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Making the most of the world's **energy resources**

Demand for energy is set to grow rapidly during the next 15 years—unless governments, businesses, and consumers take advantage of the many substantial, economically viable, and technologically proven opportunities to boost energy productivity.

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It isn't easy to be optimistic about energy resources these days. The supply of fossil fuels on the Earth, the number of rivers amenable to damming, the amount of arable land available to generate biomass, the willingness of citizens to accept the perceived risks of nuclear power—all of these have limits. And it isn't clear how quickly scientists can develop innovative alternatives.

Furthermore, recent McKinsey Global Institute (MGI) analysis of the economic sectors most responsible for the end use of energy indicates that overall demand, which has increased by 1.6 percent a year for the past decade, is on track to grow by 2.2 percent annually over the next 15 years (see sidebar "Modeling energy demand").[1] Developing countries such as China account for the largest part of this growth. Curbing demand for energy in the emerging world would mean asking its consumers to reduce their newfound expectations of comfort, convenience, and economic growth—an unacceptable proposition for them.

[1] MGI analyzed the residential, commercial, industrial, transportation, and energy generation and refining sectors, with an emphasis on China, the European Union, and the United States. For details, see MGI's full report, *Productivity of Growing Global Energy Demand: A Microeconomic Perspective*, November 2006, available free of charge online at www.mckinsey.com/mgi.

Article at a glance

New research from the McKinsey Global Institute (MGI) reveals that global energy demand is on a path to grow by 2.2 percent a year over the next 15 years.

MGI's analysis also highlights a number of substantial, economically viable, and technologically proven opportunities to boost energy productivity and to slow growth in demand.

To capture these opportunities, it will be necessary to remove existing policy distortions, to make the pricing and use of energy more transparent, and to deploy demand-side energy policies (such as building codes and efficiency standards) selectively.

Taking these steps will require political will. But the prize—less pressure on global energy supplies—will make the effort worthwhile.

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Is there an escape from the vice grip of finite supplies and surging demand? We believe there is. Both developed and developing economies could use energy more productively by reducing the raw-materials inputs required to produce a given level of energy use, increasing the quantity or quality of the economic output from a given set of energy inputs, or both. These approaches wouldn't call for reducing the benefits that energy's end users enjoy.

As part of a broader report on global energy markets, MGI has uncovered many opportunities to boost energy productivity beyond base-case levels. All are substantial, economically viable, and technologically proven.[2] MGI identified large opportunities across all the sectors we studied, including residential use, industrial use, and power generation. In these and many other sectors, capturing the wide variety of opportunities for greater productivity—each boasting an internal rate of return (IRR) of at least 10 percent—could cut the growth in annual global energy demand, through 2020, to 0.6 percent, from the base case of 2.2 percent.

Market-distorting subsidies, information gaps, misaligned incentives, and other market inefficiencies now undermine energy productivity. Consumers often lack the information and capital they need to use energy more productively and tend to make comfort and convenience higher priorities. Manufacturers of consumer products such as the automobile often don't invest in energy efficiency because they cannot recoup the savings that consumers would enjoy. Businesses refrain from boosting energy productivity because energy costs are fragmented. And a range of policies—particularly subsidies—dampen price signals and give end users less incentive to become more efficient.

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[2] World energy productivity is currently on track to increase by 1 percent a year through 2020 as a result of shifts to services (which are less energy intensive than manufacturing), higher-value products, and more efficient technologies.

It would be far from easy to implement the remedies: removing policy distortions, making the price and usage of energy more transparent, and selectively deploying demand-side energy policies, such as building codes and efficiency standards for appliances. But if policy makers muster the political will to put incentives in place, and if businesses and consumers respond, the results will be dramatic. A 25 percent drop in overall consumption by 2020, relative to business-as-usual growth, is achievable. Because many of the opportunities lurk in emission-intensive areas (such as electricity use and power generation, as well as industrial use in developing countries) such a decline would bring about a corresponding 27 percent reduction in carbon dioxide emissions. (For a detailed analysis of the relative economics of available approaches to decreasing greenhouse gas emissions, see "A cost curve for greenhouse gas reduction," in the current issue.)

Why energy productivity matters

When wildcatters struck oil in the United States, the Caucasus, and the Middle East, cheap and seemingly limitless supplies encouraged its use in countless ways. The resulting new products and services and automation of processes stimulated economic growth, labor and capital productivity, and, of course, demand for energy. The oil crises of the 1970s awakened the world to the need for and possibility of constraints, and the policy changes, technological innovations, and consumer and business choices that followed shifted the global economy to a more energy-productive path. Today's surging demand calls for a renewed focus on energy productivity.

What does energy productivity mean?

MGI defines energy productivity as the ratio of value added to energy inputs. Like labor or capital productivity, energy productivity thus measures the output and quality of the goods and services generated with a given set of inputs. Today, it stands at $79 billion of GDP per quadrillion British thermal units (QBTUs).[3]

Energy prices, business practices, market forces, and government policies all influence energy productivity. Japan leads the world here thanks to consistently high energy prices and strict government energy efficiency standards based on the best practices of leading companies. Japanese gas- and coal-fired power plants are 70 percent more energy productive than Russian ones, and Japan's 2007 standards for room air conditioners are nearly 50 percent stricter than their Chinese counterparts. The

[3] Energy productivity is the inverse of the energy intensity of GDP (the ratio of energy inputs to GDP), currently 12,600 BTUs of energy consumed per dollar of output produced. While both MGI's productivity metric and the more standard BTU-per-dollar-of-output one are useful diagnostic tools, placing GDP in the numerator heightens the emphasis on the benefits of efficiently boosting growth in output.

Arab Gulf, by contrast, is among the least energy-productive parts of the world as a result of large, sustained energy subsidies and an energy-intensive growth model. Similarly, US cars are 15 percent less energy efficient than European ones in the same class, partly because European gasoline taxes are roughly seven times higher and partly because US regulatory exemptions have long helped automakers market SUVs as light trucks, which are subject to less stringent fuel-efficiency rules than passenger vehicles.

Economies can improve energy productivity in two ways:

- They can generate a given level of energy-related benefits with fewer inputs by using energy less intensively (with smaller appliances, for example), using energy in a more technically efficient way (car engines

Modeling energy demand

The energy demand analysis undertaken by MGI and McKinsey's global energy and materials practice diverged from conventional approaches in two ways. First, we made end use the foundation of our analysis and therefore allocated the power sector's energy consumption and losses to end-use segments instead of following the standard distinction between "primary" and "delivered" energy demand. Our approach helped us to arrive at a single figure for global demand, while capturing the full range of behavioral and policy factors influencing demand in each end-use segment.

Second, we employed a microeconomic perspective. The more common macroeconomic approach, which many energy analysts use, involves pairing historical year-on-year GDP growth figures with the corresponding numbers for energy demand growth at both the national and fuel level—for example, oil demand in Japan—and then finding the long-term correlations. MGI's microeconomic approach, by contrast, is based on the fact that global energy demand is really nothing more than the sum of demand in hundreds of microeconomic sectors, such as road transportation in China and residential energy consumption in the United States. We covered nearly 60 percent of global energy demand by conducting detailed case studies of nine microeconomic sectors[1] and used extrapolation techniques for the remainder.

In each sector, we broke down energy demand into its key components: demand for energy services (for instance, how many refrigerators or cars?), the intensity of usage (how big are the energy-consuming devices and how often are they used?), the efficiency of usage (say, what gas mileage or how many kilowatt-hours per cubic meter?), and the fuel mix (for example, how much gasoline or diesel?). The outcomes for any sector vary from country to country because of different development levels, urbanization rates, and policy environments, among other factors.

Finally, we developed dynamic, forward-looking scenarios that model the way these factors might respond to different price and policy environments. By aggregating sector-level insights into a global end-use model for energy demand, we parsed current and potential future demand by sector (exhibit), country, fuel, and region.

[1] MGI has nearly 15 years of experience applying this methodology to such diverse areas as productivity, offshoring, foreign direct investment, and capital markets.

that use less fuel, say), or changing the mix of fuel they use (for instance, by switching from wood-burning stoves to electric ranges powered by coal-generated electricity).

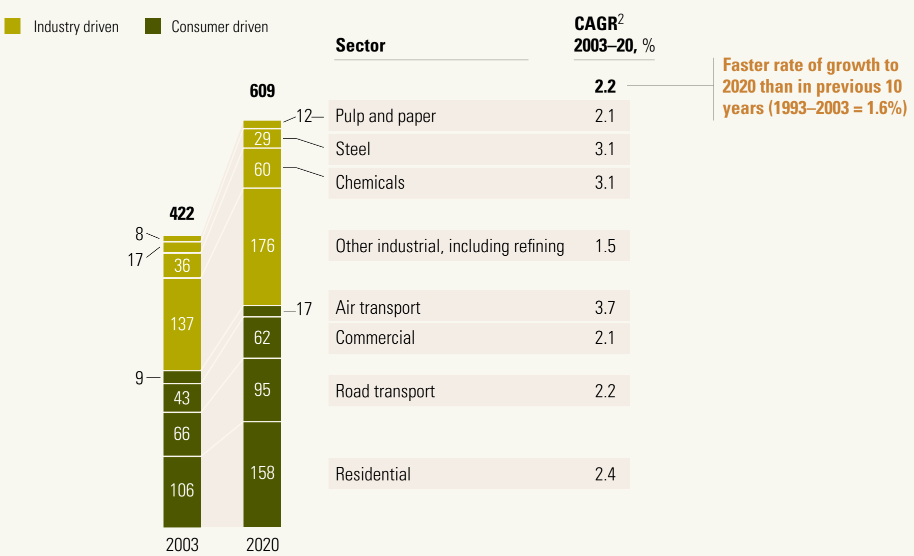
- They can increase output more rapidly than demand for energy by changing the composition of economic activity. Energy productivity rises, for example, when growth shifts from more to less energy-intensive sectors—from steel, say, to services, or to higher value-added activities within services.

Since 1980 changes in input intensity, technology, the fuel mix, and economic activity have generated annual worldwide energy productivity improvements of roughly 1 percent a year—a pace that should continue

EXHIBIT

Parsing demand by sector

Projected growth in global end-use energy demand, quadrillion British thermal units (QBTUs)[1]



[1] Base-case "business-as-usual" scenario; assumes global GDP growth of 3.2% and oil price of $50 a barrel; power generation losses (eg, during generation and distribution) have been allocated to end-use segments.
[2] Compound annual growth rate.

Source: McKinsey Global Institute analysis over the next decade and a half in the absence of significant changes in the way energy regulations and markets operate. The pace will continue to be most rapid in emerging markets, particularly China, simply because they start from very low energy productivity levels that provide huge opportunities for improvement (Exhibit 1). The rapid construction of new urban housing, for example, should help the country boost its residential energy productivity by 2 percent a year.

How energy productivity is related to global demand

Unfortunately, the gain of 1 percent a year in energy productivity over the past decade has been outstripped by global energy demand, which has risen by 1.6 percent a year. In the near future, that demand is likely to grow even faster—by 2.2 percent a year in MGI's base-case scenario. Growth of this magnitude would increase global energy demand to 610 QBTUs in 2020, from 422 QBTUs in 2003 (see sidebar "Sources and uses of energy today").

EXHIBIT 1

Improvements in energy productivity

Energy productivity, GDP in $ billion per quadrillion British thermal units (QBTUs)

	1980	CAGR[1] 1980–90, %	1990	CAGR[1] 1990–2003, %	2003	Base-case CAGR[1] 2003–20, %	2020[2]
European Union[3]	101.5	1.8	120.9	1.0	137.9	1.0	162.6
United States	71.8	2.6	93.0	1.5	112.2	2.2	161.9
Arab Gulf[4]	63.4	–5.8	34.9	–1.1	30.3	0.1	30.6
China	10.5	4.7	16.5	5.2	31.8	2.4	47.5
OECD[5] total	88.1	2.2	110.1	0.9	123.5	1.3	154.6
Non-OECD[5] total	20.8	1.9	25.2	3.1	37.5	1.9	51.3
World average	59.2	1.6	69.7	1.0	79.4	1.0	94.2

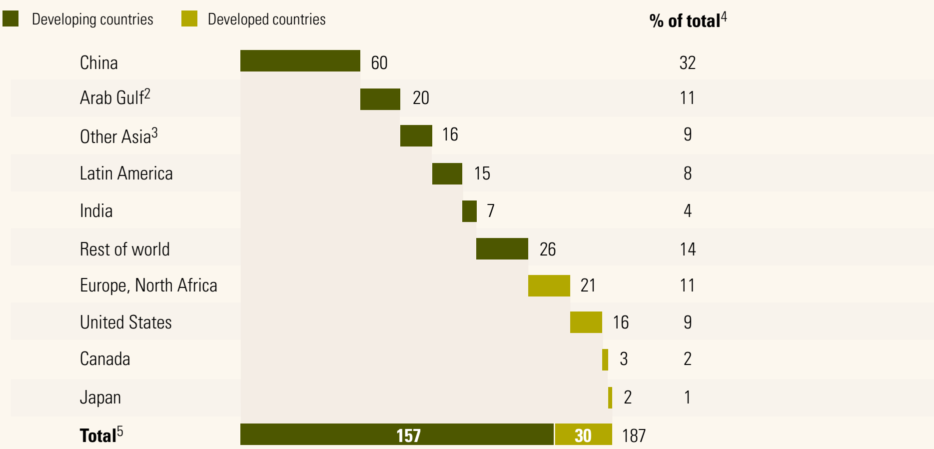
1 Compound annual growth rate; 2003–20 CAGR reflects base-case scenario.
2 Base-case "business-as-usual" growth scenario; assumes global GDP growth of 3.2% and oil price of $50 a barrel.
3 EU15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom; 2003 data and 2020 projection are for northwestern Europe (Belgium, France, Germany, Iceland, Ireland, Luxembourg).
4 Includes Bahrain, Iran, Iraq, Kuwait, Kyrgyzstan, Oman, Pakistan, Qatar, Saudi Arabia, Syria, Tajikistan, United Arab Emirates, Yemen.
5 Organisation for Economic Co-operation and Development; 2003 data and 2020 projection include North Africa.

Source: International Energy Agency (IEA); Global Insight; McKinsey Global Institute analysis

EXHIBIT 2

The energy appetite

End-use energy demand growth by region, 2003–20, QBTUs[1]



[1] Quadrillion British thermal units.
[2] Includes Bahrain, Iran, Iraq, Kuwait, Kyrgyzstan, Oman, Pakistan, Qatar, Saudi Arabia, Syria, Tajikistan, United Arab Emirates, Yemen.
[3] Data include the developed country Australia.
[4] Figures do not sum to 100%, because of rounding.
[5] Figures for developing and developed countries do not sum to totals, because the regional groupings in some instances do not break out those categories.

Source: McKinsey Global Institute analysis

That growth comes mainly from rapidly developing emerging markets, which together are projected to generate nearly 80 percent of the growth in world energy demand in our base case through 2020 (Exhibit 2). China, with six of the ten sectors likely to grow most quickly, represents 32 percent of world growth. In contrast, India's growth in energy demand represents just 4 percent of the world total through 2020. One explanation for the lower Indian figure is that rapid urbanization should lead to a significant change in the mix of fuels residential consumers use—from relatively inefficient biomass (wood and dung, which today meet roughly 80 percent of India's residential energy needs) to electricity.

Although these projections rest on bottom-up forecasts of demand in dozens of microeconomic sectors, they are subject to considerable uncertainty. In particular, the rate of global GDP growth (3.2 percent in MGI's base-case scenario) will have a major impact on the rate of growth in energy demand.[4] Our analysis indicates that GDP growth, particularly in developing

[4] MGI's global growth forecast is approximately 0.5 percent higher across all end-use sectors than the corresponding projections of the *International Energy Agency World Energy Outlook 2004*. The sources of the additional growth we project are more rapid industrial expansion in China and faster overall growth in the Middle East and in middle-income Europe.

Sources and uses of energy today

In 2003 the world used 422 quadrillion British thermal units of energy. Petroleum products met a third of this demand (about 76 million barrels a day, or 145 QBTUs annually); coal and natural gas, 100 and 90 QBTUs, respectively. The remainder was split among many fuels, including biomass.

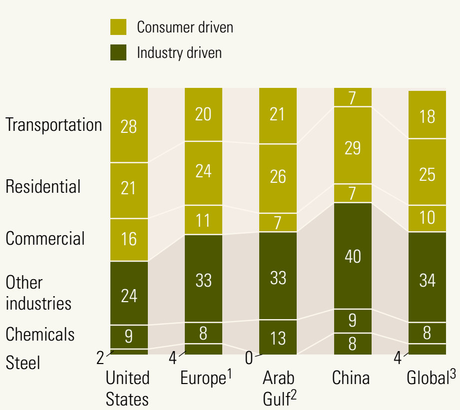
Consumers (as opposed to industrial users) accounted for more than 50 percent of total energy demand and for 60 percent of demand in the developed world (exhibit). On the national and regional level, the largest energy consumers are the United States, with 92 QBTUs (22 percent of the global total); Europe, with 86 QBTUs (20 percent); and China, with 60 QBTUs (14 percent). The sectors that now consume the largest amounts of energy are US road transport (5.4 percent of global energy demand), residential heating and lighting in China and the United States (4.0 and 4.5 percent, respectively), and US commercial buildings[1] (3.5 percent).

[1] Commercial buildings are nonresidential and nonindustrial. Typical examples include retailing and office real estate, and common energy applications include heating, operating appliances, and lighting.

EXHIBIT

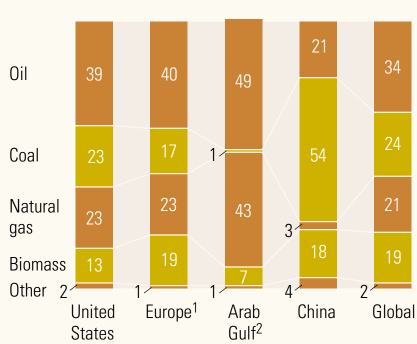
Consumers demand more

End-use energy demand by sector, 2003, %



	United States	Europe[1]	Arab Gulf[2]	China	Global[3]
Total, QBTUs[4]	92	86	20	60	422

Primary demand by fuel, 2003, %



[1] Includes Baltic states; Eastern Europe; northwestern Europe (Belgium, France, Germany, Iceland, Ireland, Luxembourg); Mediterranean, including North Africa.
[2] Includes Bahrain, Iran, Iraq, Kuwait, Kyrgyzstan, Oman, Pakistan, Qatar, Saudi Arabia, Syria, Tajikistan, United Arab Emirates, Yemen; figures for primary demand by fuel do not sum to 100%, because of rounding.
[3] Figures do not sum to 100%, because of rounding.
[4] Quadrillion British thermal units.

Source: McKinsey Global Institute analysis economies, will drive the biggest swings in global energy demand. Higher than expected GDP growth would boost growth in energy demand to 2.7 percent a year (an increase in global energy demand of roughly 50 QBTUs by 2020 over the base case), while slower GDP growth would reduce demand (from the base level) by around 50 QBTUs.[5]

Sustained oil prices of $70 a barrel would cut global energy demand much less—by roughly seven QBTUs. A key explanation for this modest reduction is a complex brew of market failures, market-distorting public policies, and information and capital constraints. In addition, changes in relative prices induce energy users to switch to other fuels—from gasoline to biofuels for transportation, from natural gas to coal for generating electricity—but don't reduce overall energy demand as significantly. And high oil prices boost GDP and energy demand in the Arab Gulf region, where energy productivity is low, thereby partially offsetting lower GDP and energy-demand growth in more efficient, oil-importing regions.

Boosting energy productivity

All this should make clear the inextricable relationship between energy demand and energy productivity: the higher the productivity, the lower the demand at any level of GDP. But to make energy productivity grow more quickly, a variety of targeted interventions will be needed.

Seeking out the opportunities

Conventional technologies with an IRR of 10 percent or more offer tremendous opportunities for improving productivity in a broad range of end-use areas. Capturing these opportunities would reduce growth in global energy demand to below 1 percent annually (from 2.2 percent in the base-case scenario) while shrinking projected 2020 end-use demand—perhaps 610 QBTUs—by somewhere between 116 and 173 QBTUs, some 19 to 28 percent of total energy demand (Exhibit 3). To put these figures in context, consider the fact that if nonhydroelectric renewable power sources increased their share of global power generation from 2 percent today to 5 percent in 2020, and if biofuels boosted their share of the transportation fuel market to 10 percent, from 1 percent, all of these sources would contribute only about 30 QBTUs to the world's energy supply in 2020. What's more, rather than requiring subsidies, energy-productivity opportunities provide a positive rate of return, freeing up resources that could be consumed elsewhere or invested for faster growth. We consider some of the most promising opportunities below.

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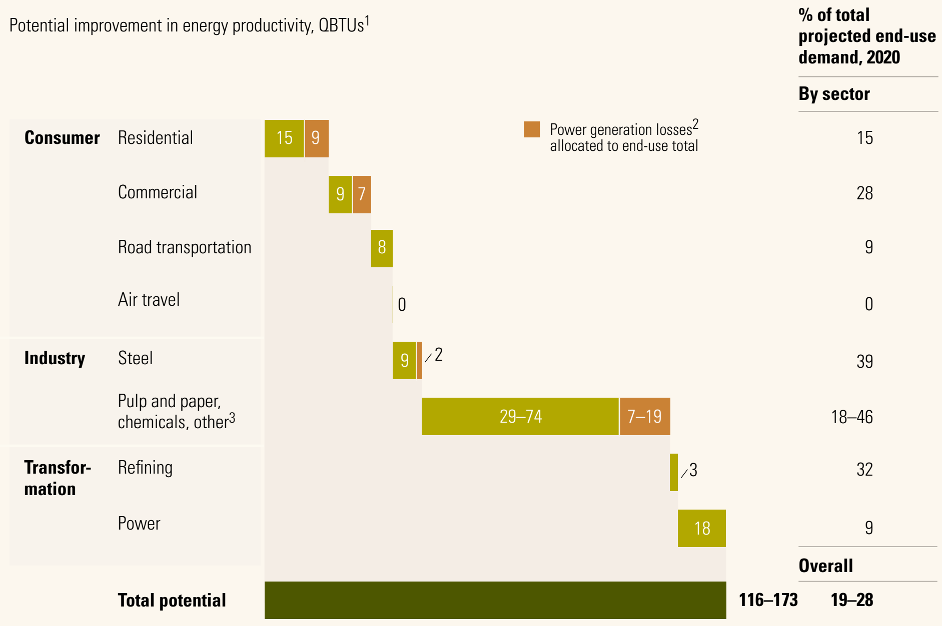
[5] Our model's assumptions of high and low GDP growth rest on growth that would be two percentage points above and below the forecast base-case rates in China and India, one percentage point above and below the forecast base-case rates in other emerging markets, and half a percentage point above and below the forecast base-case rates in developed countries.

EXHIBIT 3

Opportunities in conventional technologies



¹From conventional technologies with internal rate of return ≥10%; QBTUs = quadrillion British thermal units.
²For example, during generation and distribution.
³For example, cement, food processing.

Source: McKinsey Global Institute analysis

Residential heating and lighting. With 25 percent of global energy demand, residential property represents the largest energy-use segment. Key opportunities include fitting out new homes with tight building shells, including chemically treated windows to reduce the amount of cold that comes in during the winter and the amount of heat that comes in during the summer; high-grade insulation; compact fluorescent lighting; and solar water heaters. In addition, higher efficiency standards for appliances and reductions in standby power requirements yield positive returns and simultaneously cut demand for energy. We estimate that these and other technologies in lighting, heating, and cooling could slow growth in residential energy demand to 0.5 percent a year, from 1.4 percent, and reduce 2020 energy demand by 15 QBTUs (or 3 percent of the total).

Electricity generation and distribution. Another large opportunity would come from reducing the losses that arise in generating and distributing electricity. In 2003, 129 QBTUs (30 percent of global energy use) were needed to generate 57 QBTUs of delivered electricity—meaning that generation and distribution consumed nearly 60 percent of all energy inputs. This implies a conversion rate (energy delivered divided by energy used) of around 40 percent. Some of the losses are unavoidable, but even today conversion rates range from under 30 percent in older coal plants to more than 50 percent in newer gas ones. We estimate that new technologies, such as advanced combined-cycle gas turbines, with an IRR of 10 percent or more, could reduce demand by 18 QBTUs as of 2020.

By then, the expansion of China's power sector will represent 13 percent of the growth in global energy demand. If China meets it by building new, high-efficiency coal plants, the country's overall energy demand will fall by 7 QBTUs—more than 1 percent of the global total—by 2020.

Steel, refining, and other industrial sectors. There are enormous opportunities to improve energy efficiency by replacing the least efficient tail of production with current technologies and by implementing currently economical energy-saving upgrades. These opportunities could reduce global energy demand roughly 65 QBTUs by 2020.

In the US steel industry, for instance, realizing a large number of small opportunities, such as expanding cogeneration and improving recuperative burners,[6] would allow steel mills to cut their demand for energy by about 30 percent. The opportunity in the developing world's steel mills, which are some 20 percent less efficient than their US counterparts and could be maintained more efficiently thanks to less expensive labor, is even larger.

Similarly, recent demonstration projects in US petroleum refineries have highlighted numerous opportunities with a payback of one year or less—opportunities that taken together would raise the sector's energy productivity by 12 percent.[7] As with steel, the opportunities in developing countries should be larger because their refineries are relatively inefficient.

Paper manufacturers can boost their energy productivity by introducing equipment such as extended nip presses, which extract an additional 5 to 7 percent of water from intermediate products, thereby reducing the load on relatively less energy-efficient dryers. Cement makers can save energy by fitting out their traditional ball mills (used to grind materials such as limestone) with high-pressure roller presses or by replacing those mills with more modern horizontal roller mills.

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[6] Devices that control the loss (in the form of flue gases) of the heat that goes into the high-temperature furnaces used in steelmaking. Without a recuperative burner, a steel manufacturer can lose up to 50 percent of the heat it puts into them.

[7] One such demonstration project is the effort (cosponsored by the US Department of Energy) at Equilon Enterprises' Martinez plant, in northern California.

Correcting market failures

In view of today's high oil prices, why haven't companies and consumers already seized the opportunities? The answer is that systematic market failures involving consumers, businesses, and governments dampen the demand response to changes in price. Any effort to boost energy productivity must take these issues into account.

- *Consumers, information, and capital.* Most consumers lack information about the range of energy productivity improvements available to them, even though exploiting these improvements would serve their economic interests. Furthermore, to capitalize on energy productivity opportunities, consumers must often make up-front capital investments for which they have neither the funds nor the desire. Another issue, particularly in developing countries, is the fact that energy savings are often highly fragmented and their impact on household expenditures murky. As a result, the benefits of greater energy productivity are often obscured by the consumer's focus on using energy for comfort, convenience, style, and health or safety. And since few consumers are willing to pay now for energy savings in the future, suppliers of energy-consuming products (such as cars and appliances) have less incentive to develop, produce, or market energy-efficient technologies and features.

- *The relative unimportance of energy costs to business.* Total US energy costs now represent less than 10 percent of the value of the output in all nonenergy sectors—indeed, less than 5 percent for most economic activities. Energy efficiency is thus typically a minor consideration, at most, when businesses invest in equipment such as automated-manufacturing tools or IT hardware. Many companies require a payback of three years or less (corresponding to an IRR of more than 30 percent) for capital expenditures to reduce energy consumption.

- *Governments and subsidies.* Energy productivity is systematically undermined by government policies. For starters, many developing-world industries that transform energy or use it intensively are state owned, which often reduces the financial incentives to improve energy productivity. What's more, at least 20 percent of current global energy demand is subsidized or priced in a nonmarginal way, and both practices reduce or eliminate incentives to use energy as productively as possible. These energy-distorting policies include fuel subsidies in oil-producing countries in the Middle East and elsewhere, a lack of metering for the gas used in Russia's homes (setting energy's marginal cost at zero), and widespread energy subsidies for state-owned enterprises. Not surprisingly, energy efficiency in these areas lags behind global best practice dramatically.

The first step for governments hoping to solve these problems is to remove policies, such as subsidies, that discourage energy productivity. Governments should also look for sector-specific opportunities to promote it. Building codes and appliance-efficiency standards, for example, can help overcome the information barriers that inhibit many consumers from installing more efficient heating and lighting. Codes and standards are also helpful in dampening the impact of an agency problem in the construction industry: builders of offices, apartments, and homes often have little incentive to focus on energy efficiency, because the potential occupants may be reluctant to spend more now for a building that promises energy savings in the future.

Innovative companies also have a role to play in ameliorating market failures. Consider, for example, a general problem: energy users implicitly place extremely high discount rates on investments in fuel-efficient technologies, thereby limiting their adoption. Creative sales terms, perhaps developed through collaborations between utilities and the companies that sell the relevant technologies, could bridge the time gap and dampen the impact of high discount rates.

The right policies are likely to vary by region. Average fuel economy targets would have a faster impact in countries such as China, where new vehicles purchased over the next 15 years will represent most of the country's stock of automobiles. By contrast, in the United States, where the stock of vehicles will turn over more slowly, higher gasoline taxes would create broader incentives for existing car owners to use private cars less and public transport more and to move closer to the workplace.

The world faces many problems whose scope and complexity make them virtually intractable, but energy doesn't have to be one of them. If leaders muster the political will to eliminate market inefficiencies, companies and consumers will seize attractive energy productivity opportunities and create a brighter future. Q

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