The R&D Challenges to Secure Energy Supply for the Third Trillion Barrels and Beyond

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To address the world's energy needs and demands over the next 20 to 30 years and beyond, a substantial increase in energy research and development (R&D) is critical. Without this increase in R&D investments and activities worldwide, adequate and affordable energy will not be available to maintain economic growth and quality of life in the growing populations around the world.

The world's population of 6.6 billion is forecast to reach 8.3 billion by 2030, according to the United States Census Bureau.[1] Moreover, the increasing populations in developing nations outside the Organization for Economic Cooperation and Development (non-OECD nations) are pursuing higher standards of living made possible by recent economic reforms.

The forecasted growth in the world economy—with much taking place in non-OECD Asia—is driving enormous growth in global energy demand. The International Energy Agency (IEA) forecasted in its World Energy Outlook 2006, the Reference Scenario, that global energy demand will grow by just over one-half by 2030, with demand growing by one-quarter by 2015 alone.[2]

Industry and political leaders are today acknowledging the importance of global energy security in providing reliable and affordable energy through measures such as technical innovation, supply diversification and energy conservation, while mitigating geopolitical risks and managing the interdependent relationships among consuming and producing countries.[3]

Continued strides in technological innovation to ensure global energy security will necessitate sizable R&D investments to develop and produce both an increasing and increasingly secure supply of energy in the coming decades. Oil and gas in harsher and deeper environments and frontier hydrocarbons, including unconventional resources, are more technically difficult and economically challenging to exploit, requiring new approaches in their development. The disciplines of chemistry, the biosciences and chemical, mechanical and electrical engineering will play increasingly important roles in new energy R&D areas. Collaboration among industry, academia and governments will be essential in creating solutions to these increasingly complex technical problems and meeting economic challenges that demand vast R&D investments and capital projects.

Leaders also say that energy supply can be made more secure if its sources are better diversified. The IEA predicted, however, that fossil fuel resources will remain the dominant energy source; accounting for more than 80% of energy supply in both the Reference and Alternative Policy Scenarios.[2] Thus, the primary focus over the short and mid terms will remain on the major sources of oil, natural gas, and coal, with a measured nuclear resurgence in the mix.

The United States Geological Survey (USGS) has estimated that there are just over 3 trillion bbl of recoverable conventional oil worldwide, with one-third already consumed.[4] However, about two-thirds of the remaining proven conventional oil resides in the Middle East, where there is also believed to be a substantial portion of undiscovered conventional reserves, according to Saudi Aramco President and CEO Abdullah Jum'ah.[5] Moreover, the six largest publicly-owned international oil companies (IOCs) have direct access to only about 5% of the

SPE's Research and Development Advisory Committee is a standing committee with the role of promoting R&D that contributes materially to the production of energy. One initiative is to promote awareness of R&D challenges in the oil and gas industry to an audience wider than petroleum professionals. To this end, members of the committee documented the industry's R&D challenges in this "white paper" for the information of those within and outside the industry. This document focuses on the challenges to secure energy supplies for the third trillion barrels and beyond. In addition to this paper, the R&D Committee has developed two series of JPT articles delving more deeply into areas of challenge for the industry. The SPE R&D Committee has 12 members and is chaired by Vikram Rao, Senior Vice President and Chief Technology Officer, Halliburton Company.

world's oil reserves, and another 30% indirectly through partnerships with national oil companies (NOCs), according to ConocoPhillips Chairman, President and CEO Jim Mulva.[6]

So while NOCs will continue to play a major role in conventional oil supply, increasingly limited quantities, and restricted access will require IOCs to increase their focus on the development of both frontier environments and challenging hydrocarbons, comprised primarily of heavy oil, shale oil, tight gas, coalbed methane (CBM) and tarsands. Additionally, gasification of coal and petroleum coke, gas-to-liquids (GTL) and the companion coal-to-liquids (CTL), and liquefied natural gas (LNG), will all play increasingly important roles in the coming years.[7]

The IEA also found that although global oil demand will continue to increase, and will remain the largest single fuel in the world energy use mix, its share will actually drop between 2004 to 2030.[2] The gap will be made up with mainly natural gas and coal. Coal will experience the largest demand increase driven primarily by power generation, with China and India accounting for almost four-fifths of the incremental increase.

However, increasing fossil fuel prices, particularly gas, enable renewable energy sources to compete more economically in the electric power sector. Renewables also will have the potential to modify the fuel supply mix by creating new feedstocks while providing environmental benefits. More than twice as much private equity investments were directed toward renewable and clean energy technology in 2006 compared to 2005, said Chevron Chairman and CEO David O'Reilly, adding that the commercialization of the new technologies cannot be far behind.[8]

Consequently, both energy supply diversification and technical innovation through global R&D investments and collaboration will be crucial in meeting world energy demand and ensuring global energy security for the next generation and beyond.

Industry collaboration/ globalization

Global collaboration is key to ensuring continued R&D investment and technology transfer. DeepStar, a joint industry technology development organization, focuses on developing the technology to meet its members' deepwater business needs to increase production and reserves.[9] A collaboration among operators, suppliers, regulators and academic and research institutes, DeepStar has a proven success record in accomplishing its vision to provide a forum to execute deepwater technology development projects worldwide and to leverage the financial and technical resources of the global deepwater industry.[10]

The American and European Drilling Engineering Associations (DEA and DEA-Europe) both provide an effective vehicle for industry collaboration to improve access to drilling technology and information on a worldwide basis.[11] Operators' technology needs and gaps are identified and prioritized, which are then communicated to suppliers, who propose innovative solutions at workshops and other venues.

Another example of industry collaboration took place in late 2006 in Canada, where R&D got a boost with the signing of a Memorandum of Understanding between the Petroleum Technology Alliance Canada (PTAC) and industry partners, including most of Canada's operators, namely the Canadian Association of Petroleum Producers and the Small Explorers and Producers Association of Canada.[12] Started in 1996, PTAC has facilitated industry collaboration, helping more than 200 R&D projects get off the ground.

Also facilitating technology transfer and application are professional societies like the Society of Petroleum Engineers (SPE) and the American Association of Petroleum Geologists (AAPG). For example, specific SPE efforts supporting industry R&D include creating the R&D Providers Directory now accessible on www.SPE.org and organizing the first R&D Conference held in San Antonio, Texas, last April 2007. Also, one of the roles of SPE's R&D Committee is to promote interaction among universities, governments and industries. In another example, AAPG supports R&D through its Committee on Research, whose mission includes research idea interchange and information distribution through conferences and symposia.[13]

University collaboration/ globalization

On the one hand, collaboration is more essential than ever between industry and academia. One of the main ways it can be promoted is by having broader industry participation in university research programs. On the other hand, universities must focus on research that is relevant and attractive to companies that support it, while still preserving the freedom of academic pursuit. Collaboration also is crucial within academia, which can be facilitated via networks, forums and non-conventional exchanges among universities and their departments. However, government regulations regarding intellectual property can provide obstacles even for inter-university collaboration.

As far as globalization is concerned, universities now have a global presence more than ever before. A prime example is Education City, a 2,400 acre multi-university campus located in Qatar's capital of Doha, which houses several universities offering programs available at their respective main campuses. The Qatar Foundation has facilitated the presence of Texas A&M University and Carnegie-Mellon University on its campus, with the former offering BS and MS degrees in engineering, including petroleum engineering, with a student body of 200 this year.[14] The latter offers BS degrees in business and computer science.[15] In both cases, the degrees have the standing of degrees from the host campuses.

Education of professionals, public

The oil and gas industry is facing a shortage of technical professionals in the US and Western Europe, where more than half will be eligible for retirement in the next few years. One US academic institution addressing this trend is the former department of Petroleum Engineering at Stanford University, which was renamed to Energy Resources Engineering. The department's redirection goes beyond the name change, though, by expanding its academic mission and adding new curriculum for undergraduates and graduates wanting to pursue broader careers in energy and conservation.[16] The shortage of technical professionals experienced in the US and Western Europe is not the case in other areas of the world. Two countries producing engineers at high rates are China and India, where the industry can increasingly source from, the latter presenting no language barrier because of its English curricula.[17] Rather than petroleum engineers, these countries produce more of the generic mechanical, electrical and chemical engineers, which already make up the vast majority of degreed technical professionals in the oil and gas industry.

While petroleum engineers remain important in this industry, the R&D committee foresees an increasing need for other specialists, such as chemists and biochemists as well as even more chemical, electrical and mechanical engineers, in light of the increasingly complex processes needed for petroleum extraction, particularly unconventional hydrocarbons.[18] Developing these technologies will require crossing the traditional boundaries separating this industry's upstream and downstream sectors. Boundary distinctions will undoubtedly lessen as the need for collaboration between the two sectors from both business and technical standpoints continues to grow.

The education of the public at large also is an urgent need. Lack of communication to the public and its elected officials has led to narrow perspectives, outdated information and short-term thinking. The ExxonMobil Chairman and CEO Rex Tillerson said that many policymakers think in shorter timeframes of election cycles.[19] However, the industry operates on much longer timeframes defined by an oilfield's life cycle. Setting policy impulsively with quick fixes and unrealistically expecting immediate results can jeopardize project viability and negatively impact operations for years to come.

Vast in-place hydrocarbons

While the amount of conventional oil deemed recoverable is declining, there are vast amounts of in-place hydrocarbons—about two-thirds—that are left behind after currently available primary, secondary and tertiary recovery methods are utilized. Increasing recovery efficiencies would supply much of the needed energy to meet demand into the distant future. Former Saudi Aramco Reservoir Management Manager Nansen Saleri said that a 10 percentage point incremental recovery increase translates to about 1.4 trillion bbl of reserves, which would supply global crude consumption at current rates for about 50 years.[20] Recovery improvements in gas reservoirs could have similar results. IOCS and NOCs alike understand the need for more R&D in areas of increasing their production in existing operations and improving recovery efficiencies of their conventional oil reservoirs. New technologies can increase recoveries in many forms. For example, horizontal wells drilled in reservoirs where EOR technology is applied can improve chemical placement and pattern effectiveness. By pushing the technological frontiers of chemistry and chemical engineering and marrying them with mature oil and gas technologies, recovery factors can be dramatically increased given sufficient R&D. Saleri outlined four main R&D challenges toward increasing these efficiencies, namely deeper pore understanding, smarter wells, faster well construction and better electrical submersible pumps.[20]

Vast unconventional gas resources

To meet future energy demand, conventional oil will need to be supplemented with unconventional hydrocarbon resources, comprised of the various forms of heavy oil and tight gas. It has been suggested that anticipated demand for cleaner energy will drive a trend toward a gas economy. As stated previously, energy demand will grow by just over one-half by 2030. However, natural gas demand is expected to increase during the same period by more than two-thirds. Focusing R&D efforts to sustain long-term productivity and to maximize ultimate recoveries of unconventional gas resources - shale gas, tight gas and CBM accumulations—is essential.

CBM gas is methane associated with coal deposits. Coal's large internal surface area enables it to store six to seven times the gas as the equivalent volume of typical gas reservoir rock.[21] CBM exploration costs are low because coal locations are known. Drilling and completion costs are also relatively low, because coal and its associated methane reside at shallow depths. However, these costs increase with increasing depths, as do production difficulties because of decreasing coal permeabilities. Estimates for world CBM resources range from 100 to 260 Tm^3, of which Canada, Russia and China collectively represent 80%.[22] Other large coal producing countries also have CBM resources, namely Australia, Ukraine, Germany, Poland and the US.

Shale gas is taking on special prominence in the US, with all unconventional gas now comprising 39% of US production. The Arkansas Fayetteville, the Oklahoma Caney and the North Texas Barnett are large, economic Mississippian-aged shale gas plays, with the latter being the fastest growing US natural gas field.[23] Shale gas is also available elsewhere in the US and in Europe and several Canadian provinces. Recoveries have been improved by changing fracturing fluids, modifying the type and placement of the proppant and incorporating novel perforating techniques.

While not considered a typical unconventional gas, another promising long-term R&D topic and potentially enormous energy source down the road are gas hydrates. However, sizeable R&D is needed to determine how to best exploit them. Japan, India and the US are among the countries currently funding and sponsoring their research.

Vast unconventional oil resources

Heavy oil production also can help close the conventional oil gap toward meeting global energy demand beyond the next 20 to 30 years. However, heavy oil is difficult to produce, transport and refine, resulting in high costs and risks in up-, mid- and downstream operations. On the other hand, like CBM deposits, its exploration costs and risks are low, as its locations are known. Moreover, the in-place deposits of heavy oil, including natural bitumen, tar sands, and viscous and ultraheavy oils, are huge—in the 5 to 7 trillion bbl range by conservative estimates, and mostly in the western hemisphere, namely Canada, the US (Alaska and California) and Venezuela.[24,25] Current technology is expected to recover amounts ranging from 500 billion to 1 trillion bbl.[24]

The technical and economic challenges of heavy oil range from its production and upgrading to its transportation and refining. Its high carbon-to-hydrogen ratio makes it many hydrogen atoms short of the required form for light and middle distillates, or gasoline and diesel.[17] New technologies and thus R&D investments are needed to unlock heavy oil's potential at reasonable costs, not only to the consumer, but also to the environment. Heavy oil's high carbon content means that about two to six times more CO_2 is emitted in its producing and upgrading compared to conventional oil.[26] Efficient, integrated energy solutions are key to keeping these CO_2 emissions in check.[27]

Employing gasification in conjunction with heavy oil processing creates valuable synergies, especially important in light of the larger future role heavy oil will play. Comprised of 20% or more carbonaceous material, heavy oil's processing results in an asphaltene or coke residue having a carbonaceous value higher than the most premium coal. The gasification of coke or asphaltene produces synthetic gas, or syngas, a mixture of carbon monoxide and hydrogen that can be used like natural gas. After processing, the syngas can either be used directly for power or liquefied. While gasification is relatively inexpensive, liquefaction is not, because of the sheer scale required for its economic feasibility. Fischer-Tropsch synthesis, better known as GTL technology, requires very large reservoirs for favorable GTL plant project economics. Consequently, heavy oil's synergistic gasification counterpart requires significant R&D for benefits to be fully realized.

Oil shale is another unconventional hydrocarbon having potential to supplant conventional oil, but in the more distant future with sufficient R&D. Oil shale is a sedimentary rock containing organic kerogen, a solid bituminous material, which releases hydrocarbons when heated slowly over time.[28] While both in-situ and surface retort recovery processes have been evaluated for extracting oil and gas from kerogen-filled sediments, in-situ retorting holds the most technical and economic promise and least environmental impact.

Most of the world's oil shale resides in the US. The largest of US hydrocarbon resources (USGS estimates about 2 trillion bbl in-place deposits), oil shale is also the most costly to develop and produce.[28,29] Chevron and Los Alamos National Laboratory recently announced a joint research project to study hydrocarbon recovery from oil shale in the Piceance Basin, northwestern Colorado, conducted under the Strategic Alliance for Energy Solutions launched in 2004. Shell has conducted its oil shale R&D for about 25 years, including field tests on an in-situ conversion method, also in the Piceance Basin. The company said that decisions on whether to move forward with full-scale implementation will not be reached until the end of the decade.[30]

Energy diversification through biofuels

In 2006, Chevron formed strategic research alliances with Georgia Institute of Technology, the University of California at Davis and the US DOE National Renewable Energy Laboratory (NREL) to develop cellulosic biofuels with the overall aim of diversifying the energy mix and broadening the feedstock of transportation fuels. The three joint programs will conduct R&D that will focus primarily on creating next-generation process technologies to convert cellulosic biomass into biofuels. While first-generation biofuels are made from food feedstocks like corn, wheat, and sugar cane and beets, second-generation biofuels are made from non-food feedstocks such as wood chips, straw, fast-growing trees and hardy grasses like switchgrass.[31] BP also recently announced its selection of the University of California Berkeley, the University of Illinois Urbana-Champaign and the Lawrence Berkeley National Laboratory to form the Energy Biosciences Institute, a USD 500 million research program that will conduct mainly bioscience-based R&D to develop transportation biofuels that reduce environmental impact.

Shell has distributed first-generation biofuels for more than 30 years, and is conducting R&D in second-generation biofuels, partnering in 2002 with Canada-based Iogen to create the processing technology to make cellulose ethanol from straw.[32] It also has a technical partnership with Choren Industries in Germany to construct the first commercial biomass to liquids (BTL) plant in the world, expected to come on line in late 2007. In Europe, BTL fuels have gained auto manufacturer support because they can be blended with diesel and used in the existing fleet.

Generally, because of the current engine fleet and worldwide distribution systems, biofuels would be used in the foreseeable future as a blend in gasoline or diesel rather than a fuel in itself. Introducing biofuels into the current fuel supply while maintaining the stability of existing fuel streams will extend rather than replace current petroleum-based products, serving to increase both fuel efficiency and tolerance to import volatility. If biofuels are to compete economically as stand-alone transportation fuels, however, R&D is needed to improve biomass conversion technologies, increase process efficiency and enable suitability for industrial-scale deployment similar to current transportation infrastructure systems, according to Chevron's former Chief Technology Officer Donald Paul.

Environmental considerations

Over 80% of world energy supply will continue to come from fossil fuel resources during the next 20 to 30 years. Therefore, global measures must be taken to address the impact they have on the environment, especially with regard to CO_2 emissions and their effects on climate change. R&D of carbon capture and storage (CCS) technologies and the implementation of both pilot and full-scale CCS projects are either underway or under consideration by governments and industry worldwide.[33] Predictions have shown that CCS technologies could reduce CO_2 emissions from power plants, oil refining and steel and cement manufacturing by up to 85%. Estimations have also found that fossil-fuel-fired power plants themselves are responsible for one-third of current CO_2 emissions.[34] Though CCS technologies that capture emissions at the source and store them in subsurface reservoirs are thought by scientists to be a viable solution, these same technologies also would reduce the efficiency and increase the costs of power production.

Therefore, economic barriers still exist, along with significant technical and social hurdles that must be cleared before the benefits of CCS technologies can be fully realized. More R&D is needed before sequestration will be a technically and economically viable method to handle the CO_2 on the scale needed for emission reduction. National and international multidisciplinary teams consisting of engineers and scientists will be required, especially those with chemistry specializations. A collaborative effort that both combines the industry's upstream and downstream sectors and crosses over into other industries like the power markets will be required. A comprehensive, collaborative solution is needed for a complex global problem.

That being said, the oil and gas industry is probably the best positioned to develop and apply CCS technologies. While some emitted CO_2 can be used for its upstream EOR projects, much of which is recycled, most emissions must be sequestered in other ways, like disposal into brine and depleted reservoirs. Existing CO_2 sequestration projects have achieved early technical successes, providing promise that long-term storage of the emitted gas is feasible in suitable reservoirs.[33] Geological CO_2 storage has been underway since 1996 at Statoil's Sleipner West field in the Norwegian North Sea. Here, about 2,800 tons of CO_2 is separated daily from the field's gas production and injected and stored in the Utsira sandstone formation 1,000 m beneath the seabed.[35] In addition, long-term geological storage of CO_2 is being evaluated at the IEA Weyburn CO_2 Monitoring and Storage Project sponsored by the IEA and various governments and industry sponsors from Canada, the US, Europe and Japan.[36] The Weyburn field, located in southeastern Saskatchewan, Canada, and operated by EnCana Resources, is undergoing an EOR CO_2 injection project using anthropogenic CO_2 drawn from the Great Plains Gasification plant located 320 km south in North Dakota, USA.[37] Weyburn's injected CO_2 that is produced back is recycled, compressed and reinjected for storage in a 1,400-m deep Mississippian reservoir. This CO_2 storage project has attracted worldwide attention in evaluating the feasibility of long-term sequestration for large-scale reduction in CO_2 emissions to the atmosphere. Information obtained from this study will be utilized to evaluate the viability of and assess other geologic sites for underground CO_2 storage in the hopes that it can be replicated in other areas around the globe.

In conclusion

The R&D committee continues to promote R&D in the oil and gas industry, and considers the need for more R&D activities and investments to be greater than ever before. The energy industry of the future will face great challenges because of increasing demand for energy as the more populous developing world becomes more prosperous. The industry will also face the continued pressures of more limited availability and accessibility of conventional oil and increased reliance on frontier and unconventional hydrocarbon resources with their added technical difficulties and environmental impacts in their development and production. At the same time, the demands to supply cleaner energy in a more environmentally responsible manner with less CO_2 emissions will continue to grow.

Collaboration among industry, academia and governments will be crucial to meet these increasingly complex technical, economic and environmental challenges that will require extensive R&D investment needs and capital intensive projects around the globe.

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