivity rather than investment. Yet for producers who do adjust to this new technology-enabled era, and especially for resource consumers, who will benefit directly from greater efficiencies and innovation, the resource revolution will provide substantial opportunity. To succeed in this new commodities era will require a degree of agility, strategic capability, and resourcefulness, yet the potential opportunities may be large. The accelerated adoption of technology could unlock billions of dollars of value for resource producers from productivity gains and trillions of dollars in savings for the global economy.



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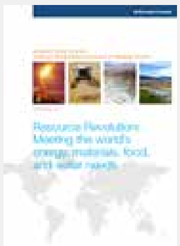

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Cover image: A drone checks solar panels at an electricity generation base in China's Jiangsu province © VCG/Getty Images.

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