**Trends in Oil Supply and Demand, Potential for Peaking of Conventional Oil Production, and Possible Mitigation Options: A Summary Report of the Workshop**

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## A Summary Report of the Workshop

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National Research Council

Board on Energy and Environmental Systems
Division on Engineering and Physical Sciences

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# Preface

The Workshop Planning Group, the Board on Energy and Environmental Systems, and the National Research Council (NRC) staff wish to thank all of the presenters at the workshop. They all gave very well-focused, professional, and substantive talks and adhered to the guidance provided by the planning group so that everyone had sufficient time to express their individual views and opinions at the workshop. The workshop was open to the public, and there was active discussion during the full two days. Many participants noted the interesting presentations and discussions and remarked on the importance and timeliness of the subject.

The workshop was motivated by recent publications and analyses indicating that global production of conventional oil might peak within the next decade or so, and in some instances projections indicated that this peaking might occur within a few years, with potentially significant global economic disruptions. They were in sharp contrast to many other analyses that oil supply could meet global demand for some decades into the future and that any potential oil peaking was much further off in the future. Given the importance of the subject, the National Academies, through its Board on Energy and Environmental Systems, sought funding for a workshop that could bring together analysts with different points of view and begin a dialogue on the subject. The U.S. Department of Energy provided funding to support the workshop.

This workshop summary identifies key issues and questions raised by individuals at the workshop and possible follow-on studies that would be important to undertake. This summary does not include any consensus of the participants or the planning group, does not contain any conclusions or recommendations, does not contain advice to the government, and does not represent a viewpoint of the National Academies or any of its constituent units. It also does not prioritize the ideas and suggestions that were generated. No priorities are implied by the order in which ideas are presented.

The workshop summary was reviewed in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee and was reviewed in draft form by David Gray, Mitretek Systems; David L. Greene, Oak Ridge National Laboratories; John Heywood (NAE), Massachusetts Institute of Technology; John E. Johnston, ExxonMobil Research and Engineering (retired); Daniel Rose, University of Pennsylvania (emeritus); Daniel Sperling, University of California, Davis; and Scott Tinker, University of Texas, Austin.

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the workshop summary before its release. The review of this report was overseen by Trevor O. Jones (NAE), Biomec, Inc. Their effort in this task was much appreciated. Responsibility for the final content of this report rests entirely with the NRC and the author.

# Contents

# WORKSHOP SUMMARY

# Introduction

This is a summary of the National Research Council's (NRC) workshop Trends in Oil Supply and Demand and the Potential for Peaking of Conventional Oil Production, which was held on October 20 and 21, 2005.[1] The interest in holding such a workshop stemmed from a variety of recent analyses projecting that the global production of conventional oil might reach a certain level and then start to decline and that this oil peaking might occur within a decade or so.[2] Some analysts were even predicting that peaking would occur much sooner, perhaps within a year or two. Many of these analyses were being put forth by individuals affiliated with the Association for the Study of Peak Oil (ASPO). The interest in peak oil reflects concern that a peaking of global conventional oil production could have extraordinary implications: namely, oil shortages, rapidly rising oil prices and inflation, economic downturns and recessions, and—possibly—catastrophic economic disruptions. These projections were in contrast to those of many other analysts and groups, such as the U.S. Geological Survey (USGS), DOE's Energy Information Administration (EIA), the International Energy Agency (IEA), major oil companies, and the Organization of Petroleum Exporting Countries (OPEC),[3] which were projecting that conventional oil production could meet rising demand for many decades to come and that any oil peaking was much further off in the future.

The importance of the workshop topic and of the issues raised during the workshop was echoed by most of the participants (speakers and guests), and there was intense discussion and an intellectual excitement during the two-day meeting. Between 125 and 150 people attended at various times, including members of the press, and audience participation was extensive. Regardless of their positions in the debate, various participants raised several issues that are potentially key to the nation's energy future: These are indicated in the chapter "Potential Follow-up Studies and Activities." Understanding these issues is urgent because of the time lags inherent in increasing the global supply of liquid fuels, reducing forecast demand, or transitioning from petroleum to alternative resources.

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[1]The workshop was held at the American Association for the Advancement of Science in Washington, D.C.

[2]Conventional oil consists of liquid hydrocarbons of light and medium gravity and viscosity that occur in porous and permeable reservoirs and that are recovered using primary, secondary, and tertiary recovery techniques. Unconventional oils have higher densities (that is, denser than water), higher viscosities (oil sands have viscosities >10,000 centipoise), and tighter formations (oil shale or kerogen).

[3]The members of OPEC are Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela.

The workshop explored the question of global conventional oil production and, in particular, considered estimates of when global conventional oil production might peak. The workshop planning group organized a set of presentations by inviting individuals who had recently analyzed global oil production, future trends in oil supply and demand, and trends in the global and regional energy markets. They came from the private sector, government, and universities. Their forecasts ranged from a production peak within the next decade or so (or sooner) to a peak sometime in the 2030-2050 time period. In addition, the workshop explored options for mitigating the possibly serious economic effects of peaking and attempted to identify topics for in-depth study that could help inform U.S. government policy. Following on the recent analyses conducted for oil peaking, most of the presentations focused on the supply of conventional oil and possible alternatives. However, future trends and the potential to reduce the demand for oil are important topics that will need to be pursued, as noted in the chapter “Potential Follow-up Studies and Activities.”

The workshop was divided into four main sessions: (1) Setting the Stage, (2) Future Global Oil Supply and Demand Balance, (3) Mitigation Options and Time to Implementation, and (4) Potential Follow-up Studies and Activities. This summary presents the key points, issues, and questions that were raised by participants at the workshop and identifies possible topics for in-depth studies by the National Academies or another group. A planning group worked with the staff of the NRC Board on Energy and Environmental Systems to organize the workshop, develop an agenda, invite speakers, and identify topics to address. This summary report does not prioritize the ideas raised, nor does the order of their presentation imply any prioritization. No consensus views, conclusions, or recommendations are presented. For details about each individual presentation, see the viewgraph presentations by the individual presenters from the workshop[4] or the individually authored summaries in Appendix C.

Appendix A contains the statement of task. The workshop agenda, including the titles of presentations, is given in Appendix B. Appendix C contains short, individually authored summaries of each presentation, and Appendix D contains biographical sketches of planning group members and NRC staff.

[4]The viewgraph presentations are available online at <http://www7.nationalacademies.org/bees/trends_in_oil_supply.html>.

# Setting the Stage

David Greene set the stage by noting that transportation, the circulatory system of the global economy, is all but entirely dependent on petroleum fuels. In light of this fact, it should be no surprise that the possibility that world oil production will soon reach a peak and then inexorably decline is a subject of great interest and intense debate. As noted by Dr. Greene, the "pessimists," a somewhat pejorative label given to those who are convinced that the oil peak is imminent and that its consequences will be dire, assert that world oil supply is chiefly determined by the geology of oil resources. They point to geologist M. King Hubbert's accurate prediction of the peak in U.S. oil production in 1970 and note that many other oil-producing regions have since reached their peaks and are now in decline. Noting that world oil discoveries peaked before 1970, they predict a peak in world oil production by the year 2010.[5] The "optimists" counter that markets and technology will determine the supply of fuel for transport, and that nearly all past predictions of resource scarcity have proved to be mistaken. Innovation guided by market signals will expand and redefine energy resources—for example, substitutes will be found as various forms of energy become too expensive.[6] It was noted at some point during the workshop that the term "concernist" might be used instead of "pessimist," indicating that there is concern about what a divergence between the demand for and supply of oil would mean for the economies and well-being of the world's population. As noted in several presentations, over the next two to three decades, OPEC will need to increase production of conventional oil substantially to meet forecast growth in world oil demand. Will OPEC increase production, which would probably decrease price? Or will OPEC try to maintain its income by regulating oil supplies to keep prices stable at a higher price benchmark?

To put the demand for oil in perspective, current global oil demand is about 82 million barrels/day (bbl/day) and with current trends is forecast to increase to about 120 million bbl/day by 2030.[7] In his presentation, Nicola Pocchetino of the IEA noted that it

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[5]See, for example, C.A. Campbell and J.H. Laherere, 1998, "The End of Cheap Oil," *Scientific American* 278 (3): 78-83; M. King Hubbert, 1956, "Nuclear Energy and Fossil Fuels," presented at the spring meeting of the Southern District Division of Production, American Petroleum Institute, in San Antonio, Tex. (March 7-9) and available online at <http://www.hubbertpeak.com/hubbert/1956/1956.pdf>.

[6]See, for example, J. Ausubel, 2003, "Decarbonization: The Next 100 Years," Alvin M. Weinberg Lecture, June 5, Oak Ridge National Laboratory. Available online at <http://phe.rockefeller.edu/PDF.FILES/oakridge.pdf>; and M.A. Adelman and M.C. Lynch, 1997, "Fixed View of Resource Limits Creates Undue Pessimism," *Oil & Gas Journal* (April 7): 56-59.

[7]Currently, the global annual consumption of oil is about 30 billion bbl/year (82 million bbl/day multiplied by 365 days). The energy content of 1 bbl of oil is about 5.8 million BTUs (British thermal units),

was not clear that such trends were sustainable over the long term. He presented the results of an IEA alternative policy forecast that assumed a number of policies that could be put in place to slow the growth of global demand for oil, such as strengthening U.S. Corporate Average Fuel Economy (CAFE) standards to reduce fuel use by light-duty vehicles (cars, light trucks, vans, sport utility vehicles [SUVs]), implementation of voluntary agreements in Europe on the reduction of oil consumption, introduction of alternative fuel vehicles, prolongation of Chinese fuel economy standards, increasing use of biofuels in Europe and Brazil, and mode switching (e.g., from private transportation to mass transport where appropriate). These efficiency policies resulted in an alternative policy forecast for global oil consumption of about 107 million bbl/day in 2030.

There were some questions about whether IEA had done a peak oil analysis and how it had done an oil field by oil field analysis to estimate reserves. IEA believes the world has sufficient resources/reserves to meet demand until 2030 and does not foresee any global oil peaking before that year. Forecasting a peak in oil production depends on the reliability of the resource and reserve estimates, with a field by field analysis conducted for all fields having reserves of more than 0.5 billion bbl. The IEA analysis uses 2004 price assumptions. A number of projects are in place that will increase the production of oil, and IEA envisions a moderation in price increases by 2010, with real prices increasing after 2030.

The USGS presentation by Tom Ahlbrandt discussed USGS estimates of cumulative production, reserves, reserve growth, and undiscovered resources of petroleum worldwide. It indicated that the resource base of conventional oil, as well as natural gas, is large. The USGS resource calculations are technical and data analysis is statistical, indicating the uncertainty surrounding how much of the resource would be recoverable. USGS low (95 percent probability), mean (expected value), and high (5 percent probability) estimates of ultimately recoverable conventional oil are 2,248 billion bbl, 3,003 billion bbl, and 3,896 billion bbl, respectively. Based on the mean estimate, EIA forecasts a potential peak in global oil production anywhere from 2025 to 2050 for 3 percent and 1 percent annual growth rates in oil production, respectively.

In the discussion period, questions were asked about the extent to which reserve growth was dependent on the recovery factors assumed from existing oil fields[8] that USGS has incorporated in its estimates of the relative contribution of technology. Ahlbrandt pointed out that the USGS assumptions about recovery factors may be low, i.e., conservative, because the data are based on analysis of U.S. oil fields, many of which are in tertiary recovery using today's technology. Global oil fields are still largely in primary or secondary recovery mode and will benefit from new future technology, which would probably lead to higher recovery factors. On the other hand, several participants argued strongly that the reserve growth estimates by USGS are too high.

The Arctic was identified as the next frontier in that its share of undiscovered resources (oil, natural gas liquids, and natural gas) is expected to be quite significant.

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or 1.46 million Kcal. One thousand cubic feet (Mcf) of natural gas contains 1 million BTUs of energy, or 0.252 million Kcal.

[8]Recovery factor refers to the percentage of oil in a reservoir that can be produced. Improvements in technology can increase the percentage of oil that can eventually be produced relative to what is estimated to be in place in a given reservoir. Hence, differences in estimated recovery factors, which have improved over time, will affect the amount of oil that is estimated to be available for production in the future.

Another question arose: What are the chances of additional major oil fields being discovered in the world? There was speculation that major fields could be found in a few regions.

There was also some question about how the USGS establishes its probability estimates. It takes a statistical approach, which is appropriate in the face of uncertainty in estimating oil resources and what proportion of them will become economically viable reserves in the future. Examining the uncertainties continues to be an important aspect in forecasting how much oil there is in the world.

# Future Global Oil Supply and Demand Balance

This session featured a variety of analyses of trends in oil supply and demand and of how the projections of oil production and future global oil demand will play out. The analyses ranged from detailed oil field by oil field analysis to much more aggregated views of oil supply and demand. A number of the forecasts for the balance between supply of and demand for conventional oil do not see a peaking of conventional oil production between now and 2030; others see this happening earlier.

Peter Jackson said Cambridge Energy Associates (CERA) anticipates that global liquid supply has the potential to grow to as much as 105 million bbl/day by 2015. A number of decades will pass before an extended undulating plateau of global oil production might be reached.

Jeremy Gilbert cited a study by the Association for the Study of Peak Oil (ASPO) suggesting that global production of conventional oil will reach a maximum within about 5 years. It will be difficult to meet projected world demand for liquid fuels in 2025. He also said that a plateau in global production would probably lead to as many problems for the world's economy as would a peak.

Matt Simmons reviewed the peak oil debate and pointed out that much better and higher quality data are needed to resolve the differences between the various points of view. He is also convinced that Saudi Arabia is either nearing its peak oil output or has perhaps passed it, and once Saudi production goes into decline, the world will also have passed peak oil.

Mike Rodgers's presentation forecast that non-OPEC production is likely to start declining sometime between 2010 and 2020, possibly early in that decade. By 2010 a wave of new projects will increase global supply to meet demand and probably lead to a softening of prices. His analysis of OPEC depletion, which is more conservative than the analysis of EIA, suggests serious constraints on global liquid fuels production once world demand reaches 100 million bbl/day.

Scott Nauman presented ExxonMobil's forecast, which envisions a worldwide demand of about 110 million bbl/day by 2030. Non-OPEC production plateaus sometime in the 2010-2020 time frame, and OPEC will be supplying about 47 million bbl/day by 2030. Technology will be essential for meeting this increasing demand. He does not see a peak or a plateau in global oil production between now and 2030.

Kjell Aleklett emphasized the view of ASPO that the world will soon have a problem supplying enough crude oil to meet rising demand. He estimates a production peak around 2010, although the exact year will depend on future demand, and ASPO estimates it will most certainly happen before 2020.

Hermann Franssen pointed out a number of issues that will make it difficult for global oil supply to meet future anticipated demand in the next couple of decades. He believes that global oil discoveries peaked several decades ago and pointed to an emerging industry consensus that non-OPEC oil production will peak about 2015. He also noted that there are technical and nontechnical reasons that OPEC production growth will not follow the smooth path projected in many long-term forecasts.

Adnan Shihab-Eldin noted that OPEC is committed to adding upstream and downstream production capacity and that oil supply is forecast to stay well above demand to 2010. Beyond 2010, demand growth will continue to rise and OPEC will increasingly supply the incremental barrels necessary to meet global demand. The global reserve/resource base can easily meet forecast demand growth for many decades to come. The world's ultimately recoverable resources (URR) increased from 1995 to 2003 with advancing technology, enhanced oil recovery, and new reservoir development. He expects the world's URR to continue to increase in the future. The real issue is not reserve availability but timely deliverability, and here enhanced cooperation and dialogue among all parties is essential to ensure security of demand as well as security of supply.

There are obviously a number of uncertainties in all of the analyses. One is the extent to which assumptions are made about additions to the reserve base from new projects as well as the expected decline of production from existing fields. The detailed field-by-field analyses indicate this varies on a case-by-case basis, depending on the field.

Another issue brought up was the energy profit ratio (EPR)—that is, the ratio of the amount of energy contained in a produced volume of oil to the amount of energy required to produce that volume. What fraction of total energy consumption is required to produce economically useful fuels from resources that are getting harder to find and exploit? For example, consider oil production from tar sands in Canada. A substantial amount of natural gas is being used to process the sands and produce the oil (see discussion of tar sands in the chapter "Mitigation Options and Time to Implementation"). How much impact will trends in the EPR have on the world's ability to meet its future energy needs? To what extent will a declining EPR lead to increased carbon dioxide ($CO_2$) emissions from the production of liquid hydrocarbon fuels?

Although natural gas was not a focus of this workshop, it was brought up in the discussions. Exploration for natural gas has not been as extensive globally as exploration for petroleum resources. It is likely that any peaking of natural gas production would occur after petroleum production peaks. Also, it should be noted, as is done in the presentation on natural gas to liquids in the session on mitigation, that one option is to convert natural gas into liquid fuels, such as diesel fuel. Thus, natural gas resources can also contribute to meeting liquid fuel demand as well as substitute for the use of petroleum in some applications in some regions.

In a number of the forecasts of conventional oil production, the producer countries are separated into OPEC members and nonmembers. A number of discussions revolved around indications that the production of conventional oil (including natural gas condensates) from the non-OPEC countries would reach a maximum sometime between 2012 and 2020. (Some participants argued that the peak would be reached earlier.) Some forecast a production plateau after the peak is reached, with non-OPEC production remaining almost constant or declining only slowly out to 2030. Other analysts envisioned an undulating plateau with ups and downs, while still others saw a rapid decline in production after the peak. In any case, OPEC will have to increase its share of global oil production if demand continues to increase. Some uncertainties identified included these: What oil production projects are planned for the post-2010 time frame? What role will Arctic production play (although it is not likely to have much impact in the next 10 to 15 years)? What role will unconventional oil play? How will prices of oil and natural gas affect the supply side and the demand side? It would probably be useful to conduct extensive uncertainty and sensitivity analyses on such forecasts.

The “concernists” and optimists also differ as to whether there will be a plateau in production or a rapid decline for the non-OPEC countries and whether OPEC can, or will, greatly expand production to meet the increasing worldwide demand. Many questions arose in this discussion. Will a plateau in non-OPEC oil production create as many problems as a peak? How fast will non-OPEC production decline after a peak? Are the data on additions to reserves robust, and is there in-depth understanding of the real ultimate recovery potential? How much can oil production technology accomplish? To what extent have production declines in some existing fields come about despite improvements in technology, or would they have declined much faster without these improvements? The answers to these questions are viewed very differently by the optimists and the concernists.

As noted above, the recovery factor from different fields is an important component of projections. How much can recovery factors be increased by implementing technology? How high can recovery factors go? Are original oil-in-place calculations accurate? Assumptions about ultimate recovery factors have a significant impact on projections of future oil production.

A number of questions were raised about the difficulties of gaining access to OPEC reserves and resources data and to oil field data, which are necessary to make projections. This is understandable since private companies and countries have vested interests in protecting data that can affect their economics and future viability. A number of participants emphasized that better data and more rigorous reporting are needed and suggested that there is a need for better dialogue between oil-producing and -consuming nations, which would allow consuming nations to clarify the implications of their national energy policies. Given the importance of the international oil market to their economies and the well-being of their citizens, how can policy makers and decision makers understand the data, have confidence in them, and know what is really happening? Would some sort of international agreement on obtaining realistic estimates of reserves and making the data more transparent be workable? Can we be confident that OPEC nations, such as Saudi Arabia, will have the production capacity to meet growing world oil demand as non-OPEC producers reach a plateau or start a decline in production? In particular, Matt Simmons expressed concern that Saudi oil production might be nearing its peak and might not be able to meet the expectations of many analysts for future increases. Can decision makers have confidence in published oil reserves of various countries, especially in the Middle East? Even with access to data and geological information, it is difficult to project how much oil will ultimately be produced from an individual oil field given uncertainty about changes in price and technology.

The issue of energy prices arose in a number of questions and discussions. It was noted that many of the forecasts did not explicitly specify the price of energy, although it may have been implicit in some of the complex models that generated the results. Price will affect consumer demand for oil, as well as the incentives for oil producers to invest in oil exploration and production. Given the difficulty of making forecasts, several participants suggested that it might be better to undertake scenario analyses to understand the significant trends and timing of potential imbalances between supply and demand and the potential for production to peak.

Oil price volatility also creates problems because prices can collapse suddenly, which discourages investors and producers from timely investments to meet growing demand. It also makes it problematic to invest in alternative forms of energy or in technology to reduce fuel consumption on the demand side (e.g., automobiles with better fuel economy or more efficient oil furnaces). How can investments be made at the right time so they can survive when prices are low? In addition, although policy makers may pay attention when prices are high, how can their attention be sustained over the longer term if prices fluctuate?

High prices place enormous burdens on developing countries. There may be a need for new policies and a robust international discussion between technical and policy experts about how to manage oil supply/demand trends and, eventually, make a transition to alternative supplies of energy. Also, political events in the world can affect the supply/demand balance in unforeseen ways. Scenario analyses could incorporate more than economic and technical assumptions and factors.

Scott Tinker, chair of the session, summarized the main issues that had arisen in the discussions: (1) data transparency, especially for policy and decision makers; (2) oil price volatility; (3) projections of oil reserve growth; (4) the extent to which recovery efficiencies can increase; (5) the global availability of conventional and unconventional oil that can be ultimately recovered and used; and (6) the extent to which oil field extensions can be expected to contribute to the oil reserve base.

# Mitigation Options and Time to Implementation

This session focused on options that could mitigate any shortfall between the supply of conventional oil and the demand for it and for other liquid fuels. This session focused on a number of technologies and covered their state of development or technical readiness, the time frame for implementation, and their potential contribution to the supply of liquid fuels or a reduction in the fuel consumption of light-duty vehicles. Increasing the supply of liquid fuels included consideration of improved technology for conventional oil exploration and production, as well as technologies for the production of liquid fuels from alternative feedstocks. Advanced technologies for improving the fuel economy of light-duty vehicles (cars, light trucks, vans, SUVs) were also considered. The workshop focused on liquid fuels and did not address in any great detail a long-term transition to a "hydrogen economy" or an "electric economy" or some other non-liquid-based system, which could mitigate a declining availability of petroleum.

One of the main issues discussed early in the session was the question of timing. Bob Hirsch's presentation considered currently viable, potentially high-impact mitigation options, including (1) improved/reduced vehicle fuel consumption, (2) enhanced recovery of conventional oil, and (3) substitute liquid fuels from heavy oil/oil sands, coal, and remote natural gas. A scenario analysis of an hypothesized worldwide "crash" mitigation program utilizing related commercial and near-commercial technologies arrived at the following most optimistic possible outcomes:

- Waiting until world oil production peaks before embarking on a crash mitigation program that deploys all options simultaneously would leave the world with a significant liquid fuel deficit for more than two decades.
- Initiating such a crash program 10 years before world oil peaking helps considerably but still leaves a liquid fuels shortfall for roughly a decade after the time that oil would otherwise have peaked.
- Initiating a crash mitigation program 20 years before peaking could avert a world liquid fuels shortfall for the forecast period. Hirsch noted that if timely investments are not made before the peak, there would probably be severe economic impacts.

In the discussions about preparing for a future transition from conventional oil to other feedstocks for liquid fuels, it was noted that significant amounts of capital investment will be required and that a crash program would accelerate the increase in costs. Also, are alternatives to oil, such as biofuels, going to yield an EPR sufficient to replace the higher EPRs that oil has offered? On the demand side, for example, vehicle fuel economy needs to be looked at in more detail: Has its potential been underestimated? What is the potential for plug-in hybrids, which could help to substitute electricity for liquid fuels?[9] What is the timing? What will happen to the world's less developed countries as the richer countries bid up the price for oil in a transition? Some participants noted that a transition could take longer, even if we knew when a peaking was likely to occur. The oil and gas industry probably does not have the infrastructure, including skilled and experienced technical people, to undertake a crash program. Some noted that it's not clear how the market will work and what kinds of mitigation strategies will emerge; there could be many unforeseen consequences if oil becomes more expensive and scarce and clear price signals emerge.

A number of advanced technologies will be required to increase the economically recoverable reserves of conventional petroleum. As noted by Don Paul, the resource base is large and the focus is on reducing cost, advancing technology, and implementing environmental management. Technology advancement is focused on leveraging major trends in the economy as a whole—for example, in information imaging and processing technologies. There are also growing organizational challenges to integrate all the facets of the oil business—from finding and developing reserves through producing and marketing fuels to meet world demand. Costs have to be brought down to manage capital requirements. Most of the time technology improvement is incremental, but evolving technologies can have a substantial impact. For example, the digital revolution enabled a two- to threefold increase in the number of barrels of oil produced per professional (largely as a function of workforce reduction, not a production increase); the revitalizing of reservoirs can extend the time at which older, mature areas peak; and three-dimensional imaging and modeling have improved capital investment efficiency. Also, new approaches will make resources more accessible—for example, drilling in 10,000 feet or so of water may be about the limit for drilling for undersea resources, but operations might move to the sea floor and under the ice caps. The next trillion barrels of oil will come predominately from frontier regions (Arctic and deepwater); from advanced technology, including enhanced oil recovery (EOR); and from unconventional reservoirs.

There was some discussion of how technology could affect reservoir recovery factors. Since there is so much variation from field to field, there can be no generalization about recovery factors, but they could probably be raised in every field by 5 to 30 percent. It will be important to redo studies of major reservoirs with new tools to better understand the potential for enhanced production. In general it would be important to clarify the information on resources, reserves, and production and to communicate it in a more transparent fashion to decision makers, politicians, and the public.

In starting his heavy oil presentation, Bob Heinemann noted that increasing oil production over the next 10 to 20 years by a sizeable amount to meet projected demand will

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[9]A plug-in hybrid is a variation of the traditional hybrid vehicle, which incorporates an engine, battery storage, and an electric drive propulsion system. A hybrid vehicle can operate at times on battery power alone, when it does not need the engine, and provides better fuel economy than a conventional vehicle. A plug-in hybrid's batteries could be charged by plugging into the electric grid (say, overnight), which would store enough electricity to achieve a significant proportion of a vehicle's range during a given day. This would reduce demand for petroleum and increase demand for electricity, the vast majority of which is produced from nonpetroleum resources in the United States.

be a daunting task and perhaps more interesting than the peak oil debate. Huge amounts of capital, skilled technical people, and equipment will be needed. Worldwide, somewhat over 3 million bbl/day of heavy oil are produced, a little less than 4 percent of the world's total oil production. Several technologies for supplying heat to mobilize heavy oils were reviewed, such as cyclic steam injection and steam flooding. Heavy oil production could double in the next 10 years to, say, 6 or 7 million bbl/day, depending on the economics of the energy system. Worldwide, the recoverable heavy oil resource base is estimated at about 435 billion bbl (does not include bitumen resources).

The issue of price volatility arose again, as it did earlier in the workshop: Longer term price volatility will discourage sustained investment. From a company's point of view, it is a market risk that has to be hedged against, although a number of audience participants wondered if some sort of policy intervention would be required to stimulate investment in some alternative sources of oil. For in situ heavy oil production, advances in technology could help to reduce well spacing, or other sources of heat, such as solar, could be developed. It did not appear that even at an oil price of $60/bbl, production of heavy oil could accelerate much above what it is now, although at $40/bbl there would probably be somewhat less production. One participant asked about the EPR. As one point of reference, it was noted that three cogeneration plants that sell electricity[10] use about 37 million $ft^3$/day of natural gas to produce about 17,000 bbl/day of heavy oil.

Canadian oil sands (tar sands) operations are currently producing about 1 million bbl/day (about 19 percent from mining and 81 percent from in situ operations). The technology for conversion to synthetic oil has improved significantly over the past 20 years, and the in situ recovery factor is 60-70 percent. Advances in well completion, horizontal drilling technology, and steam injection have been applied. There is about $US 20 billion in projects under construction or approved, and $US 50 billion in announced projects. Canada projects that about 2.7 million bbl/day will be produced by 2015. It plans on expanding its exports to the Far East and California, and expanding pipeline capacity to the United States.

Exploitation of the oil sands resource has caused land disturbance from mining and had significant impacts on water. Advances have been made that reduce land disturbance and increase water recycling. Tailing ponds and lakes of polluted waters that were generated in past operations are being closed down.

The EPR came up again from the audience in discussions about tar sands, with one of the workshop participants claiming that because every 3 to 4 units of energy produced require about 1 unit of energy it is an energy-intensive process, mostly using natural gas at this point.[11] However, the resource base is large. During discussions, it was unclear

[10]Assuming a value of 5.8 million BTUs per barrel of oil produced and 1 million BTUs per thousand cubic feet (Mcf) of natural gas, an EPR of about 2.7 units of energy output is produced per unit of natural gas energy used.

[11]Currently, about 1 Mcf of natural gas for thermal in situ processing and 0.5 Mcf of natural gas for upgrading are required per barrel of synthetic crude oil produced. This corresponds to an EPR of about 3.86 units of energy output of oil per unit of natural gas energy used. Such EPR calculations will depend on the processes used and the particular character of the resource. See, for example, *Canada's Oil Sands, Opportunities and Challenges to 2015*, National Energy Board, May 2004. Available on the Web at <http://www.neb.gc.ca/energy/energyreports/emaoilsandsopportunitieschallenges2015/EMAOilSandsOpportunities2015Canada2004_e.pdf>.

whether there were better processes for reducing the carbon dioxide ($CO_2$) emissions from such energy-intensive processes—for example, by using nuclear energy to generate heat or by capturing $CO_2$ and sequestering it. Some in the audience were skeptical that using nuclear energy to produce heat for the process would be an attractive commercial option and noted that reservoirs for $CO_2$ sequestration are about 300 miles away.

Oil shale resources are large, with the United States having approximately 1,200 billion bbl of resources. As described in the presentation on shale oil, Shell's in situ conversion (ISC) process for producing oil from oil shale is a slow electrical heating process that converts the oil shale to a light crude oil, which then needs some above-ground refining. Shell has produced about 1,500 bbl of oil in a concept test program that heats the subsurface to 600°F-700°F over several years. Further testing is necessary to demonstrate commercial viability by 2010. It is estimated that a 150,000 bbl/day operation would require a 2-3 GW power plant with an EPR of about 3:1 (energy output of the liquid fuels to the energy input to the power plant). Carbon dioxide emissions are projected to be similar to those from light conventional crude oil.

Both the direct and indirect liquefaction of coal to liquid fuels are technologies that produce substitutes for petroleum. A direct liquefaction process is being built in China, and gas-to-liquids technology has advanced the state of knowledge of Fischer-Tropsch processes. A 120,000 bbl/day plant would probably cost about $75,000 per daily barrel, resulting in a capital cost on the order of $9 billion. According to David Gray, coal-to-liquids technology is competitive at a crude oil price between $30 to $50/bbl, depending on coal type and location. Dr. Gray estimated that with an assumed slow ramp-up of coal-to-liquids plants under an oil price of $50-$60/bbl, perhaps 35 plants could be built by 2030, corresponding to 4 million bbl/day of production capacity. Note that a coal-to-liquids plant producing 120,000 bbl/day of liquid fuels would sequester about 16,000 tons C per day (53,500 tons/day of $CO_2$) and would emit about 1,700 tons C per day to the atmosphere. If $CO_2$ was not sequestered, C emissions to the atmosphere per barrel of oil produced from coal would be almost twice as much as that from conventional oil.

In the discussion, it was noted that coal gasification processes are flexible as to what products they make—liquids, electricity, or hydrogen. There were also questions of whether such capital-intensive investments would require price guarantees or loan guarantees. One participant asked about the production of methanol via coal gasification. However, using methanol as a fuel would require a major infrastructure transition from gasoline and diesel fuel, the primary fuels now used for transportation.

In his natural gas-to-liquids presentation, Emil Jacobs noted that natural gas demand is increasing worldwide and that there are extensive reserves of natural gas worldwide, with about 70 percent of conventional natural gas reserves residing in the Middle East and Asia. Qatar has approximately 900 trillion cubic feet (TCF) of natural gas, and ExxonMobil is building a natural gas-to-liquids plant there that is slated for operation in 2011. The plant will cost $7 billion and produce 154,000 bbl/day of hydrocarbon products, including 80,000 bbl/day of diesel fuel. It will consume 1.8 billion $ft^3$/day of natural gas. The current world market for diesel fuel is about 15.4 million bbl/day. Several companies will probably have three to five gas-to-liquids plants in place by 2015, producing a total of perhaps 450,000 bbl/day of diesel fuel.

Dan Sperling noted that liquid fuels from biomass may require a transition to a more decentralized, distributed energy system since the size of production plants for biofuels will probably be constrained by the limited amount of feedstock that can be collected economically from the surroundings of a biomass fuel production facility. Thus, local or regional markets may be more appropriate for this resource. Given advances in the processes for converting cellulose into liquid fuels, biofuels could make a substantial contribution in a few regions and countries. Such conversion is relatively easy to implement but expensive. It offers the potential of producing liquid fuels with low greenhouse gas emissions, but it is not clear at this point how a substantial biofuels industry will arise. Who will invest in and promote cellulose conversion technology and other advanced biofuels options?

John Heywoods's presentation and the associated discussion of fuel efficiency/economy improvements for vehicles focused on light-duty vehicles and trends in the U.S. market but made some reference to the global implications. He noted that in the United States, light-duty vehicles account for about 50 percent of the fuel used in the transportation sector, freight movements account for about 40 percent, and air travel for about 10 percent. The scale of activity is enormous, with perhaps 2 billion vehicles expected to be operating worldwide by 2050.

In his presentation, Dr. Heywood estimated that mainstream engines, vehicles, and transmissions can be steadily improved over time to reduce fuel consumption in new vehicles by 35 percent in about 20 years, but at an additional cost of between $500 and $1,000 per vehicle; hybrid vehicles can improve on this by 20 to 30 percent at additional cost. Incrementally improving baseline vehicle technology will be important to developing nations as well to keep costs low and help enhance market penetration. But the fleet turnover is slow, and it is not clear that advanced technologies for fuel economy improvements will be taken up by the market in a substantial way. Improvements in fuel economy could have a substantial impact by the 2025-2035 time frame, but it is not clear that this will happen. Much of what happens depends on the price of gasoline. Some participants asked what would happen with a strong gasoline price signal, say $10/gal.

In the long term, if reductions in greenhouse gas emissions are critical, then fuel cell vehicles and hydrogen from non-$CO_2$-producing sources are one means of achieving this. In addition, if liquid fuels become very expensive, the transition to such technologies would also be stimulated. Dr. Heywood noted that even with successful development of fuel cell and hydrogen technologies, the potential of fuel-cell hybrid vehicles for reducing petroleum use by the on-the-road fleet before 2035 is small.

# Potential Follow-up Studies

The discussions on oil peaking reflected a variety of perspectives on whether conventional oil production will peak or plateau, when that might occur, and how markets and governments would prepare and transition to alternatives to conventional oil when a peak or a plateau seems likely. Some believe that global conventional oil production will peak soon, generally because they do not believe OPEC has as much oil as the USGS and others believe it does. Others disagree, believing that oil supply will be able to meet demand for decades to come. Some believe that oil peaking will have catastrophic economic consequences, while others believe that markets and innovations will handle this problem just as they have handled many others. It is a good debate. Although participants had differing views on the timing, drivers, and impacts of peak oil, many of them felt that mitigation planning needs to begin now. If the transition through a peaking phase is not managed well, it could have significant adverse implications for the global economy.

Other key issues arose at the workshop:

- Non-OPEC regions will find it more and more difficult to increase conventional oil production over the next 5-10 years.
- If world demand for oil continues to increase at rates expected, either (1) OPEC's market share will increase greatly and OPEC will expand production rapidly or (2) much of the growth in demand for liquid hydrocarbons will have to be met from unconventional sources. This heightens the usual energy security concerns.
- Satisfying the expected levels of demand for liquid hydrocarbons from unconventional sources will require enormous capital, both physical and human, and there are important concerns about the availability of that capital.
- To what extent can market forces, technology, and policies change the demand for petroleum?
- The environmental consequences of increasing use of unconventional oil sources could be serious.

Understanding these and other key issues is urgent because of the time lags for adaptation.

This part of the workshop focused on eliciting suggestions from participants for in-depth studies that ought to be carried out that could clarify issues surrounding the supply and demand of oil, help to inform decision makers and others, bring some consensus, or at least better communicate differing points of view. As part of the introduction to this session, it was noted that the National Academies is a nonprofit organization and not part of the government. It conducts studies by relying on volunteers who are appointed to committees based on their expertise. The National Academies, through its National Research Council (NRC), is known for conducting studies in a manner that is independent, objective, and credible, bringing to bear the best scientific and technical talent on any particular issue. Its reports are subject to an extensive review process before they are issued and made available to the public.

Since the timing of global oil peaking is uncertain, there was discussion of how this issue could be brought to the attention of politicians and policy makers even though there is not necessarily a crisis. Given the large quantities of liquid fuels needed by the world economy and the large investments, long lead times are needed to either increase the supply of liquid fuels or reduce the demand for them. Thus, an understanding of some of the key issues raised at the workshop is urgent, as is planning for a possible transition. One challenge is how to create enough momentum and attention by policy makers without creating a sense of crisis. How should a dialogue with policy makers be opened without damaging credibility? That timing is uncertain and energy prices may well decline creates a problem for politicians, who do not always consider the long term. Could the NRC play a role here, perhaps by holding workshops? Perhaps a roundtable of industry, government, and public interest representatives could foster dialogue and understanding on the subject. The other role the NRC could play is to conduct studies, the topics of which were identified in the workshop discussions as follows:

- The enormity of the problem and the magnitude of the supply of and demand for petroleum and liquid fuels, as well as the long time scales involved for any transition from conventional petroleum to substitutes, is probably not known by the public. Regardless of when a peak in conventional oil production occurs, there will be a substantial need for capital investment. This need will be exacerbated if peaking takes place sooner rather than later. How should a limited amount of capital be invested, not only for technology that would increase the supply of fuels but also for technology that would reduce demand? What are the infrastructure requirements and how can they be met? What are the implications for the United States given the extent to which its debt is supported by the rest of the world?
- The constituents of the supply of liquid fuels and the demand for them should be analyzed in detail and explained to decision makers and the public. For example, what additions are being made to oil reserves each year, how much investment is required to increase recovery factors, how much oil is being used, what would a plateau in non-OPEC oil production mean, and what will be required to meet growing oil demand for the next few decades? What do the probabilities of reserve estimates imply, and what are the consequences if the higher estimates of reserves (which have a lower probability) are not realized? The answers to such questions should be presented in a manner that is understandable and credible to decision makers. This may entail consideration of a new set of conventions for defining the various categories of resources and reserves that would address some of the perceived limitations of the Securities and Exchange Commission definitions.

- An analysis should be conducted of the increased energy, investment, materials, and skills needed to exploit harder-to-get oil resources and alternatives such as coal, heavy oil, tar sands, oil shale, and biomass. What is the EPR of alternatives, and what would be the trends in the energy yield per unit of energy and other resources invested? What will be the effect on greenhouse gas emissions to the atmosphere if liquid fuels are produced from alternative resources? It would be worthwhile to lay out potential transition strategies and investigate options for how the economies of the world might be affected under different scenarios. What are the economic costs? Will price be an adequate signal to motivate investment in alternatives? What can the market be expected to do, and what policies will be needed to avert severe economic dislocations?
- A study by the NRC could focus on solutions and opportunities for reducing petroleum consumption. This should include the impact of rising fuel prices, technology advances, and policies on reducing the demand for petroleum. As part of this study, a deeper analysis of non-OPEC production forecasts could be undertaken, since—as seems to have been indicated by presentations at the workshop—non-OPEC production could peak within a decade. If so, that is a powerful statement and conclusion, and opportunities for reducing petroleum consumption will be a very important strategy.
- It was suggested that a broad energy study be conducted by the NRC, perhaps encompassing the next 25 years, that would look at fuels and electric power and address the options available for meeting anticipated demand for both. While the study could be focused on the United States, it would have to consider the global oil market and its impact on the U.S. economy. Or it could look at the entire global economy. It could look at different scenarios for fuel and electric power demands and investigate the means of meeting those demands using different feedstocks. It could address questions like these: What will it take to meet anticipated demand, including human and capital resources? What is the likely timing? What are the implications for greenhouse gas emissions to the atmosphere? What kinds of investments could be made on the demand side to reduce consumption? What are the costs of different technologies for supply, and what stage of development are they at? What are the roles of the private and public sectors? What policies might be required, and what are the implications of different policies? The study could lay out transition strategies under different scenarios for how to avoid significant economic dislocations and "demand destruction" (forced reductions in demand because of insufficient supply) and meet anticipated future demand for energy.
- A study of trends in oil supply and demand and the potential for peaking of conventional oil should be undertaken, to help the public and decision makers make informed decisions about whether policy measures are required or not. This study could incorporate the following considerations:
  —What would happen when a peak in global conventional oil production occurs?
  —How can the peak oil challenge be communicated to the public and politicians?

—What do we know about oil reserve growth, and how can we better understand rates of oil reserve growth and recovery efficiencies?
—For how long after non-OPEC producers peak will OPEC be able and willing to bridge the supply/demand gap?
—Will alternatives to conventional oil be able to bridge the gap?
—What can we say about efficiency and vehicle fuel economy, and how much can they contribute to reducing the demand for petroleum?
— How much oil does OPEC have? Can we rely on OPEC's reserves?
—Are sufficient human resources and capital available for investments to meet global oil demand and avoid serious economic impacts?
—What should scientists/engineers do next to help inform policy makers and politicians about the issue?

- A study focused on a risk mitigation strategy could be developed that incorporates the probabilities of the various factors that affect oil supply and demand and that allows estimating when a peak might occur. The study could consider what kinds of plans should be put in place and how they might be executed. Uncertainties other than technical and economic would also need to be considered, such as environmental constraints, political trends, and trade issues. A scenario analysis might be more appropriate for developing and prioritizing a set of actions that would reduce the risk to the economies of the world posed by a peaking of oil production.
- Regardless of when a peak in oil production might occur, the transition to alternatives to conventional oil, and the timing of this transition, is an important topic and could be studied. What has to be done to make a transition to a sustainable energy system that in the long run will be less dependent on conventional oil? How will the governments and private companies of the world ensure that investments will take place in a timely fashion? Will prices signals be sufficient? What policies need to be considered? If the study is focused on the United States, how will the U.S. economy or other economies be affected? What are the implications of global flows of petrodollars?
- There is a great amount of information that is not available. Either as part of one of the bigger studies noted above, or as a separate study unto itself, we need a better understanding of oil reserves outside the United States, energy use in different sectors of national economies, transportation use internationally, and other components of oil supply and demand worldwide. The data need to be made transparent so that decision makers and other concerned groups can develop some confidence in the projected trends and claims of various analysts. International standards for oil reserves accounting are desirable.
- An educational activity could be initiated, possibly aimed at K-12 levels, to teach citizens about the issues and what a transition might entail. Social scientists as well as engineers, scientists, policy makers, and public interest representatives should be included in this activity. The activity should consider a potential transition to a post-peak, potentially lower energy world that would not generate current levels of economic growth and that people would have to learn to adapt to.

- A broad energy study could be undertaken, perhaps addressing in some generic manner "Our Energy Problem." Given how broad the subject is, it might be broken down into a half dozen or so manageable themes that address the following:
  —Husbanding petroleum,
  —The clean use of coal,
  —Diversity of energy sources,
  —Opportunities for energy efficiency and reduced energy consumption,
  —Opportunities for solar energy,
  —An energy strategy, and
  —The need for human resources (talent).
- A study could be conducted on the impacts on developing countries of oil price volatility, potential peaking, and international competition for oil. Among other factors, it should include what might happen to fertilizer and food production and potential impacts on developing countries, and consider policies that could alleviate potentially severe disruptions to these countries.

# APPENDIXES

# A

# Statement of Task

The National Research Council (NRC) will hold a workshop that will explore the question of global oil production and, in particular, estimates of when global oil production may peak. The workshop will include analysts who have recently published such forecasts, which range from the conclusion that global oil production may peak within the next decade or so to those that estimate sometime in the 2030-2050 time period. In addition, it will explore options for mitigating the possible serious economic implications of world oil production peaking, and will also identify possible topics for in-depth study that could help inform U.S. government policy. It is anticipated that the workshop will be about 2 days long. Individuals will be invited that have conducted analyses on global oil production, on future oil demand, on trends in the global energy market, as well as in regional energy markets, and that have expertise in energy policy. Participants will be sought from the private sector, from government agencies, and from universities, as appropriate. The workshop will be open to the public to help bring attention of the issue to a broad set of interested individuals. A summary of the workshop will be prepared in accordance with institutional guidelines.

# B

# Workshop Agenda

## THURSDAY, OCTOBER 20, 2005

### Setting the Stage—Michael Ramage, Chair

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| 7:30 am | Sign In |
| 8:00-8:10 | Overview of Plan for the Workshop<br>*Michael Ramage, chair, Workshop Planning Group (retired executive vice president, ExxonMobil R&D Company)* |
| 8:10-8:45 | Issues in the "Peaking of Global Oil Production" Debate<br>*David Greene (corporate fellow, Oak Ridge National Laboratory)* |
| 8:45-9:20 | World Oil Demand: Key Trends and Uncertainties<br>*Nicola Pochettino (senior energy analyst, International Energy Agency)* |
| 9:20-9:55 | Global Overview of Petroleum Resources<br>*Thomas Ahlbrandt (project chief, United States Geological Survey)* |

### Future Global Oil Supply and Demand Balance—Scott Tinker, Chair

| | |
|---|---|
| 9:55-10:00 | Introduction<br>*Scott Tinker (director, Bureau of Economic Geology, and Department of Geological Sciences, University of Texas, Austin)* |
| 10:00-10:35 | A View from Cambridge Research Associates<br>*Peter Jackson (director, Oil Industry Activity, Cambridge Energy Research Associates)* |

| | |
|---|---|
| 10:35-11:10 | A Case for a Near-Term Peak in Global Oil Production<br>*Jeremy Gilbert (Barrelmore Ltd.)* |
| 11:10-11:45 | Questions Regarding Saudi Arabian Petroleum Supplies<br>*Matt Simmons (Simmons & Company International)* |
| 11:45-12:20 pm | Exploration Trends, Diminishing Success, and Implications for Future Crude Supplies<br>*Michael Rodgers (senior director, Exploration and Production Portfolio and Business Development Unit, PFC Energy)* |
| 12:20-1:40 | Recess |
| 1:40-2:15 | The View from ExxonMobil<br>*Scott Nauman (manager, Energy and Economics, Corporate Planning Department, ExxonMobil Corporation)* |
| 2:15-2:50 | Looking In from the Outside<br>*Kjell Aleklett (Association for the Study of Peak Oil (ASPO) and professor of physics, Uppsala University)* |
| 2:50-3:25 | A View of Global Oil Peaking<br>*Herman Franssen (president, International Energy Agency)* |
| 3:25-4:00 | OPEC Outlook on Oil Supply and Demand<br>*Adnan Shihab-Eldin (acting secretary general, Organization of Petroleum Exporting Countries*) |
| 4:00-5:15 | Group Discussion |
| 5:15 | Adjourn |

## FRIDAY, OCTOBER 21, 2005

### Mitigation Options and Time to Implementation—David Greene, Chair

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|---|---|
| 7:30 am | Sign In |
| 8:00-8:05 | Introduction<br>*David Greene (corporate fellow, Oak Ridge National Laboratory)* |
| 8:05-8:50 | Overview of Mitigation Strategies<br>*Robert Hirsch (Science Applications International Corporation)* |

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|---|---|
| 8:50-9:35 | Key Technology Trends Impacting Exploration and Production<br>*Donald Paul (chief technology officer, Chevron Corporation)* |
| 9:35-10:10 | The Potential of Heavy Oil<br>*Robert Heinemann (president and CEO, Berry Petroleum Company)* |
| 10:10-10:45 | Oil Sands Development and Future Outlook<br>*Eddy Isaacs (managing director, Alberta Energy Research Institute)* |
| 10:45-11:20 | The Potential of Shale Oil<br>*Stephen Mut (Shell Exploration and Production Company)* |
| 11:20-11:55 | Producing Liquid Fuels from Coal<br>*David Gray (director, Energy Systems Analysis, Mitretek Systems)* |
| 11:55-1:00 pm | Recess |
| 1:00-1:35 | Liquid Fuels from Natural Gas<br>*Emil Jacobs (vice president, R&D, ExxonMobil Research and Engineering)* |
| 1:35-2:10 | Producing Liquid Fuels from Biomass<br>*Daniel Sperling (professor and director, Institute for Transportation Studies, University of California at Davis)* |
| 2:10-2:55 | Opportunities for Reducing Oil Demand for Transportation<br>*John Heywood (director, Sloan Automotive Laboratory, Massachusetts Institute of Technology)* |
| 2:55-3:10 | Break |

**Potential Follow-up Studies and Activities—Robert Hirsch, Chair**

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|---|---|
| 3:10-3:15 | Overview and Purpose of the Session<br>*Robert Hirsch (Science Applications International Corporation)* |
| 3:15-4:30 | Group Discussion |
| 4:30-5:00 | Summary of Salient Points from the Group Discussions and Suggestions for Follow-on Studies<br>*Robert Hirsch (Science Applications International Corporation)* |
| 5:00 | Adjourn |

# C

# Individually Authored Summaries of Presentations

## ISSUES IN THE PEAKING OF GLOBAL OIL PRODUCTION DEBATE

**David L. Greene, Corporate Fellow, Oak Ridge National Laboratories**

Transportation, the circulatory system of the global economy, is all but entirely dependent on petroleum fuels. In light of this fact, it should be no surprise that the possibility that world oil production will soon reach a peak and then inexorably decline is a subject of great interest and intense debate. The "pessimists," a somewhat pejorative label given to those who are convinced that the oil peak is imminent and that its consequences will be dire, assert that world oil supply is chiefly determined by the geology of oil resources. They point to geologist M. King Hubbert's accurate prediction of the peak in U.S. oil production in 1970 and note that many other oil-producing regions have since reached their peaks and are now in decline. Noting that world oil discoveries peaked before 1970, they predict a peak in world oil production by the year 2010. The "optimists" counter that markets and technology will determine the supply of fuel for transport, and that nearly all past predictions of resource scarcity have proven to be mistaken. Innovation guided by market signals will expand and redefine energy resources. They point to increased recovery rates, advances in the technology for exploring and developing oil in deep water, and the redefinition of oil sands as proved reserves. "The stone age did not end for lack of stones; the oil age will not end for lack of oil."

The debate hangs on several key questions addressed in this workshop.

1. Will geology or technology dominate?
2. What is the oil resource, and how much is there?
3. How much oil can and will OPEC supply?
4. Will the demand for oil continue to grow, or will demand peak and decline?
5. Is development of unconventional resources consistent with protection of the earth's environment and, especially, its climate?

Change is inevitable. There will be a transition, but to what? In the most pessimistic view, the transition will be to a global depression because it will simply not be possible to develop adequate economical replacements for petroleum fast enough to keep the world's economy moving. Optimists seem to be of two minds. Some note that for the past 150 years the world's energy system has been "decarbonizing" as it switched from wood to coal to oil, and now to natural gas. These optimists see an inevitable, technologically driven migration to a hydrogen economy. Other optimists note that the world's resources of unconventional oil (heavy oils, oil sands, shale oil, and even coal) are vast in comparison to conventional oil and gas, and point out that the heavy oil of Venezuela and the oil sands of Canada are already being economically developed. In effect, they see a "recarbonization," since these unconventional resources are either more carbon intensive or will require far more energy to produce and refine.

## WORLD OIL DEMAND: KEY TRENDS AND UNCERTAINTIES

### Nicola Pochettino, Senior Energy Analyst, International Energy Agency[1]

The International Energy Agency's *World Energy Outlook 2004* paints a sobering picture of how the global energy system is likely to evolve from now to 2030. If governments stick with the policies in force as of mid-2004 (Reference Scenario), the world's energy needs will be almost 60 percent higher in 2030 than they are now. Fossil fuels will continue to dominate the global energy mix, meeting most of the increase in overall energy use. Oil will remain the single largest fuel in the primary energy mix. Among the fossil fuels, demand for natural gas will grow most rapidly, mainly due to strong demand from power generators. The share of coal will fall slightly, but coal will remain the leading fuel for generating electricity. Nuclear power's share will decline during the *Outlook* period.

Global primary oil demand is projected to grow by 1.6 percent per year to 2030, continuing to grow most quickly in developing countries. Most of the increase in world oil demand will come from the transport sector. Oil will face little competition from other fuels in road, sea, and air transportation during the projection period. Huge investments will be needed.

If current government policies do not change, energy-related emissions of $CO_2$ will grow marginally faster than energy use. $CO_2$ emissions will be more than 60 percent higher in 2030 than now. Transport will consolidate its position as the second-largest sector for $CO_2$ emissions worldwide. More than half the increase in the sector's emissions will occur in developing countries, where car ownership is expected to grow rapidly.

These trends, from our Reference Scenario, are, however, not unalterable. More vigorous government action *could* steer the world onto a markedly different energy path. This *Outlook* presents an Alternative Scenario, which analyses the global impact of environmental and energy-security policies that countries around the world are already considering, as well as the effects of faster deployment of energy-efficient technologies. In this scenario, global energy demand and $CO_2$ emissions are significantly lower than in our Reference Scenario. Dependence on imported energy in major consuming countries is also

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[1]OECD/IEA, 2005. This summary is used with permission from the IEA, an autonomous agency of the Organization for Economic Cooperation and Development.

lower. However, a truly sustainable energy system will call for faster technology development and deployment.

## GLOBAL OVERVIEW OF PETROLEUM RESOURCES

### Thomas Ahlbrandt, World Energy Project Chief, U.S. Geological Survey

The World Energy Program of the U.S. Geological Survey (USGS) has been studying the volumes and distribution of potential resources of petroleum from both undiscovered fields as well as from reserve growth in discovered fields for the total petroleum systems contained within 128 provinces in 96 countries, exclusive of the United States and Canada. This global assessment, the USGS World Petroleum Assessment 2000 (U.S. Geological Survey Digital Data Series DDS-60, 2000), was released in June 2000 using known reserve data as of January 1, 1996, and provided estimates of potential new resources to be added to the total during the next 30 years. New field discoveries and reserve growth within the assessed provinces between January 1, 1996, and January 1, 2004, accounted for 18 percent of the oil resources and 27 percent of the gas resources of the total that were estimated as potential by the year 2025 for those 128 provinces. Additionally, there have been a number of discoveries in provinces other than those assessed in the USGS 2000 assessment. If these discoveries were added to those of the previously assessed provinces, the percentages represented by new field discoveries and reserve growth would increase to 23 percent of the oil and 32 percent of the natural gas of the estimated total potential to the year 2025. Reserve growth added three times the volume of reserves added by new field discoveries during the 1996 to 2003 period. During that period, 26 percent of the estimated mean oil reserve growth and 52 percent of the estimated mean natural gas volume reserve growth were realized. Results of these analyses suggest that estimates in the USGS 2000 assessment are reasonable assuming comparable rates of reserves additions for the remainder of the 1995-2025 time frame of the assessment. The USGS 2000 estimates are moderate relative to recent higher estimates from other organizations estimating recoverable reserves and resources for both oil and natural gas. Significant future potential for oil and natural gas are estimated for Arctic regions, including the United States and Canada, where approximately 25 percent of the USGS 2000 undiscovered volumes of oil and natural gas are located. These Arctic resources are thought to be gas-prone petroleum systems which should balance the oil and natural gas endowment of the world.

## WORLDWIDE LIQUID PRODUCTIVE CAPACITY: TIGHT SUPPLY OR EXCESS OF RICHES?

**Peter Jackson, Director Oil Industry Activity, Cambridge Energy Research Associates (CERA)**

No summary available.

## THE AGE OF OIL—BEGINNING OF THE END?

**Jeremy Gilbert, Barrelmore Ltd.**

After a century of exploration and huge advances in our understanding of the origins of hydrocarbons, we can describe quite reliably what we have inherited. Our estimates of the size of this resource would be more accurate still were we to have access to the records of those who control it, namely, the western oil companies and the national oil companies of the OPEC countries. Both groups have what seem to them to be good reasons to keep this data confidential, but the information available to outsiders suggests that we may be significantly overestimating remaining reserves.

Many independent estimates of future world oil demand have been made. Although these have large variations, virtually all of them anticipate an increase in demand substantially above the present 80 million bbl/day. A level of about 100 million bbl/day by 2025 can be taken as representing a minimum; reputable companies predict demand of 125 million bbl/day. Analysis by a number of groups suggests that it will be very difficult for the world to significantly reduce consumption, through improved efficiency or substitution, before 2025.

A detailed analysis of the world's reserves, carried out country-by-country by the Association for the Study of Peak Oil (ASPO), suggests that world production of "conventional" oil will reach a maximum within the next 5 years at about its present level. Although the reliability of the predictions decreases with time, it is predicted that after a plateau period of just a few years production will begin to fall at a rate of about 2 to 3 percent per year. Although opinion at the workshop was divided on the realism of these predictions, there was near-consensus on the likelihood that non-OPEC conventional oil supply would indeed reach a maximum within the next 10 years and then begin a slow decline. Whether or not the OPEC countries could or would meet the challenge of filling the gap between the 60 million bbl/day from the other suppliers and possible demand of 125 million bbl/day was left unclear. There appear to be substantial technical and economic reasons to doubt that this will happen.

For the world to analyze and begin to deal with the challenge posed by a possible shortfall in hydrocarbon supply, accurate data are critically needed. We must urgently enroll our politicians and policy makers in persuading those who control this data that is essential it be made available for impartial study.

Without such urgent action we are dooming our children to the strong likelihood of energy deprivation and civil unrest.

## QUESTIONS REGARDING SAUDI ARABIAN PETROLEUM SUPPLIES

**Matt Simmons, Simmons and Company International**

The peak oil debate is gathering steam. Unfortunately, so far the two sides of the debate team are "snarling" at each other. One group, often called pessimists, tends to be primarily petroleum scientists. They argue that oil is a finite resource and that its use is about as high as can be sustained. Moreover, oil supply will soon peak and then begin a steady and probably irreversible decline. The other group, often called optimists, tends to be economists or social observers. They are certain that oil peaking will never happen within any relevant time frame, since demand will either peak and then decline, or technology will continue to find ways to bring on more supplies. Most optimists also argue that long-term oil prices will fall back to the very low levels they stayed at for most of the last 150 years. Lacking in the optimists' argument is any data to support this view, other than history.

A wrong interpretation of peak oil makes the debate even fuzzier. Too many peak oil skeptics assume that peak oil means that oil has "run out." Nothing could be farther from the truth. Peaking means oil supply will no longer grow. Peak oil will occur unless, by some miraculous event, we finally prove that oil is a renewable resource. A handful of proponents claim oil is still being created but they have no explanation for why so many once prolific oil-producing regions are now far beyond peak supply. Since oil is a finite resource, the higher oil demand rises, the faster we will reach peak oil. The timing of this earth-shattering event is the only issue deserving serious debate.

A major reason why people still debate whether peak oil is a serious problem or not, and the timing when peak oil might occur, is the immense and gaping hole in high-quality data to shed light on the topic. For decades, what were reported as "proven oil reserves" were blissfully accepted as "proven" until Shell Oil Company, the gold standard for high efficiency and top professionalism, suddenly found a series of gross overstatements of what had been booked as proven reserves. Ever since this bombshell event, scores of other public oil and gas companies have undergone similar proven reserve write-downs.

At the same time there has been a renewed focus on the reliability of published Middle East proven reserves. Many oil observers have finally remembered that all OPEC Middle East oil producers along with Venezuela doubled or tripled their reported proven reserves within a short time span in the 1980s, adding a mysterious 300 billion bbls of proven reserves without a single significant oil discovery. Whether these numbers were real or not is a very serious question.

In the past several years, "unconventional oil reserves" have also been added to the world's proven reserve base, which raised global proven reserves by another 200 billion bbls, although these unconventional oil resources are extremely energy intensive to produce and never come out of the ground at rates more than a fraction of the volume of oil a highly pressured reservoir can deliver.

I am convinced that Saudi Arabia is either nearing its peak oil output, or could even have passed its old peak supply record, set in 1980-1981. Once Saudi Arabia's oil goes into decline, the world will also have passed peak oil.

There are two ways to resolve the peak oil debate. Only one makes any sense. The smart fix is for the world to quickly adopt a new standard of energy data and insist that all key oil producers furnish the last 5 years, quarter-by-quarter, of their oil production on a field-by-field basis and the number of well bores within each field that create the oil flow. Once this reform begins, all key players must also report their ongoing production, similar to the financial transparency we presently require of all publicly held companies. The wrong way to resolve this issue is to wait until historical data make it clear that we have passed peak oil since it is so obvious that global oil production is in decline.

If the world chooses what I described as the rearview mirror approach to the peak oil debate, we lose the chance to properly organize an intelligent response to how the world copes in a post-peak oil environment. The rear-view mirror solution will likely lead to a vicious battle among oil users as to who gets their fair share of a precious, high-value-added resource that is unfortunately in decline. This era will resemble the outbreak of World War I.

## RECENT TRENDS IN EXPLORATION RESULTS AND THE IMPLICATION FOR FUTURE PETROLEUM LIQUIDS SUPPLY

### Michael Rodgers, Senior Director, E and P Portfolio and Business Development Unit, PFC Energy

With a few exceptions, large discoveries from 1960 to 1980, as well as sizable reserves surpluses, allowed for sustained crude market equilibrium, to which much of the world grew accustomed. However, as demand has grown and as exploration has matured in the majority of the world's basins, production levels have begun to exceed additions of new reserves by 12-15 billion bbl/year. For each of the last 20 years, the world has been producing and consuming two to three times as much oil as it has been finding.

PFC Energy conducted a detailed analysis of historical reserves growth, production, demand growth, and recent discovery trends. The study examined every country and broke out each country's production into multiple segments: reserves already discovered (the existing base with projected decline rates, identified development projects, and reserves with no current development plans) and reserves yet to be discovered. This included a detailed assessment of field size distributions, exploratory drilling levels, and commercial threshold analysis.

The analysis suggests that the world's ability to increase liquids production outside members of the Organization of Petroleum Exporting Countries will be severely challenged in the early part of the next decade and beyond unless there are significant shifts in oil recovery factors or improved results from exploration. The average annual volume of new oil discovered after 1990 was approximately 8 billion barrels per annum while average annual demand for production outside of North America will increase from a current volume of 25 billion barrels per annum to 35 billion barrels per annum by 2020. In order to stabilize conventional crude oil depletion levels it would be necessary to triple recent exploration success as measured by annual volumes of newly discovered oil.

In addition, as demand continues to grow beyond 2010 and non-OPEC production peaks or goes into long-term decline, the burden will fall on OPEC to make up the difference. When this occurs, OPEC production capacity and reserves will be strained, and models suggest that OPEC will struggle to fill the differential between non-OPEC supply and global demand beyond as early as 2015-2020.

## THE OUTLOOK FOR ENERGY—A VIEW TO 2030

**Scott Nauman, Manager, Energy and Economics, Corporate Planning Department, ExxonMobil Corporation**

This presentation highlights ExxonMobil's global energy outlook, with an assessment of supply and demand through 2030. This outlook underscores the connection between economic growth and energy consumption, and the importance of meeting key energy supply and demand challenges to improve economic prosperity around the world. By 2030, the world's population will grow to 8 billion. Coincident with this population rise will be continuing economic growth, both in developed and developing economies. This combination of population and economic growth will lead to a primary energy demand increase of approximately 50 percent, reaching close to 335 million bbl/day oil equivalent by 2030. The vast majority (80 percent) of the increase will occur in non-OECD countries.

As demand rises, energy efficiency will become increasingly important, with the pace of improvement likely to accelerate. This accelerated pace is the outcome of expected improvements in personal transportation and power generation, driven by the introduction of new technologies, as well as a myriad of other improvements which span the residential, commercial, and industrial sectors.

Oil, gas, and coal will remain predominant energy sources, with approximately 80 percent share of total energy. These well-established fuel sources are the only ones with the versatility and scale to meet the majority of the world's growing energy needs. Alternative fuels, like solar and wind power, will grow rapidly, underpinned by government subsidies and mandates. But even with assumptions of robust 10 percent/year growth, solar and wind will represent just 1 percent of the total energy portfolio by 2030.

The supply outlook is also addressed in the presentation. A discussion of global oil resources highlights the long life supply that still remains. This resource estimate represents a detailed technical assessment of global supply sources. A world liquid production outlook explores the trends among OPEC and non-OPEC production.

Technology advances will remain critical to successfully meeting the significant energy demand, supply, and environmental challenges ahead.

## LOOKING IN FROM THE OUTSIDE:
## EXPLORING THE EVIDENCE OF PEAK OIL PRODUCTION

**Kjell Aleklett, Uppsala University, Sweden, and the Association for the Study of Peak Oil and Gas**

Since 2001, when the Association for the Study of Peak Oil and Gas was founded, we have tried to tell the world that there will soon be a problem supplying the world with crude oil while demand continues to rise. The estimated peak-production year is 2010. The exact year for peak oil depends very much on future demand, and we will not know when we have peaked until we have crossed the threshold. It will certainly happen before 2020.

Fifty years ago the world was consuming 4 billion bbl of oil per year, and the average discovery rate (the rate of finding undiscovered oil fields) was around 30 billion bbl per year. Today we consume 30 billion bbl per year and the discovery rate is dropping toward 4 billion bbl per year. (By discovery, I mean only new oil fields. Some analysts include reserve growth—newly accessible oil in old fields—as new discoveries). If we extrapolate the downward discovery slope from the last 30 years, we can estimate that about 134 billion “new” barrels of oil will be found over the next 30 years.

The USGS has 649 billion bbl as a mean discovery rate of new oil fields (not growth) for the period from 1996 to 2025. According to available databases the world has found 100 billion bbl during the first 10 years of the period. For the next 20 years we estimate from existing trends that we will find another 100 billion bbl, in total 200 billion bbl. This is far from 649 billion bbl.

Today many use scenario numbers from the IEA base scenario as future production. Since IEA uses the USGS mean data as a resource base, we think that that these numbers are too high. This is just one of several indications that we are facing peak oil in the near future.

## THE FUTURE OF OIL: WILL DEMAND MEET SUPPLY?
## DEMAND IMPLICATIONS OF PEAK OIL
## AND THE GEOPOLITICS OF THE MIDDLE EAST

**Herman Franssen, President, International Energy Agency**

For the first time since the late 1970s and early 1980s, the issue of peak oil has moved from academic discussions among a few dedicated believers, to debates and investigations by national academies of science (Sweden, United States), the oil industry (Chevron ad campaigns), and governments (Secretary Bodman’s request to the National Petroleum Council [NPC] to make a study of peak oil). There is little doubt that like in the late 1970s, when oil prices reached record post-World War II highs, the recent steep oil price increases and the immediate modest supply response have heightened concern about the ability of the global oil industry to maintain, let alone expand, conventional oil production.

The perception that global oil production could very well peak in the 1990s was genuine among many oil industry senior geologists and petroleum engineers in the late 1970s. The timing of peak oil, however, was predicated on oil demand growth of 5 percent plus annually. Many oil experts believed that oil demand was fairly inelastic and would not respond to higher prices. Events since the late 1970s proved otherwise, and at $30 plus oil (1970 dollars) much of the oil used as a boiler fuel was replaced by other, cheaper fuels. High oil prices and government policies (ranging from taxes to CAFE standards) also resulted in major efficiency gains in the transportation sector. Perhaps by coincidence, the burst of postwar OECD economic growth came to an end during the oil price shocks of the 1970s, but it is difficult to quantify the role of energy and oil in this.

On the supply side, a combination of high prices, loss of assets in OPEC oil-producing countries, and the development of new cost savings and deepwater technologies led to a large increase in E&P expenditures in the upstream sector, resulting in major expansion of non-OPEC production. By the mid-1980s, OPEC's market share had declined sharply and half of its capacity was shut in.

What is different today from the late 1970s? On the demand side, most of the oil used as a boiler fuel has already been substituted by other fuels, and oil in the industrialized world is largely used in the transportation sector and as feedstock. There is still room for further substitution, but it is limited and will take more time, in particular, in the transportation sector. On the demand side, some 80 percent of the global population uses on average 2 barrels per person per year, compared with close to 15 barrels for Europe and Japan and 26 for the United States. As shown in the recent growth in Chinese oil demand, pent-up demand for oil is huge in the developing world, and demand growth is directly linked to economic activity.

Assuming long-term global economic growth at 3-3.5 percent per year, most long-term energy demand projections show global oil consumption rising from about 84 million bbl/day in 2005 to 120 million bbl/day by 2025, and most of the demand growth is projected for the developing countries. To achieve 120 million bbl/day of oil production by 2025 and assuming a modest depletion rate in producing fields of 3-5 percent annually, some 98 million bbl/day of oil production in 2025, must come from other than current proved reserves, i.e., from new discoveries or extensions of producing fields. This seemingly impossible task would only raise the annual consumption in the developing world from an average of 2 to an average of about 4 barrels per person per year over the next two decades (Europe's consumption level in the early 1950s). Already high oil prices are having a deleterious effect on economic development in the poorest countries, and it is not yet clear how much of an impact it will have on medium-income countries. High prices lead to improved efficiency and fuel substitution where possible but can also cut into economic growth and reduce living standards.

There are too many as yet unknown and speculative parts of the global peak oil puzzle to expect early agreement among experts and policy makers on the timing of peak oil. Perhaps it is less important to speculate on when conventional oil will peak than to focus on timely mitigation strategies. Since there are certain synergies between peak oil mitigation and reducing $CO_2$ emissions, some of the mitigation strategies to cope with peak oil will also lower $CO_2$ emissions without reducing prospects for global economic growth.

## OIL OUTLOOK, CHALLENGES, AND OPPORTUNITIES

### Adnan Shihab-Eldin, Acting Secretary General, OPEC

This reviews the oil outlook, challenges, and opportunities in the early 21st century. It provides assurances of supply security at a time when there has been much market volatility and rising prices and unprecedented demand growth. There are six sections: current oil market assessment, medium- to long-term outlook, outlook beyond 2010, reserves/resources, uncertainties, and technology.

The current market is characterized by resilient economic growth and high oil demand growth, in particular from large developing countries with low consumption per capita. Supply chain tightness, particularly downstream, has contributed to a loss of market confidence. OPEC has increased production significantly to help stabilize the market, resulting in global supply exceeding demand for the last 3 years and rising oil inventories. But geopolitical tensions, hurricanes, and other unpredictable events, together with increased activity in futures markets, have translated into significant volatility and rising prices.

In the medium term, OPEC is committed to continuing upstream capacity expansion at an accelerated rate, and this is expected to rise cumulatively by 5.5 million bbl/day to 38 million bbl/day by the end of 2010, and other liquids by 1.5 to 1.8 million bbl/day. OPEC will also add downstream capacity well in excess of 2 million bbl/day. Oil supply is thus forecast to stay well above demand, whereas the downstream situation may only improve in 2007, when product demand and refinery capacity expansion could come close together.

Beyond 2010, demand growth will continue rising steadily. OPEC, with nearly four-fifths of proven global reserves, will supply increasingly the incremental barrel. But, despite the upstream investment challenge having been not too dissimilar to the past, ensuring market stability will be complicated by considerable uncertainties, such as consuming countries' energy policies.

The global reserve/resource base can easily meet forecast demand growth for decades to come. Estimates of ultimately recoverable reserves (URR) have increased over time, with advancing technology, enhanced recovery, and new reservoir development. For example, according to an established industry source, reserve growth from improved recovery alone in existing fields amounted to 175 billion bbl in 1995-2003; combined with new discoveries of 138 billion bbl, total reserve growth was therefore well above the cumulative production of 236 billion bbl for that period. Moreover, technology continues to blur the distinction between conventional and non-conventional oil, of which there is also an abundance, as well as with other fossil fuels. We expect the world's URR to continue to increase in the future. Therefore, the real issue is not reserve availability, but timely deliverability, and here enhanced cooperation and dialogue among all parties is essential to ensure security of demand, as well as security of supply.

# PEAKING OF WORLD OIL PRODUCTION AND THE MITIGATION CHALLENGE

**Robert L. Hirsch, Science Applications International Corporation**

The peaking of world conventional oil production will subject the world to its first ever discontinuity in energy—a sudden limit on the supply of a commodity that is essential to the functioning of all economies. Oil peaking represents a liquid fuels problem, not an "energy crisis" in the sense that term has often been used. Motor vehicles, aircraft, trains, and ships simply have no ready alternative to liquid fuels. While many possibilities exist for the long-term future, in the next 20-40 years it is essential that we adequately provide for the enormous worldwide fleets of vehicles and for chemical processes that can only function on liquid hydrocarbons. Accordingly, mitigation must be narrowly focused, at least in the near term.

Currently viable, potentially high-impact mitigation options include (1) increased vehicle fuel efficiency, (2) enhanced recovery of conventional oil, and (3) substitute liquid fuels from heavy oil/oil sands, coal, and remote natural gas. A scenario analysis of a hypothesized worldwide crash mitigation program utilizing related commercial and near commercial technologies determined the following as the most optimistic possible outcomes: (1) Waiting until world oil production peaks before embarking on crash program mitigation on all options simultaneously leaves the world with a significant liquid fuel deficit for more than two decades; (2) initiating such a crash program 10 years before world oil peaking helps considerably but still leaves a liquid fuels shortfall roughly a decade after the time that oil would otherwise have peaked; and (3) initiating a mitigation crash program 20 years before peaking offers the possibility of avoiding a world liquid fuels shortfall for the forecast period.

If mitigation is too little and too late, world supply/demand balance will be achieved through massive demand destruction (shortages), which would translate to heretofore unimagined economic hardship; think of the aftermaths of the 1973 and 1979 embargos lasting 10-20 years instead of the brief periods that were actually involved. Indeed, the rapid rise in world oil prices in the 2004-2005 period may likely appear modest in comparison to the price escalations that could accompany the peaking of world conventional oil production.

The world will thus be faced with a liquid fuel supply risk management problem beyond anything yet experienced by modern civilization. However, with adequate, timely mitigation, the worldwide economic costs of oil peaking can be minimized.

## THE ROLE OF EXPLORATION AND PRODUCTION TECHNOLOGIES

**Donald Paul, Vice President and Chief Technology Officer, Chevron Corporation**

The debate over the potential peaking of the world's conventional oil production takes on one of the most important questions being raised by governments, societies, and industries on a global scale. The success of the workshop was its embrace of the diversity of views on the issue. While all would agree on the inevitability that a maximum of both conventional oil production and ultimate recovery exists, the views on both the timing of the onset of the maximum and its magnitude are at significant variance.

I suggest that several key dimensions shape the debate and the major differences in positions being taken:

- The size of the total conventional oil "endowment";
- The role played by reserve additions and the potential for substantial increases in recovery factors;
- The scale of the opportunity for and effectiveness of major additions from frontier exploration;
- The growth capacity in OPEC production and the state of the reserves underpinning production;
- The scale and timing of significant additions from unconventional feedstock, such as GTL, oil sands, shale oil, coal, and biofuels;
- The timing, scale, and feasibility of the massive investment capital calls required; and
- The role that will be played by significant technological advances, as outlined in my presentation.

Here are some general comments on the discussion:

- Although the total energy system, including electric power production, is involved in the issue, the central issue is about fuel production capacity, not conventional oil production alone.
- The USGS study, arguably one of the most comprehensive reviews of global oil resources, estimates the endowment at about 3 trillion barrels. This is consistent with estimates by several of the largest global energy companies. In contrast, critics argue that the realizable endowment is significantly smaller, yielding a prediction of a much earlier and lower production maximum. The lynchpin of this debate centers on the effect of reserve additions and increases in recovery factors. History has shown that the industry, through continued technological advancement, has increased both.
- While there was relatively little discussion of frontier exploration, most global majors support the belief that opportunities for significant new finds are supported by geological knowledge. Critics argue that the past 20 or so years have shown this not to be the case. However, since the oil price collapse in

1986, the driving business force in the industry has been about consolidation, reserve conversion, and cost performance, not about major frontier exploration. The supporting R&D activities, with the notable exception of deepwater E&P, also reflected this business focus.

- One of the most significant wild cards is the size and timing of fuel production from unconventional resource conversion. While not directly addressing the issue of the peaking of conventional oil production, the role of synthetics could be critical in responding to the rising demand for fuel. While the scale of the potential resources are in the trillions of barrels equivalent, critics correctly point to the enormous challenges for technology, capital requirements, and perhaps most importantly, timing.
- The history of the industry and technology has always been to deliver lower capital and operating costs, extend access to new resources (e.g., deepwater and extra-heavy oil), and increase the recoveries from existing producing assets. Most in the industry do not believe we are anywhere near the end of this process. For example, the industry has always been at the forefront of applying advances in digital technology and this will continue as a new level of automation and robotics comes to the oil field. This will both increase overall recovery performance, but will expand opportunities by improving economic outcomes. The opportunity to ride the wave of advances in molecular science also bodes very well for our fuel supply diversification options as new resource conversion technologies are developed and applied at scale. The issues of timing, scale, and capital demands remain, but history is on the side of technology to enable solutions to even the most challenging problems.

I would like to thank Dr. Ramage and the organizing team for bringing together a very knowledgeable and diverse set of participants. I look forward to continuing to participate in the debate.

## THE ROLE OF HEAVY OIL IN THE PEAKING DEBATE: HOW MUCH, HOW FAST, HOW BEST?

**Robert F. Heinemann, President and CEO, Berry Petroleum Company**

All the participants in the peak oil debate appear to converge on the near-term challenge that 45 to 50 million bbl/day must be produced from new sources over the next 10 years. This challenge is extremely daunting and is based on relatively conservative projections of demand growth and base decline of existing fields. Heavy oil and bitumen production are expected to fill a considerable portion of this gap, because of the vast amount of resources available.

Enormous accumulations of heavy oil and bitumen exist around the globe. In-place estimates have been reported of up to 6 trillion bbl, with over 65 percent of this total located in the Western Hemisphere. Venezuela holds approximately 225 billion technically recoverable barrels in the Faja belt of the Orinoco. Canada has the largest bitumen resource estimated at about 525 billion technically recoverable barrels located in the Alberta tar sands. Applying more standard reserve definitions to these resources reduces the numbers to 77 billion bbl in Venezuela and 177 billion bbl in Canada. Both of these are truly significant when compared with Saudi Arabia's reserve estimate of 262 billion bbl. In fact, the heavy oil recoverable estimate of 1,085 billion bbl around the globe now exceeds the comparable light oil estimate of 965 billion bbl.

Global production of bitumen and heavy oil today totals about 3 million bbl/day. In addition to the mining of tar sands, there are four commercially proven technologies used today. Cyclic steam injection, steam flooding, and steam-assisted gravity drainage all use thermal injection to lower the viscosity of the hydrocarbons in situ and improve the displacement efficiency of these processes. Cold heavy oil production with sand is the fourth technology and involves the primary production of heavy oil and formation sand using progressive cavity pumps. To achieve higher recoveries, these techniques are being implemented with dense well spacing and complex horizontal and multilateral well architectures. While examples of recovery factors exceeding 50 percent in specific reservoirs are not uncommon, recovery estimates on a basin-wide average rarely exceed 20 percent.

Heavy oil production can increase over the next 10 years to about 6 to 7 million bbl/day and will therefore close about 10 to 15 percent of the production gap facing the world over this period. Given the enormity of the world's heavy oil and bitumen resources, these estimates are often viewed as conservative. However, the pace of heavy oil development faces a number of challenges, which include:

- Light oil production is more profitable for companies with diversified portfolios;
- Applicability of today's technology beyond the "best" reservoirs is unknown;
- Industry is currently experiencing capital, people, and equipment constraints;
- The political situation in Venezuela is uncertain; and
- Price volatility discourages sustained investment over the longer term.

## CANADIAN OIL SANDS: DEVELOPMENT AND FUTURE OUTLOOK

### Eddy Isaacs, Managing Director, Alberta Energy Research Institute

It is estimated that there are 8 to 9 trillion bbl of heavy oil and bitumen in place worldwide, of which potentially 900 billion bbl of oil are commercially exploitable with today's technology. Canada alone has 175 billion bbl of bitumen reserves that can be processed with today's technology, making it second only to Saudi Arabia in proven oil reserves in the world. It is important to assess what impact unconventional oil will have on the world oil supply and in what time frame.

The past 20 years have witnessed several major successes for the Canadian oil sands industry, all triggered by technological innovations. The current production of bitumen and synthetic crude oil from the Canadian Province of Alberta averages 1 million bbl/day, and oil sands production is expected to triple to 3 million bbl/day by 2018 and to 5 million bbl/day by 2030.

There are, however, constraints that, without new technology, could jeopardize the above growth scenario. There is an increasing cost for natural gas, currently the fuel of choice for steam generation, upgrading, heat, and power. There is a significant dependence on water used for separation of oil from the sand in surface mined operations and for in situ steam generation. In addition, the amount of energy required to produce a barrel of synthetic crude oil is about a third of the energy in a barrel of bitumen. This makes oil sands operations large single-source emitters of greenhouse gases.

Despite these challenges, several factors have made investments in oil sands very attractive given world oil prices above about $US 25 per bbl WTI (West Texas Intermediate crude oil). There are no "finding costs" since the oil sands are well delineated. There is ready access to the largest market in the world, the United States, via established pipelines.

While nonconventional oil is emerging as a new major source of oil, even an aggressive worldwide development scenario can only capture some 15 to 20 percent of the required new oil supply in the next 20 years. Thus, there is a growing recognition that solutions to the pressing global energy needs and challenges emerge when we understand the energy industry as one interconnected system, integrated horizontally along the various energy sources and vertically along the value chain. Strategic investment in a balanced portfolio of energy innovation—with a focus on common technology platforms and points of leverage across the portfolio—has the greatest potential for returns in economic, environmental, and social terms.

## THE POTENTIAL FOR OIL SHALE

### Stephen Mut, CEO, Shell Unconventional Resources Energy

Unconventional resources and especially oil shale are potentially strategic resources for the United States and the world. Oil shales are distributed around the world in over 20 countries, but by far the thickest and richest resources are in the United States in northwestern Colorado, eastern Utah, and southwestern Wyoming. According to DOE estimates, the Piceance Basin of Colorado contains approximately 1 trillion recoverable barrels of hydrocarbons locked up in the shale, roughly equivalent to all the combined proven conventional oil reserves in the world today. It is easy to see why there have been so many past attempts to unlock this potentially enormous resource.

Oil shale is a tight-grained rock, rich in solid organic matter called kerogen. It is an immature source rock that has not yet generated liquid hydrocarbons, but when heated over geological time, will yield liquid or gaseous hydrocarbons. With oil shale the challenge is not in finding the prize but in learning to produce it in an economical and environmentally acceptable way.

In Colorado, Shell is field testing a new technology, the In Situ Conversion Process (ICP), that accelerates the natural process of oil and gas maturation by literally tens of millions of years. ICP uses heaters drilled into the oil shale resource and slowly heats to over 500$^{o}$F over a 3- to 4-year period. It produces light hydrocarbon liquids and gases with almost no heavy ends, while leaving in the subsurface a char that is extremely hydrogen deficient. A freeze wall surrounding the heated zone is used for preventing water ingress and product containment. Shell is also field testing ICP in tar sands as well as in oil shale.

New technologies including ICP are advancing to the point that there is optimism that commercial oil shale production will become a reality. Tests being performed in Colorado are reducing the uncertainties associated with recovery efficiency, product composition, and energy balance. Shell hopes to be able to declare the process commercial by the end of the decade.

## PRODUCING LIQUID FUELS FROM COAL

### David Gray, Director of Energy Systems Analysis, Mitretek Systems

This presentation started by giving a brief overview of the technologies used for converting coal into high-quality liquid transportation fuels and the current status of both coal to liquids and gas to liquids. This mitigation option could improve energy security and would produce ultraclean liquid fuels that are compatible with the existing infrastructure. The barriers to deployment are mostly economic and environmental. It was estimated that the potential contribution worldwide of coal-to-liquids (CTL) technology in the year 2030 could be about 4 million bbl/day. When considering greenhouse gas emissions, CTL would have slightly higher carbon emissions than petroleum. In conclusion, it will be necessary in the future to develop alternatives to conventional petroleum when world demand outstrips supply, and gas to liquids (GTL) and CTL could be used as petroleum alternatives. The cost of production of clean liquid fuels from coal is estimated to be in the range of $30-$50/bbl COE depending on coal type, plant location, and actual capital cost. Therefore, continued high world oil prices above $50/bbl would make CTL an economically viable option in the United States and worldwide. Countries with large coal reserves and little domestic petroleum are candidates for using CTL to provide fuels to supplement conventional petroleum (China, India, the United States, Australia). Continued R&D and GTL and CTL deployment will improve the economics; however, government incentives will probably be necessary for the first plants to reduce risks for investors and to encourage commercial deployment.

## LIQUID FUELS FROM NATURAL GAS

### F. Emil Jacobs, Vice President, Research and Development, ExxonMobil Research and Engineering

Natural gas currently provides about 20 percent of the world's energy, and demand for it is expected to increase in response to growing environmental concerns. While the bulk of natural gas sales are based on direct domestic usage, pipelines, and liquid natural gas (LNG) supplies, new options for chemical conversion of gas to liquid fuels are starting to materialize.

Key ingredients for the successful commercialization of new gas to liquids (GTL) technologies include (1) access to a premier gas resource with sufficient reserves to provide for a 25+ year project life; (2) technically ready/economically viable technology for syngas production, Fischer-Tropsch synthesis, and wax upgrading; (3) ability to execute large-scale projects; (4) access to finance for multibillion dollar investments; and (5) global marketing capabilities to take full advantage of high-quality GTL products.

In considering the overall outlook for GTL and its ability to provide for future energy needs, there are several points to consider:

- While GTL volumes are expected to increase in coming years, it is worth noting that even with the more optimistic DOE Energy Information Administration commercialization scenarios, these projects will make up only ~1.7 percent of the world transport fuel market by 2025. Studies show that the most effective contribution of GTL fuels to future energy markets will be as a blendstock with more traditional streams, and industry is working toward that objective.
- GTL will likely be pursued as a gas monetization option in addition to gas pipeline and LNG projects. It will be limited to the largest gas resources where economy of scale benefits are available and will likely be utilized as part of an overall energy diversification strategy.
- Synthesis gas-based technologies, which utilize coal, residual oil, or biomass feedstocks, will extend the potential capacity for liquids production via the GTL technology platform. Pursuit of these alternatives will occur, and their ultimate success will be determined by the extent to which they can compete with conventional resources.

## LIQUID BIOFUELS FOR TRANSPORTATION

**Daniel Sperling, University of California, Davis**

Biofuels have four large attractions: they can be produced domestically, emit few greenhouse gases, are renewable, and can be used in today’s internal combustion engines with few modifications.

These attractions must overcome the challenges of scale and cost. The challenge is to reconcile large economies of scale in feedstock processing and fuel transport, with large diseconomies of scale in feedstock collection. Today’s liquid and gaseous fuel industries have squeezed costs by building on a huge scale—pipelines that transport tens and hundreds of thousands of barrels per day and refineries that process up to a million barrels per day. A biofuels industry by its nature will not have that structure or scale; it will be far more diffuse. Overall production potential will be limited by the difficulty of assembling large tracts of land to offset high feedstock collection costs and higher costs of fuel distribution.

The largest biofuels efforts are in Brazil, where sugar cane is converted to ethanol, and the United States, where corn is converted into ethanol. Each country produced about 150,000 gasoline-equivalent bbl/day in 2004—accounting for about 1.5 percent of U.S.

gasoline consumption. About 12 percent of U.S. corn production is required to produce this quantity of ethanol. Brazilian ethanol is competitive with oil at about $30-35 per barrel. Corn ethanol is somewhat more expensive.

A more land-efficient approach to producing liquid biofuels is to shift from food crops to lignicellulosic materials. The cellulose may be wood grown on tree plantations, high-yield grasses, or crop residues (such as corn stalks). With these higher yield materials, about 5 to 10 percent of all land in the United States' 48 states would be needed to produce about 30 percent of U.S. transport fuel. The new U.S. energy bill contains incentives for cellulosic fuels, and the scientific and engineering knowledge is at hand to create a cellulosic energy industry.

Cellulosic fuels are likely to have similar costs to corn ethanol but would use much less land and fossil energy and produce much fewer greenhouse gases. But where will the investment come from (given the relatively high costs), where is the political constituency that would support these risky investments, and how will the scale challenges be overcome?

## OPPORTUNITIES FOR REDUCING OIL DEMAND FOR TRANSPORTATION

**John B. Heywood, Director, Sloan Automotive Laboratory, Massachusetts Institute of Technology**

The worldwide demand for petroleum-based fuels—gasoline, diesel, jet fuel—is enormous. It is also growing at about 1.6 percent per year. In the United States, freight consumes about 40 percent of today's total, and air transport consumes just over 10 percent. Light-duty vehicles (cars, pickup trucks, SUVs, and vans) consume close to 50 percent of transportation fuels.

The technology used in today's light-duty vehicles continues to improve. Internal combustion engines, transmissions, and vehicles can be improved over time to give some 35 percent fuel consumption reduction in new vehicles in about 20 years, at an extra cost per vehicle of $500-$1,000. Hybrids can improve on this by 20 to 30 percent, at an additional cost of a few thousand dollars. Prospects for the diesel in the United States, attractive from a fuel consumption and $CO_2$ perspective, are uncertain due to the extremely stringent U.S. $NO_x$ and particulate standards, low U.S. fuel costs, and higher initial cost.

Longer-term transportation energy and greenhouse gas (GHG) reduction options may require more radical technology changes. Liquid fuels from oil sands, heavy oil, and GTL are likely to increase to about 10 percent of petroleum-based supplies over the next 25 years. Biomass-based fuels will probably add another 5 or so percent. Different vehicle concepts, with substantially reduced weight and size will likely be developed.

Fuel cell systems using hydrogen would result in more efficient vehicles than internal combustion engine (ICE)-based technology, but the energy lost and GHG emissions released in producing hydrogen from natural gas and other short-term options are significant and result in no overall benefit. Very low $CO_2$-emitting transportation systems in the longer term (30 to 50 years) might be achieved with fuel cells and hydrogen from non-$CO_2$ releasing sources. Electricity from renewables and nuclear with advanced battery electric vehicles are a potential alternative.

Reducing U.S. light-duty vehicles fleet fuel consumption substantially below the no-change continuing growth projection will take decades. Realizing as much as possible of the efficiency improvements that technology is likely to provide (especially with mainstream gasoline ICE vehicles) in on-the-road fuel consumption is critical to achieving real-world reductions in fleet petroleum consumption. Delays in realizing such on-the-road fuel consumption improvements would make future petroleum demand significantly higher. Due to constraints on the rate of buildup of new production capacity, low-emission diesels and hybrids will have only modest fleet improvement potential before about 2025.

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# Biographical Sketches

## WORKSHOP PLANNING GROUP

**Michael P. Ramage (NAE),** *Chair*, is retired executive vice president, ExxonMobil Research and Engineering Company. Previously he was director, executive vice president, and chief technology officer of Mobil Oil Corporation. He held a number of positions at Mobil, including manager of the Process Research and Development Division; general manager of Exploration and Production Research, Development, and Technical Services; vice president of Engineering; and president of Mobil Technology Company. He has broad experience in many aspects of the petroleum industry, including R&D, chemical processes, and capital project management. He is a director of the American Institute of Chemical Engineers. He has served on a number of university visiting committees and is a member of a number of professional societies. He recently served as chair of the NRC Committee on Alternatives and Strategies for Future Hydrogen Production and Use. He is a member of the National Academy of Engineering and serves on the NAE Council. He has B.S., M.S., and Ph.D. degrees in chemical engineering from Purdue University.

**David Greene** is a corporate fellow of Oak Ridge National Laboratory (ORNL). He has spent over 20 years researching transportation and energy policy issues. His research interests include energy demand modeling, economic analysis of petroleum dependence, modeling market responses to advanced transportation technologies and alternative fuels, economic analysis of policies to mitigate greenhouse gas emissions from transportation, and developing theory and methods for measuring the sustainability of transportation systems. Dr. Greene received a B.A. from Columbia University in 1971, an M.A. from the University of Oregon in 1973, and a Ph.D. in geography and environmental engineering from the Johns Hopkins University in 1978. After joining ORNL in 1977, he founded the Transportation Energy Group in 1980 and later established the Transportation Research Section in 1987. Dr. Greene spent 1988-1989 in Washington, D.C., as a senior research analyst in the Office of Domestic and International Energy Policy, U.S. Department of Energy (DOE). He has published over 150 articles in professional journals, contributions to books, and technical reports and has given Congressional testimony on transportation and energy issues. He has recently being doing analyses of future global supply and demand of oil and energy transition issues. From 1997 to 2000, Dr. Greene served as the first editor in chief of the *Journal of Transportation and Statistics*, the only scholarly periodical published by the U.S. Department of Transportation. He currently serves on the editorial boards of *Transportation Research D*, *Energy Policy*, *Transportation Quarterly*, and the *Journal of Transportation and Statistics*. Active in the Transportation Research Board (TRB) and the National Research Council, Dr. Greene has served on several standing and ad hoc committees. He is past chair and member emeritus of the TRB's Energy Committee, past chair of the Section on Environmental and Energy Concerns, and a recipient of the TRB's Pyke Johnson Award.

**Robert L. Hirsch** is a consultant with Science Applications International Corporation. His past positions include executive advisor to the president of Advanced Power Technologies, Inc.; vice president, Washington Office, Electric Power Research Institute; vice president and manager, Research and Technical Services Department, ARCO Oil and Gas Company; chief executive officer, ARCO Power Technologies, a company that he founded; manager, Baytown Research and Development Division, and general manager, Exploratory Research, Exxon Research and Engineering Company; assistant administrator for Solar, Geothermal, and Advanced Energy Systems (Presidential appointment); and director, Division of Magnetic Fusion Energy Research, U.S. Energy Research and Development Administration. He has served on numerous advisory committees, including as a member of the DOE Energy Research Advisory Board and a number of DOE national laboratory advisory boards. He has served on several NRC committees, including the one that wrote the report *Fuels to Drive Our Future*, which examined the economics and technologies for producing transportation fuels from U.S. domestic resources; was chairman of the Committee to Examine the Research Needs of the Advanced Extraction and Process Technology Program; was a member of the Committee on Alternatives and Strategies for Future Hydrogen Production and Use; and was a former chairman and member of the Board on Energy and Environmental Systems. He has recently been involved in analysis and studies of the various views of potential global oil production, peaking, and possible transitions to other sources of liquid fuels. He brings expertise in a number of areas of science, technology, and business related to oil and gas production, analysis of oil reserves and future oil production, other forms of energy production and consumption, research and development, and public policy. He received a Ph.D. in engineering and physics from the University of Illinois.

**Scott W. Tinker** is director, Bureau of Economic Geology, University of Texas, Austin; State Geologist of Texas; and Edwin Allday Endowed Chair of Subsurface Geology, Jackson School of Geosciences. Earlier, he held a number of positions at Marathon Oil–Petroleum Technology Center, rising to advanced senior geologist. He was also once a geologist at Union Pacific Resources and at Robert M. Sneider Exploration. He has extensive experience in the broad aspects of basic and applied energy and environmental research; in reservoir characterization studies of large hydrocarbon fields; and expertise in carbonate sedimentology, stratigraphy, three-dimensional reservoir modeling, and analysis and interpretation of diverse sets of geological, seismic, and engineering data. He serves on a wide variety of boards, committees, and organizations. He served as a distinguished lecturer for the Society of Petroleum Engineers (2002) and the American Association of Petroleum Geologists (AAPG) (1997) and is the current International Distinguished Ethics Lecturer for the AAPG. He is president elect of the American Association of State Geologists (2005), received distinguished service awards from the AAPG (2005) and the West Texas Geological Society (2001), and the Marathon Achievement of Company Excellence Award among others. He is a member of the NRC Board on Energy and Environmental Systems and served as chair, Committee on U.S. Natural Gas Demand and Supply Projections: A Workshop. He brings expertise on petroleum and natural gas resources and reserves, oil and gas technologies, reservoir characterization, and geological sciences to the planning group. He has a B.S. in geology and business administration, Trinity University; an M.S. in geological sciences, University of Michigan, Ann Arbor; and a Ph.D. in geological sciences, University of Colorado, Boulder.

## NRC STAFF

**James J. Zucchetto** is director, Board on Energy and Environmental Systems, National Research Council. Since joining the National Academies in 1985, Dr. Zucchetto has been involved in a variety of multidisciplinary studies related to energy technologies, engineering, the environment, research and development programs, and public policy. In his work at the NRC, he has contributed to numerous studies and reports having an important influence on federal programs and policies. Prior to joining the National Academies, he was on the faculty of Arts and Sciences, Department of Regional Science, University of Pennsylvania; a guest researcher at the Institute of Marine Ecology and Zoologiska Institutionen, University of Stockholm; an associate in engineering, Department of Environmental Engineering Sciences, University of Florida; and a member of the technical staff, Bell Telephone Laboratories. He serves on the editorial advisory board of the *International Journal of Ecological Modelling and Systems Ecology* and is a former member of the editorial advisory board of *Ecological Economics*. He has been involved in a wide variety of activities related to energy technologies and associated environmental, economic, and policy implications since the early 1970s and has published approximately 50 articles in refereed journals, books, and conference proceedings, two monographs, and one book. He has a Ph.D. in environmental engineering sciences from the University of Florida, an M.S.M.E. from New York University, and a B.S.M.E. from the Polytechnic Institute of Brooklyn (Polytechnic University).