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Emerging Technology in the Energy Industry and Its Impact on Supply, Security, Markets, and the Environment

Technological change has been a major feature of energy markets since the 1970s oil crises. Dire predictions about the rapid depletion of moderately priced oil supplies were commonplace then. But in the intervening years, despite a rapidly expanding global economy, such prognostications have proven false.

Instead, over the last three decades, technological advances in drilling and exploration have contributed to a significant expansion of conventional hydrocarbon production available from oil and gas fields located outside the Persian Gulf. This technological progress has dramatically lowered the cost for finding and producing oil and natural gas and provided energy consumers with ample, inexpensive supplies at a time in which earlier forecasts had predicted shortages. At the same time, energy use has also been held in check by technological improvements in residential and industrial use as well as in power generation. Improved automobile mileage standards and more efficient diesel engines have also dented the uptick in consumption of oil-based transport fuels, particularly in Europe.

In recent years, technologies have emerged that could change the landscape for our primary energy sources, but few are close to rapid commercialization. Breakthroughs in the power and electricity sectors are also years away. Fusion-driven power generation is between ten and twenty years away from commercialization under the best of circumstances. Moreover, while utility Detroit Edison's pilot test with high-temperature superconductor transmission wires is due to occur as early as 2000, a breakthrough for wire casing costs must be made before the technology can be widely applied. The commercialization of fuel-cell technology is more advanced, particularly in the power generation sector, but broad application to the transportation industry could still be decades away. Some pilot programs are being conducted to develop emerging energy technologies in certain industries, including transportation sectors, in China and other developing countries. But it is unlikely that large emerging economies such as China and India will be able to cope with rising dependence on traditional fossil fuel resources in the coming years by leapfrogging to alternative energy technologies.

Still, technological change will continue to be a significant factor in energy markets during the 21st century. In examining the role technology is likely to play in the future, the Baker Institute concludes the following:

- Low oil prices do not necessarily imply that policymakers can be complacent about energy matters. Rather, complex technological and environmental changes that will develop in the coming years mean that intelligent energy policy formulation will need to consider a broad range of issues in a comprehensive and coherent fashion. It is not enough to look at only supply and security issues for oil markets. Policies related to oil, natural gas, coal, alternative technologies, and the environment should not be compartmentalized into their respective categories. Rather, the factors that will influence choices in each of these vital areas

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must be considered together and integrated into a coherent and unified energy strategy.

• The huge scale of growing greenhouse gas emissions from developing countries such as China, India, Brazil, and Indonesia casts doubts on the effectiveness of the Kyoto accords to reduce greenhouse gas emissions if these countries are not included. Cleaner, more efficient emerging technologies in the automotive and power sectors could eventually help fill the gap that the Kyoto agreement leaves behind in reducing overall levels of global emissions from key developing nations. However, in the short run, it is unlikely that these large emerging economies will be able to cope with rising dependence on traditional fossil fuel resources in the coming years by leapfrogging to alternative energy technologies.

• As energy markets develop to include innovative technologies, the oil and gas companies that will succeed will be those that transform themselves into energy businesses. Firms with expertise in the widest number of energy sources will be best positioned to exploit opportunities to expand their assets and sales markets.

• Technological innovation in hydrocarbon exploration and extraction could potentially restrain real oil prices for the foreseeable future, barring a major prolonged supply disruption, by ensuring ample, low-cost supplies. Therefore, public policy on energy should not be driven by concerns that the world will run out of oil. Rather, energy leaders should focus on the political, economic, and other factors that can lead to sudden, large oil price movements.

• While progress has been made in the development of alternatives to fossil fuels, particularly for power generation and automobile transportation, these alternatives are unlikely to have significant impact on energy markets until after 2020. Oil is likely to remain the predominant energy source for the transportation sector well into the 21st century. While alternative engine systems might play a limited role in dampening demand for diesel and gasoline fuel in industrialized countries of the Organization for Economic Cooperation and Development (OECD) during the next decade or so, they are unlikely to represent a major share of the market until 2020 or later.

• Beyond 2020, a gradual erosion of oil's share of the transportation sector may begin to develop, leading to a plateau in oil consumption levels. By the latter half of the next century, oil could have a declining role as new technologies come to the fore in the transportation and other sectors.

Technology's Role in Oil and Gas Industries

For the past two decades, analysts have underestimated the elasticity of oil supplies from countries outside the Persian Gulf, leading to

widespread predictions of rising real prices over time. In reality, real prices did not rise on a sustained basis between 1984 and 1995. Production from outside the Organization of Petroleum Exporting Countries (OPEC) was expected to decline by 3.6 million barrels per day (b/d), or about 13 percent. Instead, it rose by over 4 million b/d, or about 15 percent. In 10-year forecasts published by the U.S. Department of Energy in the early 1970s, North Sea production was expected to peak in 1986 but instead continued to rise until very recently. The elasticity of supply from non-OPEC turned out to be much greater than most assumed, raising doubts about the industry's ability to forecast future oil supply (See Jaffe, Soligo, and Mieszkowski, "Energy Security," Baker Institute working paper, April 1997).

By itself, the poor track record of oil analysts' forecasting in the 1970s, '80s and early '90s does not mean that experts now predicting a collapse in supply are necessarily incorrect. But the experience of this period highlights a chronic under-appreciation of how technological change and government oil and gas policies can bring previously undeveloped, underutilized, or unprofitable oil fields into production. What analysts missed in expecting the non-OPEC phenomenon to be short lived was that technological advances would significantly lower the costs of developing marginal reserves and improve the chances for new discoveries while at the same time enhancing recovery rates from the existing resource base.

There have been several advances that have supported the expansion of hydrocarbon resources outside the Persian Gulf over the past decade or so. Improvements in underground seismic imaging systems have had dramatic effect, driving large discoveries in the U.S. Gulf of Mexico and subsalt areas in recent years. The use of 3-dimensional (3-D) seismic capability was a major force in the 1995 offshore U.S. discoveries in the Mississippi Canyon region, for example. New discoveries under salt layers previously blocked to oil and gas explorers could contribute between 100 to 300 million b/d of oil equivalent in the coming years, notes John Kennedy, editor-in-chief of the respected weekly magazine Oil and Gas Journal. The use of 3-D seismic technologies not only minimizes the incidence of dry holes but also reduces the costs of missing a field that might not otherwise have been found. New four-component seafloor seismic systems allow explorers to see geological features below layers of gas, improving geological data.

The use of 4-dimensional seismic technology that detects movements in fluids is increasing oil recovery rates. New logging techniques, control systems, and downhole sensors also allow better control of oil well performance, lowering costs by saving the time it takes to log a well and reducing the number of costly subsea repairs and adjustments that are needed. New semisubmersible rigs have multitasking capabilities, allowing companies to save time and lower costs by not having to implement project steps in a strict sequential order. Stronger management systems for development planning can also speed project implementation and reduce the time that a new field remains in a negative cash flow situation ahead of first production. Companies are also now starting to utilize new advanced visualization equipment that allows a virtual reality interaction with real time data to improve drilling success and reduce analysis time. Improved platform design and construction have lowered the costs of deep water exploration dramatically from $12 to $15 a barrel in the late 1980s to $4 to $6 a barrel currently.

Such technologies are expected to augment recovery of oil and gas reserves by 10 to 20 percent and lower discovery costs. By 1998, technology has reduced average U.S. hydrocarbon discovery costs to around $5 a barrel down from $15 in the 1980s. Drillers are experiencing four times the success rate in natural gas exploration and six times the success rate in oil exploration. In 1952, world energy consumption rates of that time represented 4 percent of conventional proven reserves. Consumption rates for 1997 represent only 2.5 percent of proven reserves. Such statistics support the view of analysts who argue that the world is unlikely to run dry of oil.

Some analysts remain convinced that advances in technology simply speed the time it will take to deplete the world's conventional hydrocarbon resources. Some prominent theoreticians note that technology is only buying time until the major basins discovered in the 1970s move into massive decline. (See Campbell, Colin, and Jean H. Laherrere, "The End of Cheap Oil," Scientific American, March 1998.) They argue that frontier oil will not be able to replen-

ish the world's reserves, leading finally to the rise in real oil prices that has eluded oil men to date. While it is theoretically possible that a hiatus will be reached in the development of newer exploratory and extraction methods, history and the wide array of emerging capabilities strongly suggest otherwise. The oil industry continues to perfect its methods, and new moderate-cost conventional reserves continue to be brought on-line.

Technological advances and better information have done more than prompt a reevaluation of the size of older fields and enable them to continue to produce in excess of previously established reserve levels. Reserve additions also came about through the addition of new compartments or sections of the field that might have gone unnoticed but for improved technology. Such technology can also help oil companies discover satellite deposits to discovered oil fields. Moreover, the use of horizontal drilling methods can render a larger number of reserves economically recoverable. Technology-induced cost reductions can also make previously uneconomical reserves commercially viable, even under low oil price conditions, as is now being seen in several deep water provinces and even Venezuela's Orinoco heavy oil belt. The argument that the number of large basins left to be exploited is shrinking runs against the grain of the industry's recent experience. Since the early 1990s, a larger swatch of prolific acreage has been opened for drilling than in prior decades. These promising areas had been closed off to international explorers for decades due to political barriers. In recent years, for example, exploration and development activities have expanded in the former Soviet Union, Algeria, Africa, and South America, including Venezuela.

The technology-driven improvement in hydrocarbon reserve recovery and operational efficiency has translated into cash flow improvements for exploration companies. Returns on capital employed have favored the largest companies. Studies at Columbia University's Lamont Doherty Center show that the bigger the company, the better it is likely to be at applying technology in its operations. Ability to use technology properly has affected the growth capability of companies and, in part, drives today's merger and acquisition fever. Mergers can offer a potential solution for smaller companies that must prove to shareholders that they can avoid depletion and produce a longer, more stable long term outlook for oil assets, according to Roger Anderson, managing director of Columbia University's Energy Research Center.

Outlook for Technological Breakthroughs in Fueling the Transportation Sector

Prognostications that oil may remain readily available at relatively inexpensive prices have implications for development of alternative fuel sources or systems in the transportation sector. At present, it does not appear that prolonged high oil prices will be the driving factor behind the development of new nonhydrocar-bon-based engine systems. Rather, environmental or commercial considerations, such as cost of manufacturing or industry competition, are likely to be the motivating forces behind the development of automobile engine systems that consume less or no gasoline or diesel fuel.

Still, many of the major car manufacturers have committed significant financial resources to the research and development of alternatives to traditional internal combustion engine vehicles. The next generation of automobiles will almost certainly include new efficient, direct-injection gasoline engines that emit lower pollutants while consuming 20 percent less fuel. Such an engine, designed by Mitsubishi Motors, is already being used in car manufacturing in Japan and Europe. But the major auto manufacturers are also investing in research and development projects to perfect technology for the production of electric vehicles (EV), hybrid vehicles (HEV), and fuel-cell electric vehicles (FCEV). These experimental designs also offer the promise of much greater fuel economy and lower greenhouse gas emissions and may cut into future increases in gasoline use in the OECD over the coming decade or two.

Mitsubishi's direct-injection engine, which costs roughly the same price to manufacture as a conventional combustion engine, is limited in its use because it cannot burn gasoline that contains as high a sulfur content as that used in the United States, according to industry newsletter Petroleum Intelligence Weekly. But tightening quality specifications for gasoline in

Europe and Japan have rendered the engine viable there, and the U.S. Environmental Protection Agency (EPA) is proposing to introduce new product specification rules that would bring sulfur content in U.S. gasoline to similarly low levels by 2004. The catalyst of the new engine can absorb 60 percent of nitrous oxide emissions while burning off another 30 percent through exhaust recycling. Volvo has already concluded a licensing agreement with Mitsubishi for use of its direct-injection engine, and other car companies may do the same.

Processing technology is emerging that can convert natural gas into the kind of high-quality, low-sulfur diesel fuel that could be processed by the Mitsubishi direct-injection engine. Oil companies such as South Africa's SASOL, U.S. Exxon, and the Royal Dutch Shell Group all have been developing this "gas-to-liquids" (GTL) technology. Exxon has announced plans to build a GTL facility in Qatar. Specialty firm Centrolium has also developed GTL technology. Under present technology, GTL plants will have trouble breaking even in markets where crude oil prices are below $15 to $17 a barrel and natural gas supply costs exceed 50 cents per million btu (British thermal unit), according to Aaron Brady, fuel analyst with consultants Energy Security Analysis, Inc. But GTL technology remains an option down the road if oil prices recover or if technological breakthroughs can lower GTL costs.

Several major car makers are investing in the development of new generation engines utilizing EV, FCEV, or HEV technology. Within the past decade, driven by environmental concerns and recent government programs to reduce vehicle emissions, most automobile companies have begun development on both EVs and hybrid vehicles, and several companies have already introduced prototypes into the market on a small scale. Breakthroughs in fuel-cell technology have also allowed the development of the FCEV. Results have shown that all of these cars offer negligible amounts of emissions while maintaining the smooth and quiet ride required by the marketplace. However, several design, cost, and other hurdles must be conquered before these vehicles can become a realistic alternative to the combustion engine car on a mass market level.

An electric vehicle works by storing electric energy in a large, rechargeable battery. The heavy weight of such batteries and their relatively short range of 100 miles or less per recharge has limited the use of electric vehicles to a small niche market.

The HEV is currently a prime candidate to lead the transition away from the gasoline engine, and it does offer significant improvement over traditional vehicles in terms of reduced pollution emissions. Hybrids incorporate a small primary engine with an electric motor that provides additional power through traction drive while also recovering braking energy

By 2020, gradual erosion of oil's share of energy markets may begin to develop as more environmentally friendly engines and generators proliferate in industrial countries. As this trend gains momentum, the oil and gas companies that will succeed will be those that transform themselves into energy businesses that have expertise in the widest possible number of energy sources.

to recharge the battery. These vehicles use a liquid fuel such as diesel, gasoline, or ethanol to power the primary engine.

Fuel-cell electric vehicles are another potential alternative to the gasoline combustion engine. Fuel cells work by converting the chemical energy of hydrogen and oxygen directly into usable electricity and heat without combustion or pollution. Methanol serves as the best source for hydrogen extraction, and these vehicles have an advantage over electric cars since they can operate indefinitely as long as fuel is supplied to the fuel cell.

Even as research and development efforts continue to lead to improvements in these advanced technology vehicles, such vehicles are not likely to be a viable alternative to the oil-based automobile until well into the 21st century. Production costs remain high, and technological improvements are still needed to perfect most designs. Moreover, despite environmental concerns, no significant commercial push is coming from consumers. Electric and hybrid vehicles generally still cost 20 to 40 percent more than conventional automobiles; operating costs are also higher.

Today, with gasoline prices relatively low, the introduction of alternative energy vehicles is limited to marginal, niche markets such as urban Japan. The major auto manufacturers are targeting 2003-2004 to introduce new prototypes. To shift this trend more quickly, environmental legislation, a tax credit for buying these vehicles, or other special tax incentives would be needed, according to independent energy consultant and former ARCO chief economist Anthony Finizza. Some economists argue that environmental policies that force industry to create cleaner engine systems for use in transportation in the U.S., Europe, or Japan could eventually lead to commercial breakthroughs. Such breakthroughs could be applied to reduce pollution in developing countries such as China and India.

Still, even if technological breakthroughs or government policies could stimulate strong consumer demand, it would still be several years before electric, fuel cell, or hybrid vehicles would have significant impact on energy markets. The average age of cars on the road in Europe and Japan is between seven and ten years. Replacement of old vehicles with ones using alternative technology would take many years as consumers choose to retire the huge stock of conventional vehicles now on the road. Were an expedited change to be implemented, it would still take a decade to introduce 20 million alternative energy cars worldwide--a mere fraction of the world total, Finizza notes.

One of the first auto manufacturers to hit the road with an alternative engine vehicle has been Toyota Motor Co. Its Prius, an HEV, has been available in Japan since December 1997 at a cost of under $16,000. It is to be introduced into the U.S. market in the next year or so. The Prius uses a gasoline-powered engine for acceleration and highway driving in combination with a battery for city driving. Hiroyuki Watanabe, director of Toyota Motor Co.'s worldwide operations in after-sales service, supply parts, and conversion and accessory productions told a Baker Institute audience last December that Toyota does not plan to go into mass production of the vehicle until it can make a profit. Presently, production of the car is subsidized by several thousand dollars. But Watanabe noted that the Prius could possibly represent 9 percent of Toyota's market share in the future. Toyota expects alternative vehicles to be commercial by 2020.

Several other automobile companies also have programs to develop advanced technology vehicles. Ford Motor Company's Ranger is offered as an EV, and Ford also has its P2000 project. Neither car is considered a candidate for mass production at this time. Ford also has a pilot program to introduce electric vehicles in China. Daimler-Benz produced a fleet of zero-emission buses that derive electricity from methanol, and it is working on a fuel-cell methanol subcompact car. Nissan has announced plans to begin selling FCEVs as early as 2003. Nissan's FCEV runs on methanol and uses a Ballard fuel cell. Honda has similar plans for development of an alternatively-powered vehicle.

Chrysler was working with Exxon, Arco, Detroit Edison, and the U.S. Department of Energy to develop a gasoline-fired fuel-cell vehicle, and they are pursuing a hydrogen fuel-cell vehicle that could run on methanol. The latter car will be targeted for California, according to Finizza.

A breakthrough in automobile technology would have dramatic impact on energy markets since the transportation sector is expected to lead growth in energy demand worldwide. Assuming no major

breakthroughs in automotive technology, the International Energy Agency projects that 59 percent of the 41 million b/d increase in worldwide oil demand expected between 1995 and 2020 will come from the transport sector.

Outlook for Technological Innovations in the Power and Electricity Sector

Environmental factors continue to drive the search for cleaner, more efficient ways to provide power and electricity worldwide. The long-term trend in energy use in this sector has been toward fuel systems that lower carbon consumption and increase the cleaner use of hydrogen. The power sectors in the U.S. and Europe have moved increasingly away from coal to oil and, most recently, to natural gas. But on a global basis, coal use is still growing by 3.5 billion tons a year and might accelerate into the 21st century, according to Christopher Wardell, chief mining engineer for the World Bank and manager of the bank's clean coal programs. Growth in China and India alone could be dramatic, with China's growth in coal use possibly rising to 2 billion tons a year by 2010, up from 1.4 billion tons currently.

The environmental challenge of China and India's growing coal use has led to initiatives to find cleaner methods to exploit coal for energy. In many locations in China, better practices could be used to lower the environmental damage for heavy coal use, lowering the amounts of SO2 and particulate pollution that results from the country's massive coal consumption. The World Bank's clean coal initiative seeks to guide policy reform inside the big coal-using economies, with an eye to helping those countries use coal in a cleaner fashion. Selective mining, which involves choosing coal grades with lower toxicity, and coal preparation techniques can have a dramatic impact in lowering the amount of SO2 and particulate matter released into the atmosphere during coal use.

Besides searching for ways to use coal more cleanly, many developing countries are investigating new technologies that could allow them to leapfrog existing fuels to meet rising energy needs with new cleaner energy sources. Nuclear energy remains an option, but safety issues in the aftermath of the Chernobyl and Three Mile Island accidents have slowed progress in nuclear energy development. Nuclear power fueled about 17 percent of total electricity worldwide in 1996, and nuclear energy's share of the world energy mix is expected to climb over the next ten years before peaking as several U.S. reactors are retired around the turn of the century. The nuclear industry faces an uncertain future due to popular concerns about safety and the handling of nuclear waste. Some large plants are still planned in Japan, South Korea, China, Taiwan, and India, but increasingly, Asian populations are similarly questioning the wisdom of expanding energy supplies by building nuclear plants. At present, over 70 percent of new planned nuclear capacity is slated to be installed in Asia. By contrast, nuclear use is expected to decline in the U.S., Western Europe, and the former Soviet Union.

The emphasis of scientific research on nuclear energy has shifted away from fission to fusion, a form of nuclear power in which atoms are fused together to form new atoms and release energy. Fusion research has proceeded for decades, but so far, no commercially-viable process has been fully proven. A new design theory--a colliding beam fusion reactor--to contain a fusion reaction fueled by boron has been put forth by University of California at Irvine physicist Norman Rostoker and University of Florida colleague Hendrik Monkhorst. Mainstream fusion chambers that combine hydrogen isotopes to make helium require multibillion-dollar, 100-foot high tokamak reactors. By contrast, the two physicists' new colliding beam concept seeks to combine protons with boron in a far smaller, less expensive chamber about 30 feet long and six feet high. Electric coils around the chambers would be used to generate the magnetic fields needed to create the reaction that manufactures new, high-speed helium nuclei or alpha particles. These particles are then fed into generators that transform their energy into electric power.

Under the best case scenario, the new concept would take about three years to prove and an additional four years to build and operate a prototype, Rostoker told an audience at the Baker Institute. Should the prototype prove successful, it would still take another decade or so before manufacturing capability for the new plants could be established.

Complex technological and environmental changes that will develop in the coming years mean that intelligent energy policy formation must consider a broad range of issues in a comprehensive and coherent fashion. Policies related to oil, natural gas, coal, alternative technologies, and the environment should not be compartmentalized into their respective categories. Rather, the factors that will influence choices in each of these vital areas must be considered together and integrated into a coherent and unified energy strategy.

With U.S. generation systems entrenched in more traditional formats, fusion may hold more promise for providing electric power in developing countries such as China and India into the 21st century. Fusion generators are unlikely to be on-line in time to play a role in replacing aging nuclear facilities in the U.S.

While scientists believe it could be another 50 years before the global economy turns away from fossil fuels and runs instead in large measure on hydrogen-derived energy, fuel cells are beginning to see commercial application in the power sector. Ballard Power Systems Inc. announced last February that its subsidiary, Ballard Generation Systems Inc., would be selling its first full-scale, zero-pollution, natural gas/fuel-cell-powered stationary power plant to Cinergy Technology Inc., a large diversified American energy company based in Cincinnati. The Ballard field trial follows a similar initiative by Plug Power to install a prototype fuel-cell generator to provide electricity to one residential home in Latham, New York. The latter program is supported by the U.S. Department of Energy. To date, such fuel-cell ventures remain at the prototype and evaluation phase, but Ballard officials say they expect to move into an early production unit phase by 2002. It would, however, probably take the company another decade to establish commercial manufacturing capability for the innovative technology and years more before it saturated power markets.

While it is unlikely that much of existing U.S. power infrastructure will be replaced by the cleaner fuel-cell technology over the next ten or twenty years, fuel-cell generation remains a viable option for the development of new power markets in emerging economies like those in China or India by the 21st century, according to Colleen Mathis of Ballard Generation Systems. Stationary fuel-cell units such as those Ballard and Plug Power are testing today will be most marketable in these countries that lack highly developed, competitive power grids. By 2000, residential fuel cell units could cost as little as $3,000 to $5,000 apiece.

Another prototype-stage technology that could revolutionize the power industry into the 21st century

is the superconducting power line. A superconducting line transports huge electrical currents with far less resistance and loss than commercial metal wires, conserving energy and potentially reducing pollution created by generating plants. This low cost transport of electricity would also facilitate power trading over longer distances, smoothing out peaks in demand for electricity. The consequent savings in capital costs would enable large reduction in electricity prices as well as increased fuel efficiency.

The first large-scale superconducting line will begin operation next year in Detroit and could some day replace lengthy natural gas pipelines currently transporting gas energy to markets for conversion at electricity generation plants, according to Dr. Paul Grant of the Electric Power Research Institute. Today, the only way to bring distant natural gas resources, such as those located in far away Turkmenistan or northeast Russia, is to build multibillion-dollar natural gas pipelines over geographically difficult and often politically-dangerous terrain. A breakthrough in the economics of manufacturing high-voltage power lines would provide an alternative. If electricity could be transported economically over long distances, power generators could be built directly at remote natural gas fields, and only electrical wires would have to be laid over rough terrain to large electricity markets. Large-scale superconducting lines could revolutionize the transportation of electricity in certain Asian markets that are far from major natural gas fields. However, it might be a long time before such programs could be commercially viable as new breakthroughs are probably necessary, Grant noted. Current technology, for example, requires that superconductive wire be clad in silver coating, creating a major price uncertainty for long-range or extensive use.

Conclusion

Technological change has been a major influence on developments in the energy industry in recent years. Advances in oil and gas exploration and drilling technology have greatly reduced production costs and augmented the supply to markets. These advances explain why predictions that the world would run dry of oil have not come to pass.

Emerging capabilities in the oil and gas drilling industry--multitasking rigs, advanced reservoir visualization and monitoring systems, ice and salt-piercing seismic equipment, and extended-reach drilling equipment, to name a few--will help expand hydrocarbon production for years to come. Such exploration and drilling advances will greatly reduce the possibility that rising energy use worldwide will deplete conventional oil and gas reserves within the next 50 to 100 years. Public policy on energy should not be driven by concerns that the world will run out of oil. Rather, energy leaders should focus on political, economic, and other factors that can lead to sudden, large oil price movements.

The world economy is likely to remain hooked on fossil fuels for the next two or three decades. Improvements in oil and gas exploration and drilling technology will probably help limit a sustained rise in world hydrocarbon prices, and low oil prices may discourage rapid development of alternative energy. However, there are other forces that will drive the search for alternative energy sources. In particular, worldwide environmental concerns will increasingly provide incentives for governments and the private sector to develop nonpolluting solutions to the growing need for energy in the 21st century.

The transportation sector will dominate the expansion of energy demand over the next twenty years. The rise in transport fuel demand will represent almost 60 percent of the total rise in global oil demand between 1995 and 2020, driven in part by economic development in countries such as China and India. By 2020, gradual erosion of oil's share of energy markets may begin to develop as more environmentally friendly engines and generators proliferate in industrial countries. As this trend gains momentum, the oil and gas companies that will succeed in the coming years will be those that transform themselves into energy businesses that market a wide variety of products, including electricity, and utilize a wide slate of alternative resources, including everything from traditional fossil fuels to more innovative products such as fuel cells. Companies will need to provide energy in the cheapest, cleanest form available in the markets where they operate. Firms with expertise in the widest number of energy sources will be best positioned to exploit opportunities to expand their assets

and sales markets.

Current international agreements on such matters as global warming will be substantially flawed unless they include major developing economies such as China, India, Indonesia, and Brazil. The growing emissions from these four countries alone could dwarf any reductions that can be made in the OECD through compliance with the Kyoto accords, according to Rice University economist Peter Hartley. China's use of coal could expand to 2 billion tons per year by 2010, up from 1.4 billion tons currently, causing a major increase in CO2 emissions and particulate pollution. This reality casts doubts on the effectiveness of the Kyoto accords to reduce greenhouse gas emissions if developing countries are not included and begs a different approach. Cleaner, more efficient emerging technologies in the automotive and power sectors could eventually help fill the gap that the Kyoto agreement leaves in reducing emissions from key developing nations.

Emerging technologies in the field of transportation and power generation could play a critical role in reducing CO2 emissions in emerging economies where major infrastructure investments remain to be made. The economies of high-emission developing countries cannot continue to grow apace without adding dramatically to the burden of worldwide CO2 emissions unless new technologies are applied.

While it may be a decade or two before new alternative energy systems begin to replace traditional combustion engines or coal and oil-fired power generation plants in the major economies of the world, government policy in close coordination with the private sector can play a hand in speeding such a transition. While relatively inexpensive current energy prices may seem to obviate the need for government support of emerging energy technologies such as cost-effective fuel-cell generators or hybrid automobiles, environmental considerations may justify public support for research on innovative technologies.

Low oil prices do not necessarily imply that policymakers can be complacent about energy matters. Rather, complex technological and environmental changes that will develop in the coming years mean that intelligent energy policy formulation must consider a broad range of issues in a comprehensive and coherent fashion. It is not enough to look only at supply and security issues for oil markets. Policies related to oil, natural gas, coal, alternative technologies, and the environment should not be compartmentalized into their respective categories. Rather, the factors that will influence choices in each of these vital areas must be considered together and integrated into a coherent and unified energy strategy.

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