UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

June 24, 2010

EPA-SAB-10-009

The Honorable Lisa P. Jackson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Advisory on EPA's Research Scoping Document Related to Hydraulic Fracturing

Dear Administrator Jackson:

EPA's Office of Research and Development (ORD) requested that the Science Advisory Board (SAB) review the Agency's draft research scoping document related to hydraulic fracturing. ORD developed this approach in response to the U.S. House of Representatives Fiscal Year 2010 Appropriation Conference Committee Directive to EPA that urged the Agency to conduct a study of hydraulic fracturing and its relationship to drinking water resources. ORD requested that SAB comment on: a) the scope of the research program; b) proposed research categories and topic areas, and processes for prioritizing research needs; and c) design of a stakeholder process that provides for balanced input. In response to ORD's advisory request, the SAB Environmental Engineering Committee (EEC) and additional members of the SAB met on April 7-8, 2010 to provide advice to ORD about this research plan and program. The Chartered SAB conducted a quality review of this document and approved the report on June 16, 2010 by teleconference. The enclosed advisory report (Enclosure C) provides the advice and recommendations of the Committee.

In general, the SAB found ORD's overall approach and scope for the hydraulic fracturing research plan and program appropriate and comprehensive. The systems and lifecycle perspectives described in the ORD research plan for study of the environmental impacts of hydraulic fracturing are appropriate. The SAB recommends that initial research be directed to study sources and pathways of potential impacts of hydraulic fracturing on water resources, especially potential drinking water sources, and that investigations eventually occur on the impact on water resources more generally. To support this effort, ORD should consider performing in-depth case studies at five to ten different locations selected to represent the full range of regional variability of hydraulic fracturing across the nation. The SAB also recommends that ORD emphasize human health and environmental concerns specific to or significantly influenced by hydraulic fracturing rather than on concerns common to all oil and gas production activities.

Finally, the SAB recommends developing a balanced, collaborative advisory group of stakeholders representing a broad range of perspectives, and engaging with this stakeholder group throughout the research process. ORD should carefully design and clearly communicate the objectives and process for stakeholder engagement with the research.

The SAB appreciates the opportunity to provide EPA with advice on this important subject. We look forward to receiving the Agency's response and potential future discussions with the Agency.

Sincerely,

/Signed/

Dr. Deborah L. Swackhamer, Chair
EPA Science Advisory Board

/Signed/

Dr. David A. Dzombak, Chair
SAB Environmental Engineering Committee

Enclosures:

A) Roster: SAB Environmental Engineering Committee (EEC) Augmented for the Advisory on EPA's Research Scoping Document Related to Hydraulic Fracturing

B) Roster: EPA Science Advisory Board

C) Advisory Report on EPA's Research Scoping Document Related to Hydraulic Fracturing

NOTICE

This report has been written as part of the activities of the EPA Science Advisory Board, a public advisory committee providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names or commercial products constitute a recommendation for use. Reports of the EPA Science Advisory Board are posted on the EPA Web site at: http://www.epa.gov/sab.

Enclosure A
U.S. Environmental Protection Agency
Science Advisory Board
SAB Environmental Engineering Committee (EEC) Augmented for the Evaluation and Comment on EPA's Proposed Research Approach for Studying the Potential Relationships Between Hydraulic Fracturing and Drinking Water Resources

CHAIR

Dr. David A. Dzombak, Walter J. Blenko Sr. Professor of Environmental Engineering, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA

EEC MEMBERS

Dr. Viney Aneja, Professor, Department of Marine, Earth, and Atmospheric Sciences, School of Physical and Mathematical Sciences, North Carolina State University, Raleigh, NC

Dr. Robin L. Autenrieth, Associate Dean for Graduate Programs and Professor, College of Engineering, Texas A&M University, College Station, TX

Dr. John P. Connolly, Senior Technical Advisor and Principal Engineer, Anchor QEA, LLC, Montvale, NJ

Dr. Herschel Elliott, Professor, Department of Agricultural and Biological Engineering, Penn State University, University Park, PA

Dr. Arpad Horvath, Associate Professor, Department of Civil and Environmental Engineering, University of California, Berkeley, CA

Dr. Cindy M. Lee, Professor, Department of Environmental Engineering and Earth Sciences, Clemson University, Anderson, SC

Dr. Earthea Nance, Assistant Professor of Environmental Planning and Hazard Mitigation, Department of Planning and Urban Studies, University of New Orleans, New Orleans, LA

Dr. Catherine Peters, Associate Professor, Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ

Dr. Danny Reible, Professor, Department of Civil, Architectural and Environmental Engineering, University of Texas, Austin, TX

Dr. Sujoy Roy, Director, Research and Development, Tetra Tech Inc., Lafayette, CA

Dr. Mark A. Shannon, Professor, and Director, the WaterCAMPWS Center, Department of Mechanical Science and Engineering, University of Illinois, Urbana-Champaign, Urbana, IL

Dr. Paul Westerhoff, Professor and Director of the School of Sustainable Engineering and The Built Environment, Arizona State University, Tempe, AZ

Dr. Thomas M. Young, Professor, Department of Civil & Environmental Engineering, University of California-Davis, Davis, CA

OTHER SAB MEMBERS

Dr. Jeffrey Griffiths, Associate Professor, Department of Public Health and Community Medicine, School of Medicine, Tufts University, Boston, MA

Dr. Susan Korrick, Assistant Professor of Medicine, Department of Medicine, Brigham and Women's Hospital, Channing Laboratory, Harvard Medical School, Boston, MA

Dr. Duncan Patten, Research Professor, Hydroecology Research Program, Land Resources and Environmental Sciences, Montana State University, Bozeman, MT

Dr. James Shortle, Professor, Agricultural Economics and Rural Sociology, Pennsylvania State University, University Park, PA

SCIENCE ADVISORY BOARD STAFF

Mr. Edward Hanlon, Designated Federal Officer, U.S. Environmental Protection Agency, Science Advisory Board Staff, Washington, DC

Enclosure B
U.S. Environmental Protection Agency
Science Advisory Board

CHAIR

Dr. Deborah L. Swackhamer, Professor and Charles M. Denny, Jr., Chair in Science, Technology and Public Policy and Co-Director of the Water Resources Center, Hubert H. Humphrey Institute of Public Affairs, University of Minnesota, St. Paul, MN

SAB MEMBERS

Dr. David T. Allen, Professor, Department of Chemical Engineering, University of Texas, Austin, TX

Dr. Claudia Benitez-Nelson, Associate Professor, Department of Earth and Ocean Sciences and Marine Science Program, University of South Carolina, Columbia, SC

Dr. Timothy Buckley, Associate Professor and Chair, Division of Environmental Health Sciences, College of Public Health, The Ohio State University, Columbus, OH

Dr. Thomas Burke, Professor, Department of Health Policy and Management, Johns Hopkins Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD

Dr. Deborah Cory-Slechta, Professor, Department of Environmental Medicine, School of Medicine and Dentistry, University of Rochester, Rochester, NY

Dr. Terry Daniel, Professor of Psychology and Natural Resources, Department of Psychology, School of Natural Resources, University of Arizona, Tucson, AZ

Dr. George Daston, Victor Mills Society Research Fellow, Product Safety and Regulatory Affairs, Procter & Gamble, Cincinnati, OH

Dr. Costel Denson, Managing Member, Costech Technologies, LLC, Newark, DE

Dr. Otto C. Doering III, Professor, Department of Agricultural Economics, Purdue University, W. Lafayette, IN

Dr. David A. Dzombak, Walter J. Blenko Sr. Professor of Environmental Engineering , Department of Civil and Environmental Engineering, College of Engineering, Carnegie Mellon University, Pittsburgh, PA

Dr. T. Taylor Eighmy, Vice President for Research, Office of the Vice President for Research, Texas Tech University, Lubbock, TX

Dr. Elaine Faustman, Professor, Department of Environmental and Occupational Health Sciences, School of Public Health and Community Medicine, University of Washington, Seattle, WA

Dr. John P. Giesy, Professor and Canada Research Chair, Veterinary Biomedical Sciences and Toxicology Centre, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

Dr. Jeffrey Griffiths, Associate Professor, Department of Public Health and Community Medicine, School of Medicine, Tufts University, Boston, MA

Dr. James K. Hammitt, Professor, Center for Risk Analysis, Harvard University, Boston, MA

Dr. Rogene Henderson, Senior Scientist Emeritus, Lovelace Respiratory Research Institute, Albuquerque, NM

Dr. Bernd Kahn, Professor Emeritus and Associate Director, Environmental Radiation Center, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA

Dr. Agnes Kane, Professor and Chair, Department of Pathology and Laboratory Medicine, Brown University, Providence, RI

Dr. Nancy K. Kim, Senior Executive, New York State Department of Health, Troy, NY

Dr. Catherine Kling, Professor, Department of Economics, Iowa State University, Ames, IA

Dr. Kai Lee, Program Officer, Conservation and Science Program, David & Lucile Packard Foundation, Los Altos, CA (Organizational affiliation provided for identification purposes only)

Dr. Cecil Lue-Hing, President, Cecil Lue-Hing & Assoc. Inc., Burr Ridge, IL

Dr. Floyd Malveaux, Executive Director, Merck Childhood Asthma Network, Inc., Washington, DC

Dr. Lee D. McMullen, Water Resources Practice Leader, Snyder & Associates, Inc., Ankeny, IA

Dr. Judith L. Meyer, Distinguished Research Professor Emeritus, Odum School of Ecology, University of Georgia, Lopez Island, WA

Dr. Jana Milford, Professor, Department of Mechanical Engineering, University of Colorado, Boulder, CO

Dr. Christine Moe, Eugene J. Gangarosa Professor, Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, GA

Dr. Eileen Murphy, Manager, Division of Water Supply, New Jersey Department of Environmental Protection, Trenton, NJ

Dr. Duncan Patten, Research Professor, Hydroecology Research Program , Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT

Dr. Stephen Polasky, Fesler-Lampert Professor of Ecological/Environmental Economics, Department of Applied Economics, University of Minnesota, St. Paul, MN

Dr. Stephen M. Roberts, Professor, Department of Physiological Sciences, Director, Center for Environmental and Human Toxicology, University of Florida, Gainesville, FL

Dr. Amanda Rodewald, Associate Professor, School of Environment and Natural Resources, The Ohio State University, Columbus, OH

Dr. Joan B. Rose, Professor and Homer Nowlin Chair for Water Research, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI

Dr. Jonathan M. Samet, Professor and Flora L. Thornton Chair, Department of Preventive Medicine, University of Southern California, Los Angeles, CA

Dr. James Sanders, Director and Professor, Skidaway Institute of Oceanography, Savannah, GA

Dr. Jerald Schnoor, Allen S. Henry Chair Professor, Department of Civil and Environmental Engineering, Co-Director, Center for Global and Regional Environmental Research, University of Iowa, Iowa City, IA

Dr. Kathleen Segerson, Professor, Department of Economics, University of Connecticut, Storrs, CT

Dr. V. Kerry Smith, W.P. Carey Professor of Economics , Department of Economics , W.P Carey School of Business , Arizona State University, Tempe, AZ

Dr. Herman Taylor, Director, Principal Investigator, Jackson Heart Study, Jackson, MS

Dr. Barton H. (Buzz) Thompson, Jr., Robert E. Paradise Professor of Natural Resources Law at the Stanford Law School and Perry L. McCarty Director, Woods Institute for the Environment, Stanford University, Stanford, CA

Dr. Paige Tolbert, Professor and Chair, Department of Environmental Health, Rollins School of Public Health, Emory University, Atlanta, GA

Dr. Thomas S. Wallsten, Professor and Chair, Department of Psychology, University of Maryland, College Park, MD

Dr. Robert Watts, Professor of Mechanical Engineering Emeritus, Tulane University, Annapolis, MD

SCIENCE ADVISORY BOARD STAFF

Dr. Angela Nugent, Designated Federal Officer, 1200 Pennsylvania Avenue, NW 1400F, Washington, DC, Phone: 202-343-9981, Fax: 202-233-0643, (nugent.angela@epa.gov)

Enclosure C
Advisory Report on EPA's Research Scoping Document Related to Hydraulic Fracturing

A. EXECUTIVE SUMMARY

EPA's Office of Research and Development (ORD) has developed a proposed approach for a policy-relevant research program related to hydraulic fracturing. The purpose of this research program is to ensure drinking water protection and address related public health and environmental issues over the lifecycle of hydraulic fracturing, specifically as it pertains to the extraction of oil and gas from geologic formations. ORD developed this approach in response to the U.S. House of Representatives Fiscal Year 2010 Appropriation Conference Committee Directive to EPA that urged the Agency to conduct a study of hydraulic fracturing and its relationship to drinking water.

In response to a request from ORD, the EPA Science Advisory Board (SAB) convened the Environmental Engineering Committee (EEC) with additional members of the SAB to conduct a review of ORD's research scoping document related to hydraulic fracturing. The SAB Committee held a public meeting on April 7-8, 2010, to provide advice to ORD about this research plan and program. The Chartered SAB conducted a quality review of this document and approved the report on June 16, 2010 by teleconference.

Specifically the SAB was asked to comment on the following three areas:

- Scope of the research program;
- Proposed research categories and topic areas, and process for prioritizing research needs given the Congressional request and a desire by the Agency to complete initial research products by the end of calendar year 2012; and
- Design of a stakeholder process that provides for balanced input.

In general, the SAB found ORD's overall approach and scope for the hydraulic fracturing research plan and program appropriate and comprehensive. Several areas, however, can be enhanced and focused, given the limited funding, resources and time associated with this effort. While a more detailed description of the technical recommendations is contained in the report, the key points and recommendations are highlighted below.

The SAB discussed the hydraulic fracturing topic on two levels: (1) broad, long-term research goals (e.g., within five to ten years or longer), and (2) more focused, short-term research needs (e.g., within one to three years). The SAB concluded that hydraulic fracturing potentially affects water resources and drinking water supplies and has potential to pose human health and environmental risks. While there is potential for other environmental impacts and human exposure routes for contaminants associated with hydraulic fracturing, such as air emissions and occupational exposures to fracturing fluids or wastes, considering the Congressional request and a desire by the Agency to complete initial research products by the end of calendar year 2012, the SAB recommends that initial, short-term research be directed to study sources and pathways of potential impacts of hydraulic fracturing on water resources, especially potential drinking water sources. While current and potential impacts on human health and drinking water sources are a recommended starting point/priority for ORD research, investigations should eventually occur on the impact on water resources more generally and their aquatic ecosystems and ability to support fishing and recreation.

The systems and lifecycle perspectives described in the ORD research plan for study of the environmental impacts of hydraulic fracturing are appropriate. Considering the limited time, funding and resources available for the initial study by ORD, the SAB recommends using a lifecycle framework, without actually performing a formal lifecycle assessment, as an organizing tool that will facilitate identifying the most important research questions to address in the initial study. Questions pertaining to the impacts of the various stages of the hydraulic fracturing lifecycle on drinking water sources will be of primary importance and consistent with the research request from Congress.

ORD should identify knowledge gaps by outlining the hydraulic fracturing lifecycle and considering which components of the lifecycle pose potential risk to water resources and should be included in ORD's research efforts. The SAB recommends that ORD should emphasize human health and environmental concerns that are specific to or significantly influenced by hydraulic fracturing rather than concerns that are common to all oil and gas production activities. As a priority, ORD should develop a preliminary risk-based research prioritization approach that would provide the scientific knowledge necessary for characterizing the risk of human and ecological exposure to hydraulic fracturing fluids and products. This approach would be adjusted after sources and pathways of possible exposure are much better understood.

Regarding potential relationships of hydraulic fracturing to drinking water sources, the SAB recommends that ORD carefully compile and review available data and knowledge on hydraulic fracturing and interaction with drinking water sources in peer-reviewed literature, in industry, in professional and non-governmental organizations, and in government agencies at the beginning of the research study. It is important to realize that the open peer-reviewed literature in this field is limited and other literature must be carefully critiqued regarding its limitations and appropriateness for addressing ORD's specific research needs. These efforts will help ensure accurate identification of data and knowledge gaps, maximize use of existing information, and optimize use of limited research funds. Considering the range of potential environmental impacts associated with hydraulic fracturing and the range of geographic/geologic regions and site-specific conditions in which hydraulic fracturing may be implemented, the SAB recommends that ORD consider performing in-depth case studies at five to ten different locations selected to represent the full range of regional variability of hydraulic fracturing across the nation. In order to define relationships between hydraulic fracturing processes and drinking water sources, significantly improved data and information are needed on the occurrence, volume, composition, treatability and/or disposal of hydraulic fracturing source fluids, flowback water, and produced water that is co-mingled with the flowback water, and the sources of the constituents (i.e., additive, reaction product, or leaching product) throughout different phases of the hydraulic fracturing lifecycle.

Regarding potential health and environmental risks associated with hydraulic fracturing, EPA can only assess and characterize such potential risks after sources and pathways of possible exposure are much better understood. Several activities must occur before such potential risks are assessed, including: a) characterization of the composition and variability of the source fluids, flowback water and produced water that is co-mingled with the flowback water; b) assessment of possible synergistic effects of mixtures of chemicals in fracturing fluids as well as synergistic effects of chemical mixtures interacting with materials in the fractured injection zone; c) evaluation of potential pathways to human and ecosystem exposure under a range of hydraulic fracturing process conditions relative to different geological formations and conditions; d) analysis of the existence and formation of hydraulic fracturing injection and product fluid transport pathways as a result of hydraulic fracturing; and e) identification of the conditions most likely to lead to impacts on drinking water resources. Another important factor to assess is the effect of hydraulic fracturing processes on water quantity, since changes in water quantity in groundwater or surface water can have significant influences on human and ecosystem health. Also, potential secondary effects associated with hydraulic fracturing should be considered (e.g., arsenic mobilization in groundwater and aquifers due to enhanced methane transport and resulting changes in redox conditions).

Knowledge of the characteristics of the injected fluids, flowback water, and produced water that is co-mingled with the flowback water, the reactions that occur in the injection zone, the characteristics of the fluids leaving the injected zone, and the pathways for the fluids leaving the injection zone will be needed for assessing the likelihood of impacts on human health and drinking water sources, exposure of humans and ecosystems to hydraulic fracturing fluids and products, and the associated uncertainties involved in the assessment.

To help ORD prioritize the lists of possible specific research questions given in the scoping document, the SAB recommends that ORD identify a few overarching, fundamental questions which can then be placed in order of priority before revising the research plan. Examples of such questions would be: what are the fundamental physical and chemical water-related processes for each phase of the hydraulic fracturing lifecycle and what are the quality and quantity of source fluids, flowback water and produced water co-mingled with the flowback water. The SAB developed additional examples which are presented in the report.

The SAB recommends developing a balanced, collaborative advisory group of stakeholders representing a broad range of perspectives. In addition to providing information to ORD, the stakeholder group would be engaged throughout the research process. ORD should carefully design and clearly communicate the objectives and process for stakeholder engagement with the research. One important objective for engagement with stakeholders should be to gain access to and leverage the existing knowledge base on hydraulic fracturing and its environmental impacts. There is a wealth of data and experience in industry, advocacy groups, state agencies, and other groups for ORD to draw upon in the research effort. It will also be important for ORD to engage with other federal agencies to share data, collaborate, leverage expertise, and align research priorities for optimal use of limited resources.

B. EPA's CHARGE TO THE COMMITTEE

Background

In its Fiscal Year 2010 Appropriation Conference Committee Directive to EPA, the U.S. House of Representatives urged the Agency to conduct a study of hydraulic fracturing and its relationship to drinking water, specifically:

> *"The conferees urge the Agency to carry out a study on the relationship between hydraulic fracturing and drinking water, using a credible approach that relies on the best available science, as well as independent sources of information. The conferees expect the study to be conducted through a transparent, peer-reviewed process that will ensure the validity and accuracy of the data. The Agency shall consult with other Federal agencies as well as appropriate State and interstate regulatory agencies in carrying out the study, which should be prepared in accordance with the Agency's quality assurance principles."*

Hydraulic fracturing (HF) is a well stimulation technique used by gas producers to explore and produce natural gas from sources such as coalbed methane and shale gas formations. The gas extraction process includes: site exploration, selection and preparation; equipment mobilization-demobilization; well construction and development; mixing and injecting fracturing fluids; hydraulic fracturing of the formation; produced water and waste management, transport, treatment, and/or disposal; gas production (infrastructure for storage and transportation); and site closure.

EPA's Office of Research and Development (ORD) prepared the "Scoping Materials for Initial Design of EPA Hydraulic Fracturing Research Study" document, and requested that the Science Advisory Board (SAB) Environmental Engineering Committee (EEC) review this document and generate ideas/suggestions on ORD's proposed approach for developing a policy-relevant research program related to hydraulic fracturing. The purpose of the study is to evaluate the relationship between hydraulic fracturing and drinking water. ORD noted that socio-economic factors may also play a role in understanding how to address potential health and environmental concerns. To ensure that meaningful results are produced in a timely manner, ORD recognized the importance of clarifying the overall scope of the study, defining explicit short-term and long-term goals, and considering the types of information that might be needed to inform policy decisions. ORD is currently engaged in compiling available information; identifying data gaps and research needs; defining and prioritizing study objectives; and developing a timeline to implement the study. An important part of this effort will be stakeholder involvement.

Specific Request

ORD has requested that the SAB Environmental Engineering Committee (EEC), as augmented for the hydraulic fracturing review, generate ideas/suggestions and comments on the overall approach that will be used to frame the hydraulic fracturing study design and the areas that will be addressed by research. ORD is seeking specific advice on the development of the scope of the study, the approach to analyze data gaps and research needs, the stakeholder process, and the identification of the critical research questions. SAB feedback will be used to guide the development of a scientifically sound study to establish the relationship between drinking water resources and hydraulic fracturing as it pertains to the extraction of oil and gas from geologic formations.

Charge to SAB

1. **Proposed Scope of Study:**

Congress urged EPA to carry out a study on "the relationship between hydraulic fracturing and drinking water." Key to determining the scope of the study is understanding whether or not the scope of the study should be narrowly focused or broadly focused, taking into account water resources and related public health and environmental issues over the lifecycle of hydraulic fracturing.

Charge Question 1: What recommendations does the SAB EEC have regarding this question of scope?

2. **Proposed Research Topics:**

ORD has identified the following proposed research categories relevant to hydraulic fracturing pertaining to extraction of oil and gas from geologic formations and its relationship to drinking water:

- Characterization of the Hydraulic Fracturing Lifecycle
- Potential Relationships to Drinking Water Resources
- Potential Health and Environmental Risks.

Charge Question 2A: What recommendations does the SAB EEC have regarding these proposed research categories and the related questions in the scoping paper?

Charge Question 2B: What process does the SAB EEC suggest for prioritizing research needs given the Congressional request and a desire by the Agency to complete initial research products by the end of calendar year 2012?

3. **Stakeholder Process:**

It will be critical to engage the stakeholder community in the planning process to establish a research program that is reflective of diverse interests and viewpoints.

Charge Question 3: What advice does the SAB EEC offer for designing a stakeholder process that provides for balanced input in developing a sound scientific approach for the overall research strategy?

C. RESPONSE TO THE CHARGE

The EEC reviewed the Scoping Materials document and background materials provided by ORD, and considered public comments and oral statements that were received. The cover letter highlights the outcome of the SAB's deliberations and the recommendations, and the following Response to the Charge Questions provides details regarding these recommendations.

Charge Question 1: What recommendations does the EPA EEC have regarding the question of scope?

The SAB generally supports ORD's approach for this research, and recommends that ORD should follow a systems perspective, use a lifecycle framework, and address science issues before conducting detailed economic analyses. SAB also has several recommendations for adjusting the scope of ORD's research program, including the development of plans that address both short-term and long-term research needs and goals, use a lifecycle framework without actually performing a lifecycle assessment, and focus on fundamental topics that will be relevant to policy formulation and on environmental concerns related to hydraulic fracturing rather than on concerns common to all oil and gas production activities.

The SAB discussed the hydraulic fracturing topic on two levels: (1) broad, long-term research needs/ideals (e.g., within five to ten years or longer), and (2) more focused, short-term research goals (e.g., within one to three years). The SAB concluded that hydraulic fracturing potentially affects water resources and drinking water supplies, and has potential to pose human health and environmental risks. Considering the Congressional request and a desire by the Agency to complete initial research products by the end of calendar year 2012, the SAB recommends that initial, short-term research be directed to study sources and pathways of potential impacts of hydraulic fracturing on water resources, especially drinking water sources. While current and potential human health and drinking water sources are a recommended starting point/priority for ORD research, investigations should eventually occur on the impact on water resources more generally, and their aquatic ecosystems and ability to support fishing and recreation. Regarding long-term research goals, since the behavior of hydraulic fractures in geologic formations is not well understood, EPA should plan for the potential of a long term involvement in this research program.

ORD has interpreted the charge to investigate "the relationship between hydraulic fracturing and drinking water" with a systems perspective, and developed a research plan with a related broad scope. The SAB EEC supports the systems perspective reflected in the ORD research plan. Environmental science has been moving toward analysis that encompasses larger-scale systems, such as at watershed scale, in order to account for the inter-relationships that ultimately determine ecosystem health and hence the health of human communities that depend on these ecosystems. There is now widespread recognition that focusing too narrowly in assessing impacts of activities can lead to incomplete understanding of ecosystem inter-relationships and health.

The use of a lifecycle framework to plan a research study on the potential human health and environmental impacts of hydraulic fracturing is appropriate. However, a formal lifecycle assessment does not necessarily need to be undertaken. It would be useful to develop initially a lifecycle framework analysis (LCF) that is a detailed outline of the components of the hydraulic fracturing lifecycle. The LCF would identify the components that would be included in a lifecycle assessment and would help identify critical knowledge gaps and topics for priority investigation. Considering the time and resources available for the initial study by ORD, the SAB recommends use of a lifecycle framework, without actually performing a lifecycle assessment, to identify the most important research questions to address in the initial study. Questions pertaining to the impacts of the various stages of the hydraulic fracturing lifecycle on drinking water sources will be of primary importance and consistent with the research request from Congress.

Economic analyses such as cost-benefit analysis are not included in the ORD research plan. The SAB supports the omission of such analysis from the ORD research plan for this initial study. There are a number of first-order science issues that need to be addressed first.

The ORD research plan has been formulated in part by the goal of conducting policy-relevant research. While it is difficult to predict which scientific results will be of greatest use to EPA and other government agencies when they establish policies and regulations in the future, the SAB believes that the research plan includes topics that will be relevant to policy formulation.

The SAB believes that ORD should emphasize human health and environmental concerns that are specific to or significantly influenced by hydraulic fracturing rather than on concerns that are common to all oil and gas production activities. For example, management of produced water is a concern of all oil and gas production activities but hydraulic fracturing may influence the quantity and quality of produced water and the ORD research plan should address those influences.

Charge Question 2A: What recommendations does the SAB EEC have regarding these proposed research categories and the related questions in the scoping paper?

SAB has several recommendations regarding ORD's proposed research categories. Regarding characterization of the hydraulic fracturing lifecycle, the SAB concluded that the use of a lifecycle framework is appropriate as an organizing tool which will facilitate identifying the most important research questions to address in the initial study. SAB recommends that ORD identify appropriate boundaries for the assessment, and focus initially on human health and ecological drinking water issues before eventually investigating the impact on water resources more generally. Regarding potential relationships to human health and drinking water sources, SAB recommends that ORD consider performing case studies at five to ten different locations selected to represent the full range of regional variability across the nation. Improved data and information are also needed on hydraulic fracturing source fluids, flowback water and produced water that is co-mingled with the flowback water. After compiling and reviewing available data and knowledge, ORD should identify how to best address any potential problems identified through this effort, such as water treatability issues, applicability of emerging treatment technologies, methods for recycling flowback water, and accidental releases. Potential health and environmental risks should only be assessed after sources and pathways of possible exposure are much better understood. ORD should consider the cumulative impacts that additional uses of water resources have on water quality and quantity in water resource systems where hydraulic fracturing activities are occurring or are being considered before identifying the exposure routes likely to pose the greatest human health risk.

Characterization of the Hydraulic Fracturing Lifecycle

The development and use of a lifecycle framework to plan a research study on the environmental impacts of hydraulic fracturing is appropriate as an initial step. Lifecycle assessment (LCA) is a formal process for which the International Organization for Standardization developed an international standard, ISO 14040. However, a formal LCA does not necessarily need to be undertaken in this case. A full LCA for the U.S. hydraulic fracturing industry would be a complex undertaking, consider various spatial and temporal factors including the different media (e.g., air, groundwater, surface water, soil, sediment) that may be affected by hydraulic fracturing activities, and require significant time to complete. A lifecycle framework (LCF) analysis would provide a detailed outline of the components of a hydraulic fracturing LCA, and help focus efforts towards critical knowledge gaps and topics for priority investigation.

The LCF should be developed after ORD carefully compiles and reviews data and knowledge available in the peer-reviewed literature, in industry, in professional and non-governmental organizations, and in government agencies to ensure accurate identification of data gaps. It is important to realize that the open peer-reviewed literature in this field is limited and other literature must be carefully critiqued regarding its limitations and appropriateness for addressing ORD's specific research needs. ORD should also discuss the LCA framework with economists to help ensure that economic factors are properly considered in the development of potential components of a hydraulic fracturing LCA.

To the extent possible, in order to avoid duplicative research and focus on the Congressional request, the research plan and LCF analysis should focus on issues that are uniquely associated with or significantly influenced by hydraulic fracturing, including both conventional and unconventional impacts that could occur at any point in the hydraulic fracturing lifecycle. However, it will be difficult to separate some issues associated with conventional oil and gas production in the evaluation of hydraulic fracturing and movement of chemicals through fissures in interconnected geological formations.

Development of a lifecycle framework for hydraulic fracturing can help EPA ORD prioritize knowledge gaps and decide what to study. In developing the lifecycle framework, ORD must identify appropriate boundaries for the assessment in order to help inform and focus the hydraulic fracturing research planning. An important boundary issue is where to draw the line between hydraulic fracturing-specific questions and questions pertaining to all oil and gas production operations. With definition of such boundaries, LCF can be used to separate conventional, well-understood issues (potentially including impacts of site development, road construction, and trucking) from impacts that are not well understood, such as fate of chemicals in source fluids, flowback water and produced water that is co-mingled with the flowback water in storage ponds. Quantitative differences should be considered as possible factors distinguishing unconventional oil and gas hydraulic fracturing support activities from similar activities with conventional oil and gas projects. LCF will be useful in identifying cumulative risks from both conventional and unconventional practices throughout the hydraulic fracturing lifecycle. Boundary definition should also be guided by considering the types of comparisons that EPA or others may wish to undertake in the future, such as comparison of hydraulic fracturing impacts with those of other gas or energy production processes.

In developing the LCF, it will be necessary to think about the desired functional unit (e.g., single well, a multi-well pad, geological unit, or a watershed), the desired time horizon, and the most appropriate metrics (e.g., water use per unit of gas produced, total volume of water use for a region or watershed, number of conventional wells avoided each meter of horizontal drilling, mass of additives per unit of gas produced, greenhouse gas emissions per unit of gas produced). When choosing boundaries, time horizons, functional units, and metrics, EPA should acknowledge and recognize the degree to which such choices would address certain positive and negative impacts of hydraulic fracturing technology in the study and the degree to which such choices may preclude addressing certain impacts.

An additional boundary ORD should consider when developing the LCF is identification of the major threats to drinking water from hydraulic fracturing operations. For example, if Total Dissolved Solids (TDS), naturally occurring radioactive materials (NORM), and/or some specific toxic compounds are identified as the most significant threats to drinking water from hydraulic fracturing operations, it may be useful to set short-term research priorities that focus on such contaminants.

While there are multiple environmental impacts that could be associated with hydraulic fracturing, water issues are central and are the focus of the Congressional request for the research study. Because drinking water may be connected to many other water sources, water resources should be the central theme for the lifecycle framework development. Evaluation of the lifecycle assessment should be aimed at identifying knowledge gaps relevant to managing impacts on current and potential future drinking water sources and systems, and prioritizing these knowledge gaps for research. Although current and potential drinking water sources are a recommended starting point/priority for ORD research, the impact on water resources more generally, and their aquatic ecosystems and ability to support fishing and recreation, should eventually be investigated.

<u>Potential Relationships to Drinking Water Sources</u>

ORD should carefully compile and review available data and knowledge on hydraulic fracturing and interaction with drinking water resources in the peer-reviewed literature, in industry, in professional and non-governmental organizations, and in government agencies at the beginning of the research study. The analysis of this data should appropriately consider quality assurance/quality control requirements associated with the data. These efforts would help ensure accurate identification of data and knowledge gaps, maximize use of existing information, and optimize use of limited research funds. When compiling information on current and potential future drinking water sources, the definition of drinking water source should be broad, because some surface waters and deep aquifers bodies not currently considered drinking water sources will likely be viewed as such in the future. For example, some water supply utilities have conducted aquifer storage and recovery projects in which freshwater is pumped into highly mineralized aquifers not currently considered drinking water sources for storage and recovered later. The injected freshwater "bubble" is physically separated from the mineralized water due to hydraulic displacement and water density differences.

This compilation and review of existing data and knowledge will need to be conducted with critical evaluation of the quality and relevance of the information. For example, some previous studies on hydraulic fracturing were conducted for different purposes such as optimizing gas extraction efficiency, and the data collected and presented in this context are not likely to be sufficient for understanding solute generation or migration. It is important to engage the current state of oil and gas engineering and science to identify and evaluate existing knowledge and pertinent data. It is also important to realize that the open peer-reviewed literature in this field is limited and other literature must be carefully critiqued regarding its limitations and appropriateness for addressing ORD's specific research needs.

Knowledge of the characteristics of the injected fluids, flowback water, and produced water that is co-mingled with the flowback water (e.g., physical/chemical properties), the reactions that occur in the injection zone, the characteristics of the fluids leaving the injected zone, and the pathways for the fluids leaving the injection zone will be needed for assessing impacts on water resources, exposure of humans and ecosystems to hydraulic fracturing fluids and products, and the associated uncertainties involved in the assessment. Regarding the characteristics of the injected fluids, the research program should particularly identify the most toxic chemicals commonly used as injection fluids.

Considering the range of potential environmental impacts associated with hydraulic fracturing and the range of geographic/geologic regions and site-specific conditions in which hydraulic fracturing may be implemented, it will be difficult to study hydraulic fracturing with sufficient depth and breadth for the allotted time and budget of the research study. ORD should identify reasonable short term goals and accomplishments (e.g., within one to three years) and long term goals and accomplishments (e.g., within five to ten years or longer) for this research.

The research planning team should consider performance of in-depth case studies at five to ten different locations selected to represent the full range of regional variability across the nation. ORD has used the in-depth case study approach successfully in other multi-objective research programs, such as in the Arsenic Removal Technology Demonstration Program and in the Superfund Innovative Technology Evaluation Program. The in-depth case study approach is an efficient way to conduct research on groups of systems that exhibit significant variability between systems. Through careful design, the case-study approach can yield in-depth process understanding with some degree of generalization. This approach can provide a valuable basis for exchange of information between resource development companies (e.g., oil and gas industries) and interested citizen groups. Case studies offer the potential to increase our understanding of human and ecological exposure in relation to hydraulic fracturing activities in a rapid manner. Case studies can reveal those life cycle assessment parameters of significance for hydraulic fracturing analysis. Case studies can also help identify existing best management practices (BMPs) that favorably affect quality and quantity of source fluids, flowback water and produced water that is co-mingled with the flowback water. Case studies may also provide information on the impact of the composition and variability of source fluids on flowback/produced water. For example, some operators may use different source fluid additives that have different implications for flowback/produced water contaminants and management (e.g., acidic additives may enhance metal leaching from the formation into flowback/produced water.)

Case studies should be carefully designed to assess the range and variability of environmental and exposure conditions of areas where hydraulic fracturing is and will be occurring and where hydraulic fracturing fluids may be released. Characterization of potential pathways of exposure is very site specific and the locations for case studies should be based on a broad view of the hydraulic fracturing activities in location and time. Also, because of the high cost of installing and operating hydraulic fracturing systems, it is recommended that the EPA partner with industries who would develop and operate the wellsites while EPA conducts research at the sites (e.g., to install monitoring stations, monitoring, wells, etc). This partnering would promote transparency and potentially avoid the need for scale-up of research data. ORD should also consider the benefits of using existing vs. new hydraulic fracturing sites for case studies conducted in partnership with industry, including whether meaningful data can be produced within the time constraints associated with meeting the short- and long-term goals of this research program. It may take many years to assess how deeper groundwater systems react to fracturing.

In order to define relationships between hydraulic fracturing processes and water sources, the SAB believes that significantly improved data and information are needed on the occurrence, volume, composition, treatability and/or disposal of hydraulic fracturing source fluids, flowback water and produced water that is co-mingled with the flowback water and the sources of the constituents (i.e., additive, reaction product, or leaching product) throughout different phases of the hydraulic fracturing lifecycle. The composition of hydraulic fracturing source fluids, flowback water and produced water that is co-mingled with the flowback water, and the sources of the constituents need to be understood to provide knowledge about physical-chemical mechanisms governing flowback and produced water chemistry and insight into ways to control this chemistry. For improved detection, reliable surrogate constituents should be investigated. The potential and desirability of introducing tracer constituents in hydraulic fracturing fluids for studying fate and transport in these complex fractured systems should also be investigated.

To help assess impacts to water sources, ORD should consider doing mass balances on chemicals of potential concern and water quantity in areas where hydraulic fracturing is or will be occurring. Also, because impacts to water quantity affect water quality, ORD should assess hydraulic fracturing impacts to water quantity for both surface water and groundwater.

After compiling and reviewing available data and knowledge on hydraulic fracturing and interaction with current and potential future drinking water sources at the beginning of the research study, ORD should identify how to best address any potential problems identified through this effort, such as water treatability issues and applicability of emerging treatment technologies. The research plan should include a focused effort on treatability of hydraulic fracturing flowback and produced water that is co-mingled with the flowback water in several contexts. Research should be conducted on the effectiveness of municipal wastewater treatment systems with respect to hydraulic fracturing flowback and produced water that is co-mingled with the flowback water, as these waters are often being directed to Publicly Owned Treatment Works (POTWs). There are new methods emerging for treatment of very high TDS waters, such as membrane distillation. The potential for these technologies to be effective in treating hydraulic fracturing process waters should be systematically investigated. Research should be also conducted to determine the effectiveness of existing drinking water treatment technology, including public water treatment and point of use technology, for removing hydraulic fracturing flowback and produced water constituents that become introduced to water supply sources. Such constituents might be introduced into drinking water sources through inadequate treatment in POTWs or through pathways such as stormwater runoff. In addition, Best Management Practices (BMPs) should be identified for treating wastewater generated during hydraulic fracturing options, including how to dispose of brine reject waters following treatment or solid salt products in some cases.

In developing the research study plan, specific potential uses of the results should be considered. If one potential outcome is to develop scientific information to facilitate assessment of risk at particular sites, development of site assessment methodologies and related data requirements and acquisition methodologies is needed.

Potential Health and Environmental Risks

Health and environmental risk associated with hydraulic fracturing can only be assessed after sources and pathways of possible exposure are much better understood. Several activities must occur before such potential risks are assessed, including: a) characterization of the composition and variability of the source fluids, flowback water and produced water that is co-mingled with the flowback water; b) assessment of possible synergistic effects of mixtures of chemicals in fracturing fluids as well as synergistic effects of chemical mixtures interacting with materials in the fractured injection zone; c) evaluation of potential pathways to human and ecosystem exposure under a range of hydraulic fracturing process conditions relative to different geological formations and conditions; d) analysis of the existence and formation of hydraulic fracturing injection and product fluid transport pathways as a result of hydraulic fracturing; and e) identification of the conditions most likely to lead to impacts on drinking water resources.

Regarding the characterization of the composition and variability of the source fluids, flowback water and produced water that is co-mingled with the flowback water, ORD should consider initially focusing its research efforts towards chemicals of potential concern that are likely to pose the greatest human health risk and have the greatest potential for possible exposure to humans and ecological receptors. ORD should include naturally occurring radioactive materials (NORM) among the chemicals it initially focuses its research efforts towards.

ORD should apply current EPA guidance and scientifically sound methods for evaluating the potential health and environmental risks associated with human and ecosystem exposure to hydraulic fracturing operations. The SAB recognizes the difficulties in assessing possible synergistic effects of mixtures of chemicals in fracturing fluids as well as synergistic effects of chemical mixtures interacting with materials in the fractured injection zone. ORD should consider the current science associated with assessing the effects of chemical mixtures. EPA's Risk Assessment Forum produced a document which may be useful to review: *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures* (2000), available at the following Web Site: http://www.epa.gov/raf/publications/pdfs/CHEM_MIX_08_2001.PDF. Also, EPA's research strategies for an integrated, technology-based toxicological and chemical evaluation of complex mixtures of drinking water disinfection byproducts (available at the following Web Site: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=56836) may also be useful to review.

As discussed above under Potential Relationships to Drinking Water Sources, another important factor to assess is the effect of hydraulic fracturing processes on water quantity. Changes in water quantity in groundwater or surface water can have significant influences on human and ecosystem health. Also, potential secondary effects associated with hydraulic fracturing should be considered (e.g., arsenic mobilization in groundwater and aquifers due to enhanced methane transport and resulting changes in redox conditions). It would be helpful to evaluate the cumulative impacts that additional uses of water resources have on water quality and quantity in water resource systems where hydraulic fracturing activities are occurring or are being considered (e.g., pumping of water for agriculture and urban/industrial uses). After these efforts have been conducted, an initial analysis should be conducted that identifies the exposure routes likely to pose the greatest human health risk.

The SAB strongly recommends that the research planning team consider use of Geographic Information System (GIS) mapping with overlays of hydraulic fracturing activities and locations of human populations and ecological receptors in order to provide initial insights into potentially exposed populations and ecosystems and assist with the design of future health and ecosystem studies. GIS mapping may also assist in determining preferred locations for conducting the case-studies, and will serve as an initial step for subsequent studies at larger scales such as at the basin-wide, watershed, or regional level.

Occupational exposure information and data for hydraulic fracturing processes could be a potential source of information to guide initial evaluations. Such information could, for example, give some initial information on the potential health effects of mixtures of chemicals present in hydraulic fracturing fluids.

The EPA and U.S. Department of Energy are developing risk assessment approaches and data for geologic sequestration of carbon dioxide. Knowledge, tools, and data are being developed through these efforts that are applicable to risk assessment for hydraulic fracturing. The SAB encourages ORD to make use of the ongoing research and expertise pertaining to geologic sequestration of carbon dioxide.

Regardless of which topics are ultimately selected for investigation, ORD should invest in and develop effective strategies for communicating and defending the chosen research topics of focus.

Charge Question 2B: What process does the SAB EEC suggest for prioritizing research needs given the Congressional request and a desire by the Agency to complete initial research products by the end of calendar year 2012?

The SAB suggests that ORD's initial research efforts should include compiling and reviewing available data and knowledge on hydraulic fracturing and interaction with drinking water resources. SAB recommends that ORD develop a better understanding of the characteristics of the injected fluids, the reactions that occur in the injection zone, the characteristics of the fluids leaving the injected zone, and the pathways for the fluids leaving the injection zone. ORD should also develop a preliminary risk-based research prioritization approach to characterize the risk of conditions that can lead to human and ecological exposure to hydraulic fracturing fluids and products. ORD should also prioritize research towards the reactions and transport of hydraulic fracturing fluids in the complex subsurface environment. Further, SAB suggests that ORD develop several overarching, fundamental questions to be answered in its research, and then place these questions in order of priority.

Priorities

As discussed under Charge Question 2A, the Committee believes ORD should carefully compile and review available data and knowledge on hydraulic fracturing and interaction with current and potential future drinking water sources at the beginning of the research study.

Knowledge of the characteristics of the injected fluids, the reactions that occur in the injection zone, the characteristics of the fluids leaving the injected zone (e.g., physical/chemical properties), and the pathways for the fluids leaving the injection zone will be needed for assessing impacts on water resources, exposure of humans and ecosystems to hydraulic fracturing fluids and products, and the associated uncertainties involved in the assessment. As a priority, ORD should develop a preliminary risk-based research prioritization approach that would provide the scientific knowledge necessary for characterizing the risk of conditions that can lead to human and ecological exposure to hydraulic fracturing fluids and products at levels that impart health risks. This approach would be adjusted after an initial analysis is conducted to identify the exposure routes likely to pose the greatest human health risk, and sources and pathways of possible exposure are much better understood. ORD should also prioritize research towards the reactions and transport of hydraulic fracturing fluids in the complex subsurface environment, because experience with reservoir engineering and subsurface remediation makes clear that there is much to learn on developing basic scientific understanding of these processes.

The ORD research plan provides several lists of possible specific research questions. To help identify priority topics for research, ORD should develop several overarching, fundamental questions, perhaps through grouping the many questions suggested by ORD. These overarching questions can then be placed in order of priority. The SAB recommends that ORD conduct such an exercise before revising the research plan. The SAB discussed some suggested fundamental questions noted below, but did not undertake to prioritize them. These are examples, and ORD should consider and update this list as appropriate before revising the research plan.

Fundamental Questions

- What are the fundamental physical and chemical water-related processes for each phase of the hydraulic fracturing lifecycle (below ground and above ground in treatment processes and surface water)?
- What is the quality and quantity of injected fluids, flowback water and produced water that is co-mingled with the flowback water?
- How does the specific composition of TDS vary among flowback and produced waters?
- What do field case studies tell us about the effects of hydraulic fracturing on the reactions, fate, and transport of injected constituents, and the fate and transport of potential contaminants in particular regions and geologic regimes?
- What do field data convey about region-specific issues related to hydraulic fracturing and its environmental impacts?
- In what way does hydraulic fracturing, at one or multiple sites, alter existing surface and subsurface flow paths?
- What are existing best management practices (BMPs) that affect quality and quantity of flowback and produced water?
- What are opportunities to develop technologies that could lead to green additives or improved approaches to managing process waters or waters impacted by hydraulic fracturing?
- What are the mass balances for water and constituents of potential concern at a hydraulic fracturing site?
- What are the scale- and magnitude-dependent long-term consequences of bore hole drilling, aquitard penetration, hydraulic fracturing, and post-fracturing solute communication between geologic formations (e.g., shales) and overlying aquifers, especially around transport of methane and TDS?

To develop its research priorities regarding hydraulic fracturing, ORD should consider use of decision analysis techniques. Such techniques are discussed in a recent EPA Board of Scientific Counselors (BOSC) report: *Proceedings of the EPA - BOSC Decision Analysis: Supporting Environmental Decision Makers Workshop (March 30-April 1, 2009)*, available at the following Web Site:
http://www.epa.gov/OSP/bosc/pdf/deci1005proc.pdf.

Charge Question 3: What advice does the SAB EEC offer for designing a stakeholder process that provides for balanced input in developing a sound scientific approach for the overall research strategy?

The SAB recommends that ORD should develop a balanced, collaborative advisory group of stakeholders representing a broad range of perspectives and a plan for engagement with these stakeholders throughout the research process. Hydraulic fracturing for oil and gas development affects ecosystems and communities directly and is a topic of significant public interest. The technology also has the potential to vastly increase U.S. gas production and is of great interest for energy security and economic development. Early formation of an advisory group of stakeholders for the research effort will help inform the research, including helping the research teams to become aware of data and expertise that can benefit the research. To ensure that the stakeholder process is inclusive, collaborative, transparent, and legitimate, ORD should strive for broad representation on the advisory group.

The group could be comprised of representatives of industry, environmental groups, affected residents, state regulators, academia, EPA headquarters, regional and laboratory scientists and engineers, and other individuals. ORD should also consider how the stakeholder process and case study approach can be integrated, including whether it would be appropriate to include representation on the stakeholder group from the areas represented by the various case studies. This group could assist ORD in developing its research priorities, in accessing data held by the various groups, and in establishing stakeholder-based evaluation criteria. The group should comprise people of varying backgrounds, including representatives who can inform the research by providing multidisciplinary science and engineering perspectives such as in porous medium flow and reservoir engineering. At the conclusion of the research period, this group could assist other units of EPA in the transition from research results to policy recommendations. The group could also be used to help develop a community-based participatory research component that would develop technical capacity in affected communities. One approach would be to establish community-based sampling and testing centers in partnership with *pro bono* scientists and engineers, environmental groups, universities, and residents. Household water, private well water, and stream samples could be tested to provide screening level information. Hot spots could be identified for further, more comprehensive testing.

EPA needs to first set clear, realistic goals, expectations and objectives for hydraulic fracturing stakeholder engagement and communication. Prior to developing the stakeholder group, ORD should decide what it desires from a stakeholder process. ORD should consider bringing together a small group of experts in participatory research to develop a stakeholder involvement process that will accomplish the results ORD desires. EPA should then develop and undertake various approaches for stakeholder engagement with regard to the hydraulic fracturing issue. The stakeholder group should be engaged throughout the research process. With respect to stakeholder engagement for informing hydraulic fracturing research, the needs and responsibilities of ORD vs. other offices within EPA need to be considered. The SAB recommends that ORD's objectives and process for stakeholder engagement with the research should be carefully designed based on best available social science. This will help determine the appropriate composition and charge for the advisory group of stakeholders that will provide advice and information on hydraulic fracturing research activities. In addition, activities associated with the stakeholder group should be designed so that they do not adversely affect the Agency's regulatory mandates associated with review of permit applications for hydraulic fracturing operations in conjunction with the states.

Based on submitted written and oral public comments to the draft ORD hydraulic fracturing research plan, it is clear that there is a wealth of data and experience in industry, in professional and non-governmental organizations, in state agencies, and in other groups for ORD to draw upon in the research effort. One important objective for engagement with stakeholders should be to gain access to and leverage the existing knowledge base on hydraulic fracturing and its environmental impacts.

There are many technological development activities and development and study of best management practices with respect to hydraulic fracturing that are ongoing in the states. It would be helpful if EPA engaged with relevant states to inventory and conduct performance evaluations of the effectiveness of state hydraulic fracturing regulatory, technological development and BMP activities. Among other benefits of such an endeavor, the SAB expects that opportunities for collaborative EPA and state research efforts will be identified through serious engagement with the states.

Through the discussions with stakeholder groups and the engagement with states, the SAB strongly recommends that the research planning team explore opportunities to leverage ongoing or planned community-based sampling and testing, with appropriate consideration of quality assurance/quality control requirements and utilizing community resources for meaningful contributions to meeting research objectives. There may be particular opportunities to engage community resources at case-study sites, if ORD decides to pursue case studies as a component of the research effort.

It will also be important for ORD to engage with other federal agencies to share data, collaborate, leverage expertise, and align research priorities for optimal use of limited resources. The other federal agencies who could be engaged with include but are not limited to the U.S. Fish and Wildlife Service, U.S. Geological Survey, U.S. Bureau of Reclamation, U.S. Department of Energy, and the U.S. Army Corps of Engineers. In particular, the U.S. Geological Survey has had a number of research programs tied to fractured bedrock biogeochemistry, solute transport in fractures, borehole-fracture reactive transport, and other related fields that may provide useful opportunities for collaboration and engagement.

In addition, the SAB recommends that ORD develop a public communication plan that would explain the research prioritization efforts and research outcomes as they become available. The stakeholder group may be able to assist in the development of the public communication plan.