Appendix A
Statement of Work

Project: Independent Review of Scientific and Technical Information on Well Completion Techniques, including Hydraulic Fracturing, in California. Bureau of Land Management, California State Office

1. Scope of Work

The Bureau of Land Management (BLM) is seeking to obtain up-to-date scientific and independent technical assessment of well completion techniques associated with and primarily focused on hydraulic fracturing (HF), employed in California. This information will be used in future planning, leasing, and development decisions regarding oil and gas issues on the Federal mineral estate in California.

The purpose of the work is to produce a report that will synthesize and assess the available scientific and engineering information associated with HF in California. The report should include 1) a description of the process of well completion techniques, including HF, in California; (2) based on the underlying geology of California assess changes in the oil and gas potential that have been made possible by advanced well technology associated with HF; (3) an assessment of the environmental hazards associated with advanced well completion techniques, including HF, that have occurred in the past or might occur in the future in California. The focus of the assessment is to evaluate the changes in practice and environmental impacts that have occurred or might occur due to advanced technology rather than the process and environmental hazards of conventional oil and gas development as a whole.

Key questions for each of the report sections are identified in this Statement of Work, which will be a living document. The steering committee, in consultation with the BLM, will review, modify and select the key questions from the list below to be addressed at a level of detail commensurate with the available funding for the report.

Objectives and Key Questions

Since this information will be used in BLM's compliance with the National Environmental Policy Act (NEPA) for future oil and gas decisions, the report should be structured in a manner that will be easily transferable into a NEPA framework, and be written in plain language to the extent possible.

A. Characterization of Well Completion Techniques in CA, including HF. The objective of this part of the report is to provide a profile of advanced well completion techniques being employed in California including HF. A typical HF well profile(s), with cross sections, will also be included.

The synthesis on well completion techniques, including HF, in CA should seek to address the following key questions:

1. What are the basic elements of oil well construction using advanced techniques?
2. What are the steps in a hydraulic fracturing job?
3. What are the key differences in the process when fracturing for oil versus natural gas?
4. What advanced well completion techniques are commonly used in California?
5. Are most wells in CA typically vertical or horizontal? Has this changed in recent years? Are hydraulic fracturing jobs typically on vertical or horizontal wells?
6. How much water is typically used on HF projects in California, and what are the water sources and disposal methods?
7. Is recycling of water (returned, produced) practiced in California, and to what extent?
8. How does HF compare with other well completion techniques employed in CA?

B. Underlying Geology and Oil and Gas Potential. The objective of this part of the report is to synthesize, assess and publish existing information on the geology and consequent geography of oil and gas basins in California that have or might become targets of development due to the availability of advanced well technology, including HF. This information will help target BLM's future oil and gas program administration to the areas where the issues are the most geographically relevant. Maps and geographic data and metadata should be produced to accompany the report in this section.

The synthesis on the underlying geology and oil and gas potential of California should seek to address the following key questions:

1. What are the historic development trends in California in terms of targeted horizons and technologies employed in oil and gas development?
2. What specific advanced technologies have been tried in California and why and what has been the experience with them?
3. Where have these advanced technologies been used in California? Which have been used in unconventional reservoirs? Are these technology applications judged to have been successful?

4. What major geologic regions of California could be produced using advanced technology including HF? Which of these represent new targets for production as a result of new technology?

5. How do these potential targets compare to oil and gas reservoirs in other parts of the US that are currently being produced with advanced technology including HF?

6. What are the ranges of target depths for advanced technologies in California? What are the target formations? What is the vertical separation between target formations and underground useable water? How does this vary by geographic area?

7. What aspects of the Monterey formation are relevant when considering the feasibility of HF in California (ex. age of the reservoir, depositional setting, diagenesis, structural setting/trap, source rocks, other factors)?

8. Based on the above, where can we expect future oil and gas development in California?

C. Environmental Hazards of Well Completion Techniques in CA, including HF. The objective of this part of the report is to compile, synthesize and assess available scientific and engineering information on the environmental hazards of advanced well completion techniques in California, including HF.

The synthesis on the environmental hazards of well completion techniques, including HF, in CA should seek to address the following key questions:

1. What are the potential hazards to groundwater quality and supply in CA specific to HF?

2. What are the potential hazards to surface water quality and supply in CA specific to HF?

3. What are the potential releases of fugitive emissions in CA specific to HF?

4. What is the potential for induced seismicity from HF, including disposal of flowback fracturing fluids and subsequently produced water, given CA's underlying geology?

5. Are there hazards to other resources (air, noise, wildlife habitat, threatened and endangered species) that are particular to HF in CA compared to oil and gas development generally?

6. Are there differences in environmental hazards when fracturing for oil versus fracturing for gas?

7. Have Best Management Practices been developed to address the environmental impacts of hydraulic fracturing?

8. What are the environmental hazards for other well completion techniques commonly employed in California?

2. Performance Period

Team creation, literature review, and preparation of the synthesis report will take place over a 7-month period starting in September 2013.

3. Specific Tasks and Deliverables

Task 1: Establish Project Structure

The California Council on Science and Technology (CCST) will lead this independent review on the scientific and technical information on well completions, including hydraulic fracturing. As a 501(c)(3) with expertise in providing science and technology advice to governments, CCST has extensive experience in collaboration with government agencies and academic scientists. CCST is also an objective and unbiased external party, with expertise and particular focus on issues of importance to California.

As described in the associated Project Charter, CCST will:

1. Serve as the team lead and project manager for the overall project which includes a literature review, map-making, and document creation, convening and facilitating any meetings with team members. CCST will issue the final report.

2. Oversee a rigorous peer review process of the report according to established CCST guidelines and processes. This is necessary to ensure a high quality report that is both actually and perceived as being independent. This process will be similar to that used by the National Academy of Sciences and/or the Office of Management and Budget's Information Quality Bulletin for Peer Review.

3. Create a steering committee comprised of subject matter experts that will ensure quality and independence of the project.

4. Establish and coordinate a working group of agencies contributing information to the study, referred to below as "the team".

5. Monitor all deadlines identified in the Statement of Work and verify that work is of high quality.

6. Select additional team members, with feedback from participating organizations in this charter.

7. Conduct monthly briefings for the BLM to formally update project status.

8. Submit a draft report to the BLM.

9. Provide BLM with digital copies of all references, data sources, and metadata as received from team members.

10. Publish a final CCST report (digitally) once peer review is completed.

Participating team members assembling the report (referred to as "the team") are Lawrence Berkeley National Laboratory (LBNL), California Division of Oil, Gas, and Geothermal Resources (DOGGR), California Geological Survey (CGS). The US Geological Survey (USGS) will provide peer reviewers for the draft report. Team member roles and responsibilities are described in the associated Project Charter. Additional team members may be added in the future by signing on to the Project Charter, as additional needs for expertise arise.

Team members have subject matter expertise in petroleum geology, petroleum engineering, groundwater/surface water hydrology, air quality, and biology, with expertise particular to California. Scientists from agencies with expertise and/or jurisdiction on oil and gas issues will be requested. Scientists from academia will also be requested.

Task 2: Design the Scientific Synthesis and Literature Review

The team will develop a basic outline of the report to guide the literature review. The report will use a format that will be easily utilized when conveying the information into a NEPA document. Team members will conduct a literature review seeking to address the key guiding questions for the synthesis shown in the Scope of Work. The team will identify information missing from published literature and, under guidance from the steering committee, decide if it is possible to obtain this information independently, such as through interviews, under budget constraints and a priority to do so.

Task 3: Writing the Report

The team will prepare a report that characterizes the current state of science on well completion techniques, including HF, in CA, with focus on the key questions stated above. The report will be written using plain language, understandable to the public, to the extent possible.

Deliverable 1: Signed Project Charter and List of Steering Committee Members

Working Group (Team members assembling the report): CCST and BLM will collaborate with agency partners to formally initiate the start of work by signing the associated Project Charter.

Steering Committee: CCST will keep BLM up-to-date about the composition, affiliation, and qualifications of steering committee members.

Deliverable 2: Project Budget

CCST and LBNL will provide project budgets to the BLM detailing personnel, report preparation, and travel/logistical costs, at a minimum.

Deliverable 3: Initial Outline of the Report

CCST will provide a digital copy of the team's outline to the BLM for review and comments. CCST, the Steering Committee, and the BLM will communicate to prioritize key research questions to make best use of available funds and address the key questions that are most important for future BLM NEPA compliance.

Deliverable 4: Written Interim Progress Report

One written, interim progress report will be provided to the BLM when the team is 4 months in to the process. The report will discuss what the team has produced to date, what potential barriers to completion may exist, and a strategy to address those barriers and achieve completion of the project.

Deliverable 5: Monthly Briefings

CCST will provide formal monthly briefings to the Energy and Minerals Division of BLM California on the status of the project (what has been accomplished, is the timeline being met, any problems are coming up that affect the timeline, and any changes to the steering committee) and periodic informal communication on a more frequent, as-needed basis.

Deliverable 6: Draft Report to BLM

CCST will provide a draft report to the BLM prior to its release to the public.
BLM will review the draft report, commenting on formatting, language clarity issues, needs for additional information or missed requirements from the scope of work, but not commenting on the scientific findings of the team

Deliverable 7: Draft Report to Peer Review

CCST will oversee a rigorous peer review process of the report according to established guidelines and processes necessary to ensure a high quality report that is both actually and perceived as being independent. This process will be similar to that used by the National Academy of Sciences and/or the Office of Management and Budget's Information Quality Bulletin for Peer Review.

USGS will serve as a peer reviewer, providing narrative comments to CCST and providing peer review on a pro-bono basis.

Deliverable 8: Digital Copies of References, Data Sources, and Metadata

Digital copies of all references, data, and metadata used in writing the report will be provided to the BLM upon completion of the project from CCST.

Team members will provide to CCST any references, data (geospatially referenced or non-geospatial) used or referenced in the report to support the science team's synthesis. In the case of geospatially referenced data, metadata must also be sent to CCST.

Deliverable 9: Final Report to BLM and Public

The final report will be provided to BLM and made public upon final BLM review.

Deliverable 10: Maps

Aggregation of geospatial data into maps will likely elucidate the responses to key study questions (such as- Based on the geology of oil and gas basins in CA, where are different well completion techniques likely to be employed?). In those cases, maps will be prepared or referenced by the science team and included in the report. In all cases, data and metadata accompanying the maps will be sent to the BLM for use in future analyses.

4. Schedule of Tasks and Deliverables

The draft report will be due to the BLM on February 18, 2014. The final report will be due on March 14, 2014. (Dates are subject to change, based on date of IA execution).

Appendix B
CCST Steering Committee Members

Jane Long, Ph.D.

Principal Associate Director at Large, Lawrence Livermore National Laboratory, Retired

Dr. Long recently retired from Lawrence Livermore National Laboratory where she was the Principal Associate Director at Large, Fellow in the LLNL Center for Global Strategic Research and the Associate Director for Energy and Environment. She is currently a senior contributing scientist for the Environmental Defense Fund, Visiting Researcher at UC Berkeley, Co-chair of the Task Force on Geoengineering for the Bipartisan Policy Center and chairman of the California Council on Science and Technology's California's Energy Future committee. Her current work involves strategies for dealing with climate change including reinvention of the energy system, geoengineering and adaptation. Dr. Long was the Dean of the Mackay School of Mines, University of Nevada, Reno and Department Chair for the Energy Resources Technology and the Environmental Research Departments at Lawrence Berkeley National Lab. She holds a bachelor's degree in engineering from Brown University and Masters and PhD from U. C. Berkeley. Dr. Long is a fellow of the American Association for the Advancement of Science and was named Alum of the Year in 2012 by the Brown University School of Engineering. Dr. Long is an Associate of the National Academies of Science (NAS) and a Senior Fellow and council member of the California Council on Science and Technology (CCST) and the Breakthrough Institute. She serves on the board of directors for the Clean Air Task Force and the Center for Sustainable Shale Development.

Jens Birkholzer, Ph.D.

Deputy Director, Earth Sciences Division, Lawrence Berkeley National Laboratory

Dr. Birkholzer joined Lawrence Berkeley National Laboratory in 1994 as a post-doctoral fellow and has since been promoted to the second-highest scientist rank at this research facility. He currently serves as the deputy director of the Earth Sciences Division and as the program lead for the nuclear waste program, and also leads a research group working on environmental impacts related to geologic carbon sequestration and other subsurface activities. His area of expertise is subsurface hydrology with emphasis on understanding and modeling coupled fluid, gas, solute and heat transport in complex subsurface systems, such as heterogeneous sediments or fractured rock. His recent research was mostly in the context of risk/performance assessment, e.g., for geologic disposal of radioactive wastes and for geologic CO_2 storage. Dr. Birkholzer has authored about 90 peer-reviewed journal articles and book chapters, and has over 230 conference publications and abstracts.

Adam Brandt, Ph.D.

Assistant Professor, Department of Energy Resources Engineering, Stanford University

Dr. Brandt is an Assistant Professor in the Department of Energy Resources Engineering, Stanford University. His research focuses on reducing the greenhouse gas impacts of energy production and consumption, with a focus on fossil energy systems. Research interests include life cycle assessment of transportation fuels, and the energy efficiency of energy extraction and refining systems. A particular interest is in unconventional fossil fuel resources such as oil shale, oil sands, and tight oil. He also leads research into computational optimization techniques as applied to the design and operation of CO_2 capture and storage systems for mitigating greenhouse gas emissions from fossil energy consumption. Dr. Brandt received his PhD and MS degrees from the Energy and Resources Group, UC Berkeley.

Donald L. Gautier, Ph.D.

Consulting Petroleum Geologist, DonGautier L.L.C.

With a career spanning almost four decades, Dr. Donald L. Gautier is an internationally recognized leader and author in the theory and practice of petroleum resource analysis. As a principal architect of modern USGS assessment methodology, Gautier's accomplishments include leadership of the first comprehensive evaluation of undiscovered oil and gas resources north of the Arctic Circle, the first national assessment of United States petroleum resources to be fully documented in a digital environment, and the first development of performance-based methodology for assessment of unconventional petroleum resources such as shale gas or light, tight oil. He was lead scientist for the San Joaquin Basin and Los Angeles Basin Resource Assessment projects. His recent work has focused on the analysis of growth of reserves in existing fields and on the development of probabilistic resource/cost functions. Gautier is the author of more than 200 technical publications, most of which concern the evaluation of undiscovered and undeveloped petroleum resources. He holds a Ph.D. in geology from the University of Colorado.

Peter H. Gleick, Ph.D.

President, Pacific Institute

Dr. Peter H. Gleick is an internationally recognized environmental scientist and co-founder of the Pacific Institute in Oakland, California. His research addresses the critical connections between water and human health, the hydrologic impacts of climate change, sustainable water use, privatization and globalization, and international security and conflicts over water resources. Dr. Gleick was named a MacArthur “genius” Fellow in October 2003 for his work on water, climate, and security. In 2006 Dr. Gleick was elected to the U.S. National Academy of Sciences, Washington, D.C. Dr. Gleick’s work has redefined water from the realm of engineers to the world of social justice, sustainability, human rights, and integrated thinking. His influence on the field of water has been long and deep: he developed one of the earliest assessments of the impacts of climate change on water resources, defined and explored the links between water and international security and local conflict, and developed a comprehensive argument in favor of basic human needs for water and the human right to water – work that has been used by the UN and in human rights court cases. He pioneered the concept of the “soft path for water,” developed the idea of “peak water,” and has written about the need for a “local water movement.” Dr. Gleick received a B.S. in Engineering and Applied Science from Yale University and an M.S. and Ph.D. from the Energy and Resources Group of the University of California, Berkeley. He serves on the boards of numerous journals and organizations, and is the author of many scientific papers and ten books, including Bottled & Sold: The Story Behind Our Obsession with Bottled Water and the biennial water report, The World’s Water, published by Island Press (Washington, D.C.).

Robert Harriss, Ph.D.

Senior Scientist, Lead Senior Scientist, Environmental Defense Fund

Robert Harriss is a Lead Senior Scientist at the Environmental Defense Fund, with a primary focus on characterizing and mitigating fugitive methane leakage from the United States natural gas system. He is also a Distinguished Fellow at the Houston Advanced Research Center and holds adjunct professorships at Texas A&M–Galveston and the Department of Earth & Atmospheric Sciences at the University of Houston. Other career positions have included Senior/Project Scientist at NASA Langley Research Center, Director of Earth Sciences at NASA Headquarters, Senior Scientist at the National Center for Atmospheric Research (NCAR), and senior faculty positions at Florida State University, University of New Hampshire, and Texas A&M. Dr. Harriss currently serves on a variety of volunteer scientific activities including the current NASA Science Definition Team for the Arctic-Boreal Vulnerability Experiment, CCST Independent Review of Scientific and Technical Information on Advanced Well Stimulation Technologies in California, and as a Contributing Editor of Environment Magazine.

A. Daniel Hill, Ph.D.

Department Head, Professor and holder of the Noble Chair, Petroleum Engineering Department at Texas A&M University

Dr. A. D. Hill is Professor, holder of the Noble Endowed Chair, and Department Head of Petroleum Engineering at Texas A&M University. Previously, he taught for twenty-two years at The University of Texas at Austin after spending five years in industry. He holds a B. S. degree from Texas A&M University and M. S. and Ph. D. degrees from The University of Texas at Austin, all in chemical engineering. He is the author of the Society of Petroleum Engineering (SPE) monograph, Production Logging: Theoretical and Interpretive Elements, co-author of the textbook, Petroleum Production Systems (1st and 2nd editions), co-author of an SPE book, Multilateral Wells, and author of over 170 technical papers and five patents. He has been a Society of Petroleum Engineers (SPE) Distinguished Lecturer, has served on numerous SPE committees and was founding chairman of the Austin SPE Section. He was named a Distinguished Member of SPE in 1999 and received the SPE Production and Operations Award in 2008. In 2012, he was one of the two inaugural winners of the SPE Pipeline Award, which recognizes faculty, who have fostered petroleum engineering Ph.Ds. to enter academia. He currently serves on the SPE Editorial Review Committee, the SPE Global Training Committee, and the SPE Hydraulic Fracturing Technology Conference Program Committee. Professor Hill is an expert in the areas of production engineering, well completions, well stimulation, production logging, and complex well performance (horizontal and multilateral wells), and has presented lectures and courses and consulted on these topics throughout the world.

Amy Myers Jaffe

Executive Director, Energy and Sustainability, UC Davis

Amy Myers Jaffe is a leading expert on global energy policy, geopolitical risk, and energy and sustainability. Jaffe serves as executive director for Energy and Sustainability at University of California, Davis with a joint appointment to the Graduate School of Management and Institute of Transportation Studies (ITS). At ITS-Davis, Jaffe heads the fossil fuel component of Next STEPS (Sustainable Transportation Energy Pathways). She is associate editor (North America) for the academic journal, Energy Strategy Reviews. Prior to joining UC Davis, Jaffe served as director of the Energy Forum and Wallace S. Wilson Fellow in Energy Studies at Rice University's James A. Baker III Institute for Public Policy. Jaffe's research focuses on oil and natural gas geopolitics, strategic energy policy, corporate investment strategies in the energy sector, and energy economics. She was formerly senior editor and Middle East analyst for Petroleum Intelligence Weekly. Jaffe is widely published, including as co-author of "Oil, Dollars, Debt and Crises: The Global Curse of Black Gold" (Cambridge University Press, January 2010 with Mahmoud El-Gamal). She served as co-editor of "Energy in the Caspian Region: Present and Future" (Palgrave, 2002) and "Natural Gas and Geopolitics: From 1970 to 2040" (Cambridge University Press, 2006). Jaffe was the honoree for Esquire's annual 100 Best and Brightest in the contribution to society category (2005) and Elle Magazine's Women for the Environment (2006) and holds the excellence in writing prize from the International Association for Energy Economics (1994).

Preston Jordan, P.G., C.E.G., C.HG. (see also Appendix C – Report Author Biosketches)

Geologist, Earth Science Division, Lawrence Berkeley National Laboratory

Preston Jordan is a Staff Research Associate in the Earth Sciences Division at Lawrence Berkeley National Laboratory (LBNL). He received his B.A. in Geology in 1988 and M.S. Eng.Sci. in Geotechnical Engineering in 1997, both from the University of California, Berkeley. He is a California Professional Geologist, Certified Hydrogeologist and Certified Engineering Geologist. Prior to joining LBNL, Jordan worked at a geotechnical engineering consultancy. Since joining LBNL, he has performed paleoseismic research, characterized the geology and hydrogeology of the lab for environmental remediation and conducted contaminant remediation pilot tests. Over the last decade his research focus has been geologic carbon storage with a particular emphasis on risk assessment. He has published on worker safety and well blowout and fault leakage risk, and participated in risk reviews of geologic carbon storage projects. His risk review of one of the world's few industrial-scale geologic carbon storage projects led to reduction of injection pressures. He recently was the PI for a multi-year research project for the California Energy Commission regarding wide-scale pressure changes in response to historic oil and gas production in Kern County for the purpose of gaining insight into pressure changes in response to prospective geologic carbon storage. This involved dataset assembly and database construction using results of searches of California Department of Oil, Gas and Geothermal Resources records.

Larry Lake, Ph.D.

Professor, Department of Petroleum and Geosystems Engineering, University of Texas, Austin

Larry W. Lake is a professor of the Department of Petroleum and Geosystems Engineering at The University of Texas at Austin and director of the Center for Petroleum Asset Risk Management. He holds B.S.E and Ph.D. degrees in Chemical Engineering from Arizona State University and Rice University. Dr. Lake has published widely; he is the author or co-author of more than 100 technical papers, the editor of 3 bound volumes and author or co-author of four textbooks. He has been teaching at UT for 34 years before which he worked for Shell Development Company in Houston, Texas.

He was chairman of the PGE department twice, from 1989 to 1997 and from 2008-1010. He formerly held the Shell Distinguished Chair and the W.A. (Tex) Moncrief, Jr. Centennial Endowed Chair in Petroleum Engineering. He currently holds the W.A. (Monty) Moncrief Centennial Chair in Petroleum Engineering. Dr. Lake has served on the Board of Directors for the Society of Petroleum Engineers (SPE) as well as on several of its committees; he has twice been an SPE distinguished lecturer. Dr. Lake is a member of the US National Academy of Engineers and won the 1996 Anthony F. Lucas Gold Medal of the SPE. He won the 1999 Dad's Award for excellence in teaching undergraduates at The University of Texas and the 1999 Hocott Award in the College of Engineering for excellence in research. He also is a member of the 2001 Engineering Dream Team awarded by the Texas Society of Professional Engineers. He is an SPE Honorary Member.

Seth B. Shonkoff, Ph.D., MPH

Executive Director, Physicians Scientists & Engineers for Healthy Energy

Dr. Shonkoff is the executive director of the energy science and policy organization, Physicians Scientists & Engineers for Healthy Energy (PSE), and a visiting scholar in the Department of Environmental Science, Policy and Management at UC Berkeley. An environmental and public health scientist by training, he has many years of experience in water, air, climate, and population health research. Dr. Shonkoff completed his PhD in the Department of Environmental Science, Policy, and Management and his MPH in epidemiology at the School of Public Health from the University of California, Berkeley. He is a contributing author to Chapter 11, Human Health: Impacts, Adaptation, and Co-Benefits the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment report (AR5). He has worked and published on topics related to air and water quality and the environmental and public health dimensions of energy choices and climate change from scientific and policy perspectives. Dr. Shonkoff has also researched interaction between the climate and human health dimensions of shorter-live climate forcing emissions (i.e., ozone, black carbon, sulphate particles, etc.) and on the development of more effective anthropogenic climate change mitigation policies that generate socioeconomic and health co-benefits. Dr. Shonkoff's current work focuses on the human health, environmental and climate dimensions of oil and gas development in the United States and abroad.

Sam Traina, Ph.D.

Vice Chancellor of Research, University of California, Merced

Dr. Traina is the Vice Chancellor for Research and Economic Development at the University of California, Merced where he holds the Falasco Chair in Earth Sciences and Geology. He serves as a Board Member of the California Council of Science and Technology. Prior to joining UC Merced in 2002 as a Founding Faculty member and the Founding Director of the Sierra Nevada Research Institute, Dr. Traina was a faculty member for 17 years at the Ohio State University, with concomitant appointments in the School of Natural Resources and the Environment, the department of Earth Science and Geology, Civil and Environmental Engineering, Microbiology and Chemistry. He has served on the National Research Council's Standing Committee on Earth Resources. In 1997-1998 he held the Cox Visiting Professorship in the School of Earth Sciences at Stanford University. Dr. Traina's past and current research has dealt with the fate, transformation and transport of contaminants in the soils and natural waters with an emphasis on radionuclides, heavy metals, and mining wastes. Dr. Traina holds a B.S. In soil resource management and Ph.D. in soil chemistry. He is a fellow of the Soil Science Society of American and of the American Association for the Advancement of Science as well as a recipient of the Clay Scientist Award of the Clay Minerals Society.

Appendix C
Report Author Biosketches

Heather Cooley
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hcooley@pacinst.org

EDUCATION

1994-1998	University of California, Berkeley, CA. B.S. in Molecular Environmental Biology.
2002-2004	University of California, Berkeley, CA. M.S. in Energy and Resources.

RESEARCH AND PROFESSIONAL EXPERIENCE

Heather Cooley is Director of the Pacific Institute's Water Program. She conducts and oversees research on an array of water issues, such as the connections between water and energy, sustainable water use and management, and the hydrologic impacts of climate change. Ms. Cooley has authored numerous peer-reviewed scientific papers and co-authored five books, including The World's Water, A 21st Century US Water Policy, and The Water-Energy Nexus in the American West.

Ms. Cooley has received the US Environmental Protection Agency's Award for Outstanding Achievement (for her work on agricultural water conservation and efficiency) and her work was recognized when the Pacific Institute received the first US Water Prize in 2011. She has testified before the US Congress on the impacts of climate change for agriculture and on innovative approaches to solving water problems in the Sacramento-San Joaquin Delta. Ms. Cooley currently serves on the Board of the California Urban Water Conservation Council.

CURRENT AND PAST POSITIONS

Since 2004	Director, Water Program, Pacific Institute, Oakland, California
2000 – 2004	Lab Manager, Lawrence Berkeley National Laboratory, Berkeley, California

1998 – 1999 Field and Laboratory Technician, Silver Laboratory, UC Berkeley, Berkeley, California

1996 – 1997 Field and Laboratory Assistant, Weston Laboratory, UC Berkeley, Berkeley, California

HONORS AND AWARDS

2010 Board Chair, California Urban Water Conservation Council

2009 Outstanding Achievement Award, US Environmental Protection Agency

2009 Nomination for Environmental Contribution of the Year, Global Water Intelligence

2006 Water Leader, Water Education Foundation

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EDUCATION

1977-1981	Williams College, Williamstown, MA, BA in Geology (magna cum laude)
1981-1984	Stanford University, Stanford, CA, M.S. in Geology
1984-1986	Stanford University, Stanford, CA, Ph.D. in Geology

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Dobson has been a research scientist in the Earth Sciences Division of LBNL since 2000. His expertise is in the study of water-rock interaction related to geothermal systems and high-level radioactive waste repositories. His most recent work has focused on radioactive waste disposal in shales, use of He isotopes in characterization of geothermal systems, and developing methodologies for assessing geothermal resources.

CURRENT AND PAST POSITIONS

2010-present	Career Geological Staff Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA
2007-2009	Deputy Program Manager, Geosciences Program, Office of Basic Energy Sciences, US Department of Energy, Germantown, MD (on detail from LBNL)
2003-2010	Career Geological Research Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA
2000-2003	Geological Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA
1999-2001	Consultant, Empresa Nacional del Petroleo (ENAP), Santiago, Chile
1998-1999	Advising Geologist, Unocal Geothermal and Power Operations, Unocal Corporation, Santa Rosa, CA
1994-1998	Senior Geologist, Unocal Geothermal and Power Operations, Unocal Corporation, Santa Rosa, CA

1989-1994	Research Geologist, Unocal Science and Technology Division, Unocal Corporation, Brea, CA
1989	Postdoctoral Research Fellow, Department of Geological Sciences, University of California, Santa Barbara, CA
1986-1989	Postdoctoral Research Fellow, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA

HONORS AND AWARDS

2012	Geothermal Special Achievement Award, Geothermal Resources Council
2012	Fulbright Specialist Grant in Environmental Science, University of Chile
2009	Outstanding Contributions in Geosciences Research Award, DOE BES
2002, 2006	SPOT Awards (3), Lawrence Berkeley National Laboratory
1995, 1998	Special Recognition Awards (3), Unocal Corporation
1992	Fred L. Hartley Research Center Creativity Award, Unocal Corporation

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EDUCATION

2001-2005	American University, Washington, DC. B.S. in Mathematics, 2005.
2006-2008	University of Michigan, Ann Arbor, MI. M.S. in Natural Resources Management, 2008.

RESEARCH AND PROFESSIONAL EXPERIENCE

Ms. Donnelly has been a Research Associate with the Pacific Institute since 2011. Her research interests include: the social, economic, and policy aspects of water conservation and efficiency; conflict and conflict management over transboundary water resources; and US water policy and natural resources economics. During graduate school, Ms. Donnelly worked on a variety of projects, including modeling hypoxia development in the Gulf of Mexico, identifying water valuation strategies for international businesses, and analyzing water strategies for the Kingdom of Jordan.

CURRENT AND PAST POSITIONS

Since 2011	Research Associate, Pacific Institute, Oakland, California
2010-2011	Researcher and Program Coordinator, Arava Institute for Environmental Studies, Ketura, Israel
2008-2009	Sea Grant Fellow and Program Specialist, Great Lakes Commission, Ann Arbor, Michigan
2005-2006	Analyst, The Cadmus Group, Inc., Arlington, Virginia

HONORS AND AWARDS

2014	Water Education Foundation's Water Leaders Class
2008-2009	Great Lakes Commission-Sea Grant Fellowship
2008	International Economic Development Program, Ford School of Public Policy, University of Michigan

Laura C. Feinstein
California Council on Science and Technology
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EDUCATION

1994-1998	University of California at Berkeley, Berkeley, CA. B.A. in Anthropology, 1998.
2006-2012	University of California at Davis, Davis, CA. Ph.D. in Ecology, 2012.

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Feinstein has worked for the California Council on Science and Technology (CCST) since January 2014. She previously served as a CCST Science and Technology Fellow with the California Senate Committee on Environmental Quality. Her graduate student research focused on the ecology and genetics of an invasive plant species in the San Francisco Bay's tidal wetlands. She has worked on a diverse array of ecological problems, including restoration of coastal marshes, biogeochemical cycles in redwood forests, and the genetics of adaptation. Laura has published and presented at numerous conferences on ecological genetics and tidal wetland plant communities.

CURRENT AND PAST POSITIONS

Since 2014	Project Manager, Well Stimulation Technology in California, California Council on Science and Technology (CCST)
Since 2012	Postdoctoral researcher, restoration of San Francisco Bay tidal marshes, U.C. Davis
2012-2013	CCST Science and Technology Policy Fellow with the California Senate Committee on Environmental Quality
2006-2012	Ph.D. student, U.C. Davis

HONORS AND AWARDS

2007	CALFED Bay-Delta Science Fellow
2006	National Science Foundation Integrative Graduate Education and Research Traineeship on Invasive Species Research Award
2006	California Native Plant Society Research Award

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EDUCATION

1978-1981	Massachusetts Institute of Technology, Pasadena, CA. B.S. Physics
1981-1982	University of Illinois, M.S., Physics
1979-1984	University of California, Berkeley, Ph.D. Physics.

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Marc Fischer is staff scientist in the Sustainable Energy Systems Group and Environmental Energy Technology Division at the Lawrence Berkeley National Laboratory (LBNL), and an associate researcher at the Air Quality Research Center at the University of California, Davis. Dr. Fischer's work focuses on quantifying and mitigating Earth radiative forcing due to greenhouse (GHG) gases and human habitation, and development of sustainable solutions for energy related environmental problems. As part of ongoing work, Fischer and colleagues are quantifying the sources of California's GHG emissions and identifying cost-effective options to mitigate emissions. Dr. Fischer has published more than 60 peer-reviewed publications

CURRENT AND PAST POSITIONS

Since 1998	Staff Scientist, Environmental Energy Technology Division, Lawrence Berkeley National Laboratory (LBNL)
1991 – 1998	Postdoctoral Fellow and Research Associate, University of California, Berkeley

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EDUCATION

1966-1969	Queen Mary College, University of London, UK. B.Sc. in Physics, 1969.
1974-1976	University of Washington, WA. M.S. in Geophysics, 1976.
1986-1992	University of California, Berkeley, CA. Ph.D. in Geophysics, 1992.

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Foxall has lead induced seismicity research activities in the Earth Sciences Division Lawrence Berkeley National Laboratory since 2013. His expertise is in seismic source physics and wave propagation, seismic hazard analysis, and measurement and inversion of deformation in the Earth. Dr. Foxall most recent work has been on physics-based simulation approaches to seismic hazard assessment for induced seismicity related to CO_2 sequestration and analysis of induced seismicity related to enhanced geothermal systems and unconventional oil and gas recovery. Other recent work was on inversion of ground surface deformation for imaging fluid flow in CO_2, oil and geothermal reservoirs, and for characterization of underground facilities. He has also conducted research into joint inversion of seismic and acoustic data for determination of explosive yield. Dr. Foxall has authored and coauthored more than 30 peer-reviewed journal articles and conference publications.

CURRENT AND PAST POSITIONS

Since 2013	Senior Geological Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory (LBNL)
1996 – 2013	Physicist, Lawrence Livermore National Laboratory (LLNL)
1996 – 1999	Visiting Research Geophysicist, University of California, Berkeley
1995 – 1996	Staff Scientist, Lawrence Berkeley National Laboratory
1992 – 1995	Postdoctoral Fellow, Lawrence Berkeley National Laboratory
1986 – 1992	Graduate Student Research Assistant, Lawrence Berkeley National Laboratory

1983 – 1992	Seismological Consultant
1976 – 1983	Staff to Senior Project Seismologist, Woodward-Clyde Consultants, San Francisco, CA

HONORS AND AWARDS

1974	Fulbright Scholarship

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EDUCATION

1992–1996	Cornell University, Ithaca, New York. B.S. in Agricultural and Biological Engineering, 1996.
2001–2003	Tufts University, Medford, Massachusetts. M.S. in Water Resources Engineering, 2003.

RESEARCH AND PROFESSIONAL EXPERIENCE

Mr. Heberger has been a research associate in the Water Program of the Pacific Institute since 2007. He is a water resource engineer and hydrologist specializing in hydraulic, hydrologic, and water quality analyses and modeling, the nexus between water and energy, and impacts of climate change on water resources. Prior to joining the institute Mr. Heberger worked as a consulting engineer at the consulting firm of Camp, Dresser, and McKee (CDM) where he was responsible for building and calibrating rainfall-runoff, hydraulic and water quality models for major waterways across the US.

CURRENT AND PAST POSITIONS

Since 2007	Research Associate, Pacific Institute, Oakland, California
2003 – 2007	Water Resources Engineer, Camp Dresser & McKee, Cambridge, Massachusetts
2001 – 2003	Research Assistant, Department of Civil and Environmental Engineering, Tufts University, Medford, Massachusetts
1999 – 2001	Coordinator, International Network on Participatory Irrigation Management, Washington, DC
1996 – 1998	Water and Sanitation Extension Agent, United States Peace Corps, Mali, West Africa

HONORS AND AWARDS

2007	Registered Professional Engineer, Commonwealth of Massachusetts
2004	Certified Floodplain Manager, Association of State Floodplain Managers

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EDUCATION

1973-1977	California Institute of Technology, Pasadena, CA. B.S.in Environmental Engineering, 1977.
1977-1978	California Institute of Technology, Pasadena, CA. M.S. in Environmental Engineering, 1978.
1979-1984	California Institute of Technology, Pasadena, CA. Ph.D. in Environmental Engineering, 1984.

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Houseworth has been a program manager in the Earth Sciences Division of Lawrence Berkeley National Laboratory (LBNL) since 2000. His expertise is in single and multiphase flow and solute transport in porous and fractured geologic media and has worked on applications to petroleum recovery, nuclear waste disposal, and geologic CO_2 sequestration. His most recent work has centered on nuclear waste disposal in argillaceous rock, CO_2/brine leakage from geologic storage reservoirs, and risk assessments of petroleum recovery operations. Dr. Houseworth has authored over 30 peer-reviewed journal articles and conference publications.

CURRENT AND PAST POSITIONS

Since 2000	Program Manager, Earth Sciences Division, Lawrence Berkeley National Laboratory (LBNL)
1997 – 2000	Technical Systems Manager II, Duke Engineering and Services, Las Vegas, Nevada
1992 – 1997	Senior Staff Consultant, INTERA Inc., Las Vegas, Nevada
1984 – 1992	Research Engineer, Chevron Oil Field Research Company, La Habra, California
1979 – 1980	Engineer, Bechtel Inc., San Francisco, California

HONORS AND AWARDS

2012	Director's Award for Exceptional Achievement (TOUGH codes), by LBNL
2007, 2006	Outstanding Performance Award, by LBNL
1984	Ph.D. thesis - Richard Bruce Chapman Memorial Award

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EDUCATION

1982-1987 University of California, Berkeley, B.A., Geology, 1988

1996-1997 University of California, Berkeley, M.S. in Eng. Sci., Geotechnical Engineering, 1997

LICENSES

California Professional Geologist (since 1998)

California Certified Hydrogeologist (since 2007)

California Certified Engineering Geologist (since 2012)

RESEARCH AND PROFESSIONAL EXPERIENCE

Mr. Jordan has been a geologist in the Earth Sciences Division at Lawrence Berkeley National Laboratory (LBNL) since 1990. His research over the last eight years has focused primarily on the risk of geologic carbon storage, with a focus on assessing leakage risk. His work on a risk assessment of one of the few industrial-scale geologic carbon storage projects in the world led the operator to reduce the injection pressure. Mr. Jordan has co-authored over 15 peer-reviewed journal articles and conference papers.

CURRENT AND PAST POSITIONS

Since 1990	Staff Research Associate currently (after five promotions), Earth Science Division, Lawrence Berkeley National Laboratory
1988-1989	Staff Geologist, Harlan Tait Associates, San Francisco
1988	Field Geologist, Department of Geology and Geophysics, University of California, Berkeley
1987	Assistant Field Geologist, Department of Geology and Geophysics, University of California, Berkeley

HONORS AND AWARDS

2010 Outstanding Performance Award, by LBNL

1987 USGS/NAGT program nominee, by University of California, Berkeley

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EDUCATION

2006-2010	University of Rochester, Rochester, NY. B.S. in Alternative Energy and Sustainable Engineering, 2010.
2011-2013	University of Edinburgh, Edinburgh, Scotland. M.Sc. in Geophysics, 2013

RESEARCH AND PROFESSIONAL EXPERIENCE

Mr. Lindsey has been a senior research associate in the Earth Sciences Division of Lawrence Berkeley National Laboratory (LBNL) since 2012. His research seeks to improve seismic methods that characterize earthquake hazard, and apply seismic and electromagnetic geophysics to image the high-temperature hydrothermal fluid processes within geothermal energy reservoirs. Recently, his work has centered on induced seismicity related to enhanced geothermal systems in the western US, and 3-D magnetotelluric (MT) numerical simulation of geothermal systems in Iceland, East Africa, New Zealand, and the United States.

CURRENT AND PAST POSITIONS

Since 2012	Senior Research Associate, Earth Sciences Division, Lawrence Berkeley National Laboratory (LBNL)
2011 – 2012	US-UK Postgraduate Fulbright Scholar, School of GeoSciences, University of Edinburgh
2010 – 2011	Causal Employee, Dept. of Seismology, Geology, and Tectonophysics, Lamont-Doherty Earth Observatory, Columbia University
2010	NSF Research Experience for Undergraduates (REU) Intern, Summer of Applied Geophysical Experience Program, Los Alamos National Laboratory
2010	NSF REU Intern, Department of Physics, University of Rochester
2009	Summer Undergraduate Laboratory Intern, Earth Sciences Division, LBNL
2008	NSF REU Intern, Department of Chemistry, University of Rochester

HONORS AND AWARDS

2012 1st Place in International Geothermal Energy Contest, by Pacific Centre for Geothermal Energy, University of British Columbia

2012 Best Poster Award, School of GeoSciences Graduate Conference, University of Edinburgh

2011 US-UK Fulbright Scholarship (Edinburgh, Scotland)

2011 Honorable Mention for Best Poster at Annual Meeting, Society for Exploration Geophysics

2010 Dean's Prize for Undergraduate Research, University of Rochester

2009 Outstanding Commitment to Action for 'Net Metering Solar Energy in Uganda' (Undergraduate Thesis), by Clinton Global Initiative University

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EDUCATION

1998-2002	Vassar College, Poughkeepsie, NY. B.A. in Economics, 2002.
2004-2005	University of California, Berkeley, CA. M.S. in Environmental Engineering, 2005.
2005-2009	University of California, Berkeley, CA. Ph.D. in Environmental Engineering, 2009.

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Millstein is a project scientist in the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory (LBNL). His expertise is in air quality and meteorological modeling as well as emissions inventory development. His most recent work has centered on evaluating the air quality benefits of integrating renewable energy into the US power grid. Other recent work has included co-developing a spatially explicit methane emissions inventory for oil and gas operations in California. Dr. Millstein has authored over 7 peer-reviewed journal articles and conference publications.

CURRENT AND PAST POSITIONS

Since 2013	Project Scientist, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory (LBNL)
2010 – 2013	Postdoctoral Fellow, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory (LBNL)

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EDUCATION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Cambridge, MA

PhD in Chemical Engineering, September 2000

UNIVERSITY OF PENNSYLVANIA, Philadelphia, PA

Bachelor of Science in Chemical Engineering, May 1994

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Reagan has performed research on the thermodynamics, transport, and chemistry of aqueous systems in the subsurface. His work has included research on the thermodynamics of gas hydrates, gas production from methane hydrate systems, the coupling of methane hydrates and global climate. He is a developer for the TOUGH+ and TOUGH2 series of codes. Additional work includes simulation of subsurface CO_2 injection, data reduction and uncertainty quantification using statistical methods, development of interactive tools for simulation pre- and post-processing, and the simulation of methane production from shales. His most recent work involves the simulation of methane and brine transport in fractured shale systems. Dr. Reagan has authored or co-authored over 30 peer-reviewed journal articles and over 25 conference papers and reports.

CURRENT AND PAST POSITIONS

Since 2010	Geological Research Scientist, Earth Science Division, Lawrence Berkeley National Laboratory (LBNL)
2004-2010	Term Scientist, Earth Science Division, Lawrence Berkeley National Laboratory (LBNL)
2001-2004	Technical Staff, Combustion Research Facility, Sandia National Laboratories - California
1995-2000	Research Assistant, Massachusetts Institute of Technology

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EDUCATION

1993-1997	University of Leoben, Austria: Cand.-Ing. (Equiv. B.S.) Industrial Environmental Protection, Waste Disposal and Recycling.
1997-2000	University of Leoben, Austria: Dipl.-Ing. (Equiv. M.E.) Chemical Process Engineering in Industrial Environmental Protection. Mit Auszeichnung bestanden (Passed with distinction)
1999-2001	Colorado School of Mines, Golden, CO, USA: M.S. Environmental Science and Engineering. As part of the Dual-Degree Program with the University of Leoben, Austria
2001-2008	Colorado School of Mines, Golden, CO, USA: Ph.D. Environmental Science and Engineering.

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Tinnacher has been a Project Scientist in the Earth Sciences Division of Lawrence Berkeley National Laboratory (LBNL) since 2011. Her research focuses on environmental geochemistry problems driven by energy- and climate-related questions, such as the impacts of nuclear waste storage, geologic CO_2 sequestration and hydraulic fracturing on groundwater quality, and the effects of climate change on subsurface geochemistry. In particular, Dr. Tinnacher investigates parameters and processes that control the sorption, remobilization and transport behavior of metals and natural organic matter in the environment, including the role of colloids, sorption/desorption kinetics, and the influence of chemical solution conditions on transport rates. During past research, Dr. Tinnacher has also evaluated the (aquatic) toxicity of compounds. Dr. Tinnacher is the author of a number of peer-reviewed journal articles, conference proceedings and a book section, and holds a U.S. patent on a radiolabeling method for natural organic matter.

CURRENT AND PAST POSITIONS

Since 2011	Project Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory (LBNL)
Since 2011	Visiting Scientist, Chemical Sciences Division, Lawrence Livermore National Laboratory (LLNL)

2008 – 2011 Postdoctoral Fellow, Chemical Sciences Division,
Lawrence Livermore National Laboratory (LLNL)

HONORS AND AWARDS

2011 U.S. Patent (08039226):
R.M. Tinnacher and B.D. Honeyman: Methods to Radiolabel Natural Organic Matter by Reduction with Hydrogen Labeled Reducing Agents

2009 LLNL Chemical Sciences Division Spot Award

2009 2008-2009 CH2MHill/ESE Outstanding Graduate Student Award (Ph.D. thesis)

2002-3 DOC Scholarship of the Austrian Academy of Sciences

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EDUCATION

1990-1994 Ph. D., Environmental Sciences and Engineering (supporting program: Microbial Physiology and Genetics), University of North Carolina at Chapel Hill.

1982-1984 M. S., Microbiology (minor: Aquatic Ecology), Virginia Polytechnic Institute and State University, 1984.

1976-1980 B. S., Environmental Health, University of Georgia, 1980.

RESEARCH AND PROFESSIONAL EXPERIENCE

William T. Stringfellow is a Professor and Director of the Ecological Engineering Research Program in the School of Engineering and Computer Science at the University of the Pacific. He has a joint appointment as a Research Engineer at Lawrence Berkeley National Laboratory where he is the Director of the Environmental Measurements Laboratory.
Dr. Stringfellow is an expert in water quality and industrial waste management. His recent research includes evaluations of the sustainability of biomass energy facilities treating agricultural wastes and investigating the water quality impacts of the Gulf of Mexico oil spill. He is currently investigating the use of water treatment chemicals in the energy industry, with an emphasis on understanding the environmental impacts of biocides.
Dr. Stringfellow has over 30 publications in the field of water quality and industrial waste management.

CURRENT AND PAST POSITIONS

2004-present: University of the Pacific, Ecological Engineering Research Program, School of Engineering and Computer Science, Stockton, CA, Director, EERP and Professor

2003-present: Lawrence Berkeley National Laboratory, Environmental Measurements Laboratory, Earth Sciences Division, Berkeley, CA, Director, EML

1996-present: Lawrence Berkeley National Laboratory, Earth Sciences Division, Berkeley, CA, Environmental Engineer

1988-1989: Institut Pasteur, Departement d'Ecologie, Paris, France, Stagiaire (Visiting Researcher)

1983-1988: Sybron Chemicals, Inc., Salem Research Facility, Salem, Virginia, Senior Research Microbiologist

1980-1981: Ecology and Environment, Inc., Decatur, Georgia, Hazardous Waste Site Investigator

HONORS AND AWARDS

2001 Outstanding Mentor Award, Lawrence Berkeley National Laboratory

2002 Outstanding Mentor Award, Department of Energy

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EDUCATION

2009 Doctor of Philosophy Civil and Environmental Engineering, Massachusetts Institute of Technology

2004 Master of Science Civil and Environmental Engineering, Massachusetts Institute of Technology

2001 Bachelor of Technology Civil and Environmental Engineering, Indian Institute of Technology, Chennai

RESEARCH AND PROFESSIONAL EXPERIENCE

Dr. Charuleka Vardharajan is a biogeochemist in the Earth Sciences Division at the Lawrence Berkeley National Laboratory (LBNL). Her research interests focus on understanding and predicting carbon fluxes in terrestrial and subsurface environments, and development of methods to monitor and mitigate contaminants and greenhouse gases. Recently, her postdoctoral work has involved an evaluation of trace metals that could be released due to potential leakage of carbon dioxide from sequestration sites into shallow overlying groundwaters, and the mechanisms for bio-remediation of chromium at the Hanford 100H site. Her doctoral dissertation work involved the study of the methane biogeochemical cycle in a freshwater lake. Her expertise spans across various techniques for data collection and analysis including geochemical laboratory experiments, X-ray synchrotron spectroscopy, sensor-based data collection, and the use of geoinformatics and statistical data processing to manage and analyze high spatial and temporal resolution data.

CURRENT AND PAST POSITIONS

Current Project Scientist, Earth Sciences Division, Geochemistry Department, Lawrence Berkeley National Laboratory

2010-2014 Postdoctoral Fellow, Earth Sciences Division, Geochemistry Department Lawrence Berkeley National Laboratory, Berkeley, CA

2004-2009: Research Assistant, Parsons Laboratory, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA

2005-2008: Teaching Assistant, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA
Course: Introduction to Computers and Engineering Problem Solving

2001-2005: Research Assistant, Center for Educational Computing Initiatives, Department of Civil and Environmental Engineering
Massachusetts Institute of Technology, Cambridge, MA

2000-2001: Research Assistant, Department of Civil and Environmental Engineering
Indian Institute of Technology, Chennai, India

HONORS AND AWARDS

2011 Earth Sciences Division Spot Award, Lawrence Berkeley National Laboratory

2008-9 MIT Linden Earth System Fellow

2007 National Science Foundation Doctoral Dissertation Research Improvement Grant

2007 Geological Society of America Graduate Student Research Grant

2005-6 MIT Martin Family Society Fellow for Sustainability

2005 MIT Department of Civil and Environmental Engineering, Trond Kaalstad Award for leadership, community building and academic excellence

2001 Institute Blues for exceptional extra-curricular and organizational abilities, Indian Institute of Technology, Madras

1995 National Talent Search Award for academic excellence, National Council of Educational Research and Training, Government of India

Appendix D
Glossary

Acid fracturing – a form of hydraulic fracture stimulation of a formation performed by injecting the acid over the parting pressure of the rock and using the acid to etch channels in the fracture face.

Androgens – steroid hormones that promote the development and maintenance of male characteristics of the body.

Anti-androgens – a substance that can prevent the full expression of androgen.

Anti-estrogens – a substance that can prevent the full expression of estrogen.

Aquifer – a zone of saturated rock or soil through which water can easily move.

Bactericide – a product that kills bacteria in the water or on the surface of the pipe.

Basement faults – faults that occur in the undifferentiated assemblage of rock underlying the oldest stratified rocks in any region.

Basement rock – the undifferentiated assemblage of rock underlying the oldest stratified rocks in any region.

Bedding planes – surfaces that separate sedimentary layers in a rock. The beds are distinguished from each other by grain size and composition, such as in shale and sandstone. Subtle changes, such as beds richer in iron-oxide, help distinguish bedding. Most beds are deposited essentially horizontally.

Biogenic methane – methane produced as a direct consequence of bacterial activity.

Biomarkers – complex molecular fossils used to correlate crude oil and petroleum source rocks, provide information on the type of organic matter, and characterize the thermal maturity.

Borehole cuttings – the small chips and fines generated by drilling through a formation with a drill bit. Most of the cuttings are removed from the drilling mud as the fluid pass through the solids control equipment (e.g., shakers, screens, cyclones, etc.,) at the surface.

Brittle – a rock characteristic that implies mechanical failure in the form of a fracture created with little or no plastic deformation.

BTEX (benzene, toluene, ethylbenzene, and xylene) – volatile aromatic compounds typically found in petroleum products such as gasoline and diesel fuel.

Buffer – a chemical used to maintain the pH of a solution within a limited range.

Cations – positively charged ions.

Chemical Abstracts Service (CAS) number – a unique numeric identifier, designates only one substance, has no chemical significance, and is a link to a wealth of information about a specific chemical substance within the CAS registry.

Chimneys – vertically oriented geological structures that may have circular or subcircular in planform if associated with faults or may be more disperse laterally if not associated with faults. Chimneys form from gas migration processes and are often found in association with mud volcanoes.

Class II wells – used for injection/disposal of fluids associated with oil and natural gas production. Most of the injected fluid is salt water (brine), which is brought to the surface in the process of producing (extracting) oil and gas. In addition, brine and other fluids are injected to enhance (improve) oil and gas production.

Clay stabilizer – a chemical additive used to prevent clay destabilization that results in clay migration or swelling caused by a reaction to an aqueous fluid.

Conductor casing – generally, the first string of casing in a well. It may be lowered into a hole drilled into the formations near the surface and cemented in place, or it may be driven into the ground by a special pile driver. Its purpose is to prevent the soft formations near the surface from caving in and to conduct drilling mud from the bottom of the hole to the surface when drilling starts.

Conventional reservoir – reservoirs that may be produced commercially without altering the reservoir permeability or associated hydrocarbon viscosity.

Corrosion inhibitor – a chemical or mixture of chemicals that prevents or reduces corrosion.

Coulomb criterion – a criterion for rock failure as a function of the normal and shear stress conditions.

Cross-link gel fracturing fluid – is generally an aqueous fluid containing a gelling agent like guar or xanthan and a crosslinker. It has even greater viscosity than a gel fracturing fluid.

Crosslinker – A substance that promotes or regulates intermolecular covalent bonding between polymer chains, linking them together to create a larger structure.

Diagenetic –physical and chemical changes that affect sedimentary deposits during burial and may culminate in lithification, i.e., turning sediment into solid rock.

Diagenetic trap – a trap formed as a result of diagenetic alteration of rocks within a sedimentary basin, resulting in decreased permeability.

Diatomite – a fine, soft, siliceous sedimentary rock composed chiefly of the silica-rich remains of diatoms.

Dip – A measure of the angle between the flat horizon and the slope of a sedimentary layer, fault plane, metamorphic foliation, or other geologic structure.

Directional drilling – drilling the wellbore in a planned angle of deviation or trajectory other than vertical.

Dissolved Organic Carbon (DOC) – mass of organic carbon from a measured water sample that is dissolved or colloidal that can pass through a filter, typically a 0.4 to 0.7 micron filter

Dolomites – carbonate rocks made up of dolomite ($CaMg(CaCO_3)_2$).

Downdip – located down the dip of a sloping planar surface.

Drilling mud – the fluid, water, oil or gas based, circulated through the wellbore during rotary drilling and workover operations that is used to establish well control, transport cuttings to the surface, provide fluid loss control, lubricate the string and cool the bottom hole assembly.

Ductile – a rock characteristic that implies mechanical failure in the form of a fracture created with a large amount of plastic deformation.

Earthquake magnitude – a measure of the amount of energy released during an earthquake, such as the Richter scale.

Effective stress – the total stress minus the pore pressure.

Endocrine-disrupting compounds – chemicals that may interfere with the body's endocrine system and produce adverse developmental, reproductive, neurological, and immune effects in both humans and wildlife.

EPA maximum contaminant level (MCL) – threshold concentration of a contaminant above which water is not suitable for drinking.

Epicenter – a point, directly above the true center of disturbance at the earth's surface, from which the shock waves of an earthquake apparently radiate.

Estrogens – steroid hormones that promote the development and maintenance of female characteristics of the body.

Evaporative emissions – hydrocarbons released into the atmosphere through evaporation from equipment or storage facilities.

Fault – a fracture in the Earth in which one side has moved relative to the other.

Flaring – the combustion of unwanted gases produced by an oil well.

Flowback – fracturing fluid, perhaps mixed with formation water and traces of hydrocarbon, that flows back to the surface after the completion of hydraulic fracturing.

Foaming agent – a material that facilitates formation of foam.

Formation – a body of rock of considerable extent with distinctive characteristics that allow geologists to map, describe, and name it.

Fracture aperture – the distance between fracture faces.

Fracture height – the vertical extent of a fracture.

Fracture length – the horizontal extent of a fracture.

Fracture propagation – enlargement or extension of a crack in a solid material.

Friction reducer – a material, usually a polymer that reduces the friction of flowing fluid in a conduit.

Fugitive emissions – emissions of gases or vapors due to leaks and other unintended or irregular releases.

Gel fracturing fluid – is generally an aqueous fluid containing a gelling agent like guar or xanthan. It has an enhanced viscosity relative to slickwater fracturing fluids.

Globally Harmonized System of Classification and Labeling of Chemicals (GHS) – a worldwide initiative to promote standard criteria for classifying chemicals according to their health, physical and environmental hazards.

Greenhouse gas emissions (GHG) – emissions of gases such as CO_2 and methane that trap heat in the atmosphere.

Horizontal drilling – a well drilled in a manner to reach an angle of 90 degrees relative to a level plane at its departure point at the surface. In practice, the horizontal section of most horizontal wells varies by several degrees.

Hybrid fracturing – hydraulic fracturing that utilizes more than one type of fracturing fluid for a given stage.

Hydraulic diffusivity coefficient – the ratio of the hydraulic conductivity to the volume of water that a unit volume of saturated soil or rock releases from storage per unit decline in hydraulic head. It is a parameter that combines transmission characteristics and the storage properties of a porous medium.

Hydraulic fracturing – an operation in which a specially blended liquid is pumped down a well and into a formation under pressure high enough to cause the formation to crack open, forming passages through which oil can flow into the wellbore.

Hydrostatic pressure – the pore pressure that results from the static weight of pore fluid above the point of interest.

Induced seismicity – earthquakes caused by human activities.

Intercalated turbiditic sandstones – sandstones deposited from a turbidity current (an underwater current flowing downslope owing to the weight of sediment it carries) that are alternately layered between other rock types.

Intermediate casing – the casing set in a well after the surface casing but before production casing to keep the hole from caving and to seal off formations.

Iron control agent – a chemical that controls the precipitation of iron from solution.

Kelly – the heavy square or hexagonal steel member suspended from the swivel through the rotary table and connected to the topmost joint of drill pipe to turn the drill stem as the rotary table turns.

Kerogen – solid, insoluble organic material in shale and other sedimentary rock that yields oil and/or gas upon heating.

Lithology – the physical characteristics (e.g., mineral content, grain size, texture and color) of a rock or stratigraphic unit.

Matrix acidizing – use of a mineral acid (typically hydrochloric acid (HCl) or HCl in combination with hydrofluoric acid (HF)) or an organic acid (typically acetic or formic) to remove damage or stimulate the permeability of a formation.

Maturation – the chemical transformation of kerogen into petroleum fluids.

Median lethal dose (LD_{50}) – the dose required to kill half the members of a tested population after a specified test duration.

Microearthquakes – an earthquake of low intensity with a magnitude of 2 or less on the Richter scale.

Microscanner log – a geophysical measurement record from a downhole instrument that consists of four orthogonal imaging pads containing microelectrodes in direct contact with the borehole wall. It is used for mapping of bedding planes, fractures, faults, foliations, and other formation structures and dip determination.

Microseismic monitoring – a method of tracking a fracture by listening for the sounds of shear fracturing in the formation during the hydraulic fracturing process.

Migrated oil – oil that has moved from source rock to reservoir rock.

Miocene – the geologic time ranging from about 23 to 5.3 million years ago.

MODFLOW – the USGS's three-dimensional (3D) finite-difference groundwater model.

Multi-stage hydraulic fracturing – is where hydraulic fracturing is conducted repeatedly in isolated segments along the length of the well's production interval.

Nanoparticles – a microscopic particle of matter that is measured on the nanoscale, usually less than 100 nanometers.

Normal stress – the internal forces per unit area that are exerted in a material object and are also perpendicular to the selected area.

Oil window - the temperature and pressure ranges under which the organic matter in organic-rich sedimentary rocks is transformed into petroleum fluids.

Opening mode fractures – a fracture that opens in response to tensile stress, i.e., a stress that acts to pull a material object apart.

Organic shales – organic-rich shales.

Overburden – the rock layers lying above a point of interest in the subsurface.

Oxides of nitrogen (NOx) – consist of nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O).

Ozone precursors – chemical compounds, such as carbon monoxide, methane, non-methane hydrocarbons, and nitrogen oxides, which in the presence of solar radiation react with other chemical compounds to form ozone.

Particulate matter (PM) and $PM_{2.5}$ – a complex mixture of extremely small particles and liquid droplets. $PM_{2.5}$ consist of particles less than 2.5 microns in diameter.

Permeability – The ability of a rock or other material to allow fluid flow through its interconnected spaces.

pH adjuster – chemical agents to reduce, or to increase, the acidity of a solution.

Phosphatic shales – phosphate-rich shales.

Pipes – vertically-oriented geologic structures commonly circular or subcircular in planform that may have formed as a result of hydrothermal activity, overpressure, or dissolution processes.

Play – hydrocarbon reservoirs within the same region that have common sourcing and trapping mechanisms.

Pore pressure – the normal stress exerted by pore fluids on the porous medium.

Poromechanical effects – phenomena that occur in porous materials whose mechanical behavior is significantly influenced by the pore fluid.

Portland cement – a general class of hydraulic cements (cements that can harden under water) usually made by burning a mixture of limestone and clay in a kiln and pulverizing into a powder.

Precipitate – a solid substance formed from a liquid solution during a chemical process.

Produced water – water, ranging from fresh to salty, produced with the hydrocarbons as a result of pressure drawdown and flow through the petroleum reservoir.

Production casing – the last string of casing set in a well that straddles and isolates the producing interval, inside of which is usually suspended a tubing string.

Production liner – similar to casing pipe but does not extend back to the ground surface. Liners may or may not be cemented.

Propagation of water front – the movement of a constant water saturation level through a porous medium.

Proppant – well sorted and consistently sized sand or man-made materials that are injected with the fracturing fluid to hold the fracture faces apart after pressure is released.

Quaternary fault – a fault that formed sometime between the present and about 2.6 million years ago.

Radiogenic material – material produced by radioactive decay.

Redox conditions – a quantitative description of the environment in question with respect to be oxidizing or reducing.

Reservoir – a subsurface accumulation of hydrocarbon fluids that resides in rock pores and fractures.

Scale inhibitor – a chemical that prevents scale from forming in scale mineral saturated produced waters.

Sedimentary basin – a depression in the Earth's surface that collects sediment.

Seismic hazard – a phenomenon such as ground shaking, fault rupture, or soil liquefaction that is generated by an earthquake.

Seismic moment – a measure of the size of an earthquake based on the area of fault rupture, the average amount of slip, and the force that was required to overcome the friction sticking the rocks together that were offset by faulting.

Seismometer – an instrument for measuring the direction, intensity, and duration of earthquakes by measuring the actual movement of the ground.

Seismometer array – numerous seismometers placed at discrete points in a well-defined configuration.

S**emi-volatile organic compounds (SVOC)** – organic compound which has a boiling point higher than water and which may vaporize when exposed to temperatures above room temperature.

Shale – sedimentary rock derived from mud and commonly finely laminated (bedded). Particles in shale are commonly clay minerals mixed with tiny grains of quartz eroded from pre-existing rocks.

Shear failure – brittle or ductile damage that results from shear stress of sufficient magnitude.

Shear stress – the internal forces per unit area that are exerted in a material object and are also tangential to the selected area.

Siliceous – a rock rich in a silica phase, such as opal, cristobalite, or quartz.

Siliceous shales – silica-rich shales.

Slickwater fracturing fluid - a water base fracturing fluid with only a very small amount of a polymer added to give friction reduction benefit.

Solvent - a substance that will dissolve a solid. In the oil field, oil based solvents may range from xylene for asphaltenes and sludges, to kerosene and diesel/xylene mixtures for paraffins.

Source rock – a rock rich in organic matter from the original sediment deposition that can generate petroleum fluids under certain temperature and pressure conditions.

Specific conductance - the measure of a material to conduct an electric current.

Stable isotopes – two or more forms of a chemical element having different numbers of neutrons that do not have any measurable radioactive decay.

Static fractures – fractures that are not changing over time.

Steam cycling – a form of steam injection in which injection and production take place in the same well, which is accomplished by alternating steam injection with oil production.

Steam injection – a thermally-enhanced oil recovery method in which steam is forced into the reservoir by applying pressure; the thermal energy of the steam heats the reservoir which reduces the viscosity of heavy oil that are usually the target of thermal oil recovery methods.

Storage coefficient – the volume of water released from storage per unit surface area of a confined aquifer per unit decline in hydraulic head.

Stratigraphic trap – a trap formed as a result of variations in porosity and permeability of the stratigraphic sequence.

Stratigraphic zone – a body of strata that is distinguished on the basis of lithology, fossil content, age, or other rock property.

Stress – the internal forces per unit area that are exerted in a material object.

Strike – is a geometrical characteristic of a planar geologic surface and is defined by the line of intersection between the geologic surface and a horizontal plane.

Structural features – geologic features that result from tectonic, diapiric, gravitational and compactional processes.

Structural trap – a trap formed as a result of faulting or folding of the rock.

Supercritical CO_2 – a fluid state of carbon dioxide which displays characteristics of both liquid and gas that occurs at conditions above its critical temperature and critical pressure.

Surface casing – the casing following the conductor casing in a well that protects fresh water aquifers from contact with fluids moving through the well. It is always cemented across the water zone and the cement usually extends to the surface.

Surfactant – a chemical that is attracted to the surface of a fluid and modifies the properties such as surface tension.

Tectonic features – features that are a result of forces or conditions within the earth that cause movements of the crust.

Tectonic stress – stress that results from forces or conditions within the earth that cause movements of the crust.

Televiewer log – a record of the amplitude of high-frequency acoustic pulses reflected by the borehole wall; provides location and orientation of bedding, fractures, and cavities.

Thermogenic methane – methane created by the thermal decomposition of buried organic material.

Tiltmeter – an instrument used to measure slight changes in the inclination of the earth's surface resulting from subsidence or uplift, usually in connection with volcanology and earthquake seismology.

Total dissolved solids (TDS) – total amount of all inorganic and organic substances – including minerals, salts, metals, cations or anions – that are dissolved within a volume of water.

Total Organic Carbon (TOC) – total mass of organic carbon from a measured sample.

Total Suspended Solids (TSS) - total mass retained on a filter per unit volume of water, typically a 0.4 to 0.7 micron filter.

Toxicity – the degree to which a substance can harm humans or other living organisms.

Trace metals – metals that do not affect chemical or physical properties of the system as a whole to any significant extent, and have ideal solution behavior characteristic of very high dilution.

Trap – a configuration of geologic layers and/or structures that has a very low permeability and is suitable for blocking the upward movement of buoyant hydrocarbons.

Turbidity – the measure of relative clarity of a liquid. It is an optical characteristic of water and is an expression of the amount of light that is scattered by material in the water when a light is shined through the water sample.

Unconventional reservoir – oil and gas resources whose porosity, permeability, fluid trapping mechanism, or other characteristics differ from conventional sandstone and carbonate reservoirs, such as shale gas, shale oil, heavy and viscous oil, gas hydrates, tight gas, and coal bed methane resources.

Updip – located up the dip of a sloping planar surface.

Viscosity – a measurement of a fluid's internal resistance to flow, expressed as the ratio of shear stress to shear rate.

Vitrinite – a type of woody kerogen that is used to measure source rock maturity.

Vitrinite reflectance – a measure of source rock maturity based on the reflectance of vitrinite, measured as % Ro. The onset of oil generation typically occurs at around Ro = 0.6%, with gas formation occurring when Ro = 1.2 %.

Volatile organic compounds (VOC) –organic chemicals whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure.

Water flooding – purposely injecting water below and/or into the reservoir to drive the oil towards the producing wellbore.

Well completion – the activities and methods of preparing a well for the production of oil and gas or for other purposes, such as injection; the method by which one or more flow paths for hydrocarbons are established between the reservoir and the surface.

Well stimulation technology – refers to well stimulation methods of hydraulic fracturing, acid fracturing, and matrix acidizing.

Zonal isolation – the exclusion of fluids such as water or gas in one zone from mixing with fluids in another zone along pathways outside of a well casing, accomplished through cement that seals the rock to the casing.

Appendix E
Bibliography of Submitted Literature

Input was solicited by the CCST steering committee from external groups to identify documents that should be considered during the development of the report. 163 references were submitted; most of the input received was from the Natural Resourced Defense Council (NRDC) and the Center for Biological Diversity (CBD). A few additional on-line submissions were also received.

Protocol for referencing literature in the report

This report primarily relies on literature subject to systematic peer review and government data. However, a primary problem in conducting an assessment of well stimulation technology (WST) in California (and elsewhere) is a lack of credible data. Consequently, other literature - so-called "grey literature" - may be included if it meets certain criteria (categories 2-5 below), and adds important information to the assessment. When the report requires the use of grey literature as a primary source, the text also notes that the reference is not peer-reviewed literature. Literature deemed to be advocacy, policy or opinion-based material is not included in the assessment. When citing or using literature and data, authors will note any material caveats on the quality of the information.

Categories of literature that can be used as references in the WST report:

1. Published, peer-reviewed scientific papers.

2. Government data and reports.

3. Academic studies that are reviewed through a university process, textbooks, and papers from technical conferences.

4. Studies generated by non-government organizations that are based on data, and draw traceable conclusions clearly supported by the data.

5. Voluntary reporting from industry. This data is cited with the caveat that, as voluntary, there is no quality control on the accuracy or completeness of the data.

Submitted, admissible literature

The submitted references tabulated here were reviewed by the report team members and were determined to fall into one of the five usable categories of literature. While the literature below was reviewed by the authors it was not necessarily cited within the text of the report. The authors also reviewed many documents that are not included in the list below.

Adams, M. B. (2011). Land application of hydrofracturing fluids damages a deciduous forest stand in West Virginia. *Journal of Environmental Quality, 40*(4), 1340–1344.

Adams, M. B., Edwards, P. J., Ford, W. M., Johnson, J. B., Schuler, T. M., Thomas-Van Gundy, M., & Wood, F. (2011). Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow Experimental Forest.

Allen, D., Torres, V., Thomas, J., Sullivan, D., Harrison, M., Hendler, A., … Seinfeld, J. (2013). Measurements of methane emissions at natural gas production sites in the United States. *Proceedings of the National Academy of Sciences.* doi:10.1073/pnas.1304880110

Alvarez, R. A., Pacala, S. W., Winebrake, J. J., Chameides, W. L., & Hamburg, S. P. (2012). Greater focus needed on methane leakage from natural gas infrastructure. *Proceedings of the National Academy of Sciences, 109*(17), 6435–6440. doi:10.1073/pnas.1202407109

Armstrong, R., & Hadley, P. W. (1991). Where's the Benzene': Examining California Ground-Water Quality Surveys. *Ground Water GRWAAP*, 29(1).

Bamberger, Michelle; Oswald, R. (2012). Impacts of Gas Drilling on Human and Animal Health. *New Solutions : A Journal of Environmental and Occupational Health Policy : NS, 22*(1), 51–77. Retrieved from http://www.psehealthyenergy.org/data/Bamberger_Oswald_NS22_in_press.pdf

Basu, N., Bradley, M., McFeely, C., & Perkins, M. (2013). *Hydraulic Fracturing in the State of Michigan: Public Health Technical Report* (p. 37). Retrieved from http://graham.umich.edu/media/files/HF-05-Public-Health.pdf

Bayne, E. M., Habib, L., & Boutin, S. (2008). Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. *Conservation Biology, 22*(5), 1186–93. doi:10.1111/j.1523-1739.2008.00973.x

BC Oil and Gas Commission. (2012a). *Investigation of observed seismicity in the Horn River Basin. http://www.bcogc.ca/*. Retrieved from www.bcogc.ca

BC Oil and Gas Commission. (2012b). *Investigation of observed seismicity in the Horn River Basin. http://www.bcogc.ca/*. Retrieved from www.bcogc.ca

Beckmann, J. P., Murray, K., Seidler, R. G., & Berger, J. (2012). Human-mediated shifts in animal habitat use: sequential changes in pronghorn use of a natural gas field in Greater Yellowstone. *Biological Conservation, 147*(1), 222–233.

Behl, R. (1999). Since Bramlette (1946): The Miocene Monterey Formation of California revisited. Concepts: *A … View from California: …, 338,* 301–313. Retrieved from http://geology.campus.ad.csulb.edu/people/behl/MARS/files/Behl_1999_Monterey_Overview.pdf

Behl, R. J. (n.d.). Since Bramlette (1946): The Miocene Monterey Formation of California revisited.

Bergquist, E., Evangelista, P., Stohlgren, T. J., & Alley, N. (2007). Invasive species and coal bed methane development in the Powder River Basin, Wyoming. *Environmental Monitoring and Assessment, 128*(1-3), 381–394.

Berkeley, U. C., & Park, M. (2011). Strategic Plan: 2011 - 2016, 2011–2016.

Blickley, J. L., Blackwood, D., & Patricelli, G. L. (2012). Experimental evidence for the effects of chronic anthropogenic noise on abundance of Greater Sage-Grouse at leks. *Conservation Biology, 26*(3), 461–71. doi:10.1111/j.1523-1739.2012.01840.x

Blickley, J. L., Word, K. R., Krakauer, A. H., Phillips, J. L., Sells, S. N., Taff, C. C., … Patricelli, G. L. (2012). Experimental chronic noise is related to elevated fecal corticosteroid metabolites in lekking male greater Sage-Grouse (Centrocercus urophasianus). *PLOS One, 7*(11), e50462. doi:10.1371/journal.pone.0050462

British Geological Survey. (2011). Blackpool earthquake Magnitude 1.5. Retrieved from http://www.bgs.ac.uk/research/earthquakes/BlackpoolMay2011.html

Brown, W. A., & Frohlich, C. (2013). Investigating the cause of the 17 May 2012 M 4.8 earthquake near Timpson, east Texas (abstr.). *Seismol. Res. Lett, 84,* 374.

Burton, A. G., Nadelhoffer, K. J., & Presley, K. (2013). *Hydraulic Fracturing in the State of Michigan: Environment/Ecology Technical Report* (p. 13). Retrieved from http://graham.umich.edu/media/files/HF-04-Environment-Ecology.pdf

CA Department of Conservation Division of Oil Gas and Geothermal. (2014). *Well Data.*

CA Department of Conservation Division of Oil Gas and Geothermal Resources. (2012a). *2011 Preliminary Report of California Oil and Gas Production Statistics.* Retrieved from ftp://ftp.consrv.ca.gov/pub/oil/annual_reports/2011/PR03_PreAnnual_2011.pdf

CA Department of Conservation Division of Oil Gas and Geothermal Resources. (2012b). *Producing wells and production of oil, gas, and water by county. 2011 Preliminary Report of California Oil and Gas Production Statistics.* Retrieved June 24, 2014, from ftp://ftp.consrv.ca.gov/pub/oil/temp/NEWS/Producing_Wells_OilGasWater_11.pdf

CA Department of Conservation Division of Oil Gas and Geothermal Resources. (2013). *Permit to Conduct Well Operations for "Indian Well 1" API No. 069-20082.* Retrieved June 24, 2014, from ftp://ftp.consrv.ca.gov/pub/oil/BLM Study Data/NewOCRSampleData/06920082_DATA_09-24-2013.pdf

Cahill, A. E., Aiello-Lammens, M. E., Fisher-Reid, M. C., Hua, X., Karanewsky, C. J., Ryu, H. Y., … Warsi, O. (2012). How does climate change cause extinction? *Proceedings of the Royal Society B: Biological Sciences,* rspb20121890.

California Division of Oil and Gas, & U.S. Environmental Protection Agency Region 9. (1982). *Underground Injection Control Program Memorandum of Agreement.* Retrieved June 24, 2014, from http://www.conservation.ca.gov/dog/for_operators/Documents/MOU-MOA/MOA_EPA_UIC_1982.pdf

Cardno ENTRIX. (2012). *Hydraulic Fracturing Study, PXP Inglewood Oil Field* (pp. 1–206). Los Angeles, CA. Retrieved from http://www.scribd.com/doc/109624423/Hydraulic-Fracturing-Study-Inglewood-Field10102012

Cathles, L. M. (2012). Assessing the greenhouse impact of natural gas. *Geochemistry, Geophysics, Geosystems, 13(6).*

Chilingar, G. V., & Endres, B. (2005). Environmental hazards posed by the Los Angeles Basin urban oilfields: an historical perspective of lessons learned. *Environmental Geology, 47(2)*, 302–317. doi:10.1007/s00254-004-1159-0

Clark, C. E., & Veil, J. A. (Environmental S. D. (2009). *Produced Water Volumes and Management Practices in the United States* (pp. ANL/EVS/R–09–1).

Colborn, T., Kwiatkowski, C., Schultz, K., & Bachran, M. (2011). Natural Gas Operations from a Public Health Perspective. *Human and Ecological Risk Assessment: An International Journal, 17*(5), 1039–1056. doi:10.1080/10807039.2011.605662

Colborn, T., Schultz, K., Herrick, L., & Kwiatkowski, C. (2012). An exploratory study of air quality near natural gas operations. *Hum Ecol Risk Assess.*

Colborn, T., Schultz, K., Herrick, L., & Kwiatkowski, C. (2014). An Exploratory Study of Air Quality Near Natural Gas Operations. *Human and Ecological Risk Assessment: An International Journal, 20*(1), 86–105. Retrieved from http://dx.doi.org/10.1080/10807039.2012.749447

Colorado Department of Public Health and Environment, & Agency for Toxic Substances and Disease Registery.

(2008). *Public Health Implications of Ambient Air Exposures to Volatile Organic Compounds as Measured in Rural, Urban, and Oil & Gas Development Areas.* Retrieved June 24, 2014, from http://www.atsdr.cdc.gov/HAC/pha/Garfield_County_HC_3-13-08/Garfield_County_HC_3-13-08.pdf

Cooley, H., Donnelly, K., Ross, N., & Luu, P. (2012). Hydraulic fracturing and water resources: separating the frack from the fiction. *Pacific Institute, Oakland, CA.(June 2012).* Retrieved from: http://www.pacinst.org/wp-content/uploads/2013/02/full_report35.pdf

Commonwealth of Pennsylvania Department of Environmental Protection. (2009). *Inspection Report.* Retrieved June 25, 2014, from http://www.marcellus-shale.us/pdf/CC-Spill_DEP-Insp-Rpt.pdf

Cypher, B. L., Saslaw, L. R., Job, C. L. V. H., Westall, T. L., & Madrid, A. Y. (2012). KANGAROO RAT POPULATION RESPONSE TO SEISMIC SURVEYS FOR HYDROCARBON RESERVES.

Cypher, B. L., Warrick, G. D., Otten, M. R. M., Farrell, T. P. O., Berry, W. H., Harris, C. E., … Zoellick, B. W. (2000). Population Dynamics of San Joaquin Kit Foxes at the Naval Petroleum Reserves in California. *Wildlife Monographs, 145,* 1–43.

Dale, B. C., Wiens, T. S., Hamilton, L. E., Rich, T. D., Arizmendi, C., Demarest, D. W., & Thompson, C. (2008). Abundance of three grassland songbirds in an area of natural gas infill drilling in Alberta, Canada. In *Proceedings of the 4th International Partners in Flight Conference* (pp. 13–16).

Davies, R., Foulger, G., Bindley, A., & Styles, P. (2013a). Induced seismicity and hydraulic fracturing for the recovery of hydrocarbons. *Marine and Petroleum Geology, 45,* 171–185. Retrieved from http://www.sciencedirect.com/science/article/pii/S0264817213000846

Davies, R., Foulger, G., Bindley, A., & Styles, P. (2013b). Induced seismicity and hydraulic fracturing for the recovery of hydrocarbons. *Marine and Petroleum Geology, 45,* 171–185.

DiGiulio, D. C., Wilkin, R. T., Miller, C., & Oberly, G. (2011). DRAFT: Investigation of Ground Water Contamination near Pavillion, Wyoming. *US Environmental Prodection Agency Office of Research and Development.*

Doherty, K. E., Naugle, D. E., Walker, B. L., & Graham, J. M. (2008). Greater Sage-Grouse Winter Habitat Selection and Energy Development. *Journal of Wildlife Management, 72*(1), 187–195. doi:10.2193/2006-454

Dusseault, M. B., Gray, M. N., & Nawrocki, P. A. (2000). Why Oilwells Leak : Cement Behavior and Long-Term Consequences. In *SPE International Oil and Gas Conference and Exhibition, SPE 64733* (p. 8). Beijing, China: Society of Petroleum Engineers.

kassotis, M. R., Harju, S. M., Osborn, R. G., Wondzell, J. J., Hayden-Wing, L. D., Winstead, J. B., & Webb, S. L. (2011). Prioritizing conservation of ungulate calving resources in multiple-use landscapes. *PloS One, 6(1), e14597.*

El Shaari, N., Minner, W., & Lafollette, R. (2011). Is there a “Silver Bullet Technique” For Stimulating California’s Monterey Shale? In *SPE Western North American Regional Meeting* (pp. 1–10). Anchorage, Alaska: Society of Petroleum Engineers. Retrieved from http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-144526-MS

Ellis, B. R. (2013). *Geology / Hydrogeology Technical Report* (p. 29). Retrieved from http://graham.umich.edu/media/files/HF-03-Geology-Hydrogeology.pdf

Ellsworth, W. L. (2013). Injection-induced earthquakes. *Science, 341*(6142).

Entrekin, S., Evans-White, M., Johnson, B., & Hagenbuch, E. (2011). Rapid expansion of natural gas development poses a threat to surface waters. *Frontiers in Ecology and the Environment, 9*(9), 503–511. doi:10.1890/110053

EPA, U. S. (2008). *Analysis of the Causes of a Decline in the San Joaquin Kit Fox Population on the Elk Hills, Naval Petroleum Reserve #1, California.* Washington, DC. doi:EPA/600/R-08/130

Esswein, E., Kiefer, M., Snawder, J., & Breitenstein, M. (2012). Worker exposure to crystalline silica during hydraulic fracturing. *NIOSH Science Blog, Centers for Disease Control and Prevention (May 23, 2012)* at http://blogs.cdc.Gov/niosh-Science-blog/2012/05/silica-Fracking,14

Fiehler, C. M., & Cypher, B. L. (2011). ECOSYSTEM ANALYSIS OF OILFIELDS IN WESTERN KERN COUNTY, CALIFORNIA.

Field, E. H., Milner, K. R., & 2007 Working Group on California Earthquake Probabilities. (2008). Forecasting california's earthquakes - What can we expect in the next 30 years? *US Geological Survey Fact Sheet 2008, 3027.*

Field, P. X. P. I. O. (2012). Hydraulic Fracturing Study.

Fiore, A. M., Jacob, D. J., Field, B. D., Streets, D. G., Fernandes, S. D., & Jang, C. (2002). Linking ozone pollution and climate change: The case for controlling methane. *Geophysical Research Letters, 29*(19), 21–25.

Flewelling, S., & Sharma, M. (2014). Constraints on upward migration of hydraulic fracturing fluid and brine. *Ground Water,* 52(1), 9–19.

Folger, P. (2013). Earthquakes: Risk, Detection, Warning, and Research.

Fontenot, B. E., Hunt, L. R., Hildenbrand, Z. L., Carlton, D. D., Oka, H., Walton, J. L., … Schug, K. a. (2013). An evaluation of water quality in private drinking water wells near natural gas extraction sites in the barnett shale formation. *Environmental Science & Technology, 47*(17), 10032–40. doi:10.1021/es4011724

Francis, C. D., Kleist, N. J., Ortega, C. P., & Cruz, A. (2012). Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. *Proceedings of the Royal Society B, 279*(1739), 2727–35. doi:10.1098/rspb.2012.0230

Freyman, M., & Salmon, R. (2013a). *Hydraulic Fracturing & Water Stress: Growing Competitive Pressures for Water.* Ceres.

Freyman, M., & Salmon, R. (2013b). Hydraulic Fracturing & Water Stress: *Water Demand by the Numbers.* Retrieved from http://www.colorado.edu/geography/class_homepages/geog_4501_s14/ceres_frackwaterbynumbers_021014.pdf

Frohlich, C. (2012). Two-year survey comparing earthquake activity and injection-well locations in the Barnett Shale, Texas. *Proceedings of the National Academy of Sciences of the United States of America, 109*(35), 13934–8. doi:10.1073/pnas.1207728109

Frohlich, C., Hayward, C., Stump, B., & Potter, E. (2011). The Dallas-Fort Worth Earthquake Sequence: October 2008 through May 2009. *Bulletin of the Seismological Society of America, 101*(1), 327–340. doi:10.1785/0120100131

Gentes, M.-L., McNabb, A., Waldner, C., & Smits, J. E. G. (2007). Increased thyroid hormone levels in tree swallows (Tachycineta bicolor) on reclaimed wetlands of the Athabasca Oil Sands. *Archives of Environmental Contamination and Toxicology, 53*(2), 287–292.

Gilbert, M. M., & Chalfoun, A. D. (2011). Energy development affects populations of sagebrush songbirds in Wyoming. *The Journal of Wildlife Management, 75*(4), 816–824. doi:10.1002/jwmg.123

Gilman, J. B., Lerner, B. M., Kuster, W. C., & de Gouw, J. A. (2013). Source signature of volatile organic compounds from oil and natural gas operations in northeastern Colorado. *Environmental Science & Technology, 47*(3), 1297–305. Retrieved from http://dx.doi.org/10.1021/es304119a

Goodwin, S., Carlson, K., Douglas, C., & Knox, K. (2012). Life cycle analysis of water use and intensity of oil and gas recovery in Wattenberg field, Colo. *Oil & Gas Journal, 110*(5), 48–+.

Gosman, S., Robinson, S., & Shutts, S. (2013). *Hydraulic Fracturing in the State of Michigan: Policy/Law Technical Report* (p. 34). Retrieved from http://graham.umich.edu/media/files/HF-06-Policy-Law.pdf

Graham Sustainability Institute, Erb Institute for Global Sustainable Enterprise, Risk Science Center, & University of Michigan Energy Institute. (2013). *Hydraulic Fracturing in the State of Michigan: Overview and Glossary* (p. 10). Retrieved from http://graham.umich.edu/media/files/HF-01-Overview-Glossary.pdf

Green, C., Styles, P., & Baptie, B. (2012). Shale gas fracturing review & recommendations for induced seismic mitigation. UK Government. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:SHALE+GAS+FRACTURING+REVIEW+&+RECOMMENDATIONS+FOR+induced+seismic+mitigation#0

Gross, S. A., Avens, H. J., Banducci, A. M., Sahmel, J., Panko, J. M., & Tvermoes, B. E. (2013). Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. *Journal of the Air & Waste Management Association, 63*(4), 424–432. doi:10.1080/10962247.2012.759166

Habib, L., Bayne, E. M., & Boutin, S. (2007). Chronic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla. *Journal of Applied Ecology, 44*(1), 176–184.

Hamilton, L. E., Dale, B. C., & Paszkowski, C. A. (2011). Effects of Disturbance Associated with Natural Gas Extraction on the Occurrence of Three Grassland Songbirds Effet du dérangement associé à l'extraction de gaz naturel sur l'occurrence de trois oiseaux de prairie. *Avian Conservation and Ecology, 6*(1), 7.

Hansen, J., & Sato, M. (2004). Greenhouse gas growth rates. *Proceedings of the National Academy of Sciences of the United States of America, 101*(46), 16109–16114.

Hansen, J., Sato, M., Kharecha, P., Russell, G., Lea, D. W., & Siddall, M. (2007). Climate change and trace gases. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 365*(1856), 1925–1954.

Harju, S. M., Dzialak, M. R., Taylor, R. C., HAYDEN–WING, L. D., & Winstead, J. B. (2010). Thresholds and Time Lags in Effects of Energy Development on Greater Sage–Grouse Populations. *The Journal of Wildlife Management, 74*(3), 437–448.

Harvey, S., Gowrishankar, V., & Singer, T. (2012). *Leaking Profits: The U.S. Oil and Gas Industry Can Reduce Pollution, Conserve Resources, and Make Money by Preventing Methane Waste.* Natural Resources Defense Council. Retrieved from http://www.nrdc.org/energy/files/Leaking-Profits-Report.pdf

Health, S. of W. D. of. (2013). *Associations of Short-Term Exposure to Ozone and Respiratory Outpatient Clinic Visits — Sublette County, Wyoming, 2008–2011.* Cheyenne, WY. Retrieved from files/162/1038__WY_DeptOfHealth_2013_ShortTermOzoneExposureEffects_SubletteCounty.pdf

Hein, C. D. (2012). Potential impacts of shale gas development on bat populations in the northeastern United States. *Austin, Texas: Bat Conservation International.*

Hill, E. L. (2012). Unconventional natural gas development and infant health: Evidence from Pennsylvania. *Charles H. Dyson School of Applied Economics and Management Working Paper, 12.*

Holland, A. (2013). Earthquakes Triggered by Hydraulic Fracturing in South-Central Oklahoma. *Bulletin of the Seismological Society of America, 103*(3), 1784–1792. doi:10.1785/0120120109

Holloran, M. J., Kaiser, R. C., & Hubert, W. a. (2010). Yearling Greater Sage-Grouse Response to Energy Development in Wyoming. *Journal of Wildlife Management, 74*(1), 65–72. doi:10.2193/2008-291

Horton, S. (2012). Disposal of Hydrofracking Waste Fluid by Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquake. *Seismological Research Letters, 83*(2), 250–260. doi:10.1785/gssrl.83.2.250

Howarth, R. W., Santoro, R., & Ingraffea, A. (2011). Methane and the greenhouse-gas footprint of natural gas from shale formations. *Climatic Change, 106*(4), 679–690.

Hughes, J. D. (2013). Energy: A reality check on the shale revolution. *Nature, 494*(7437), 307–308. doi:10.1038/494307a

Hultman, N., Rebois, D., Scholten, M., & Ramig, C. (2011). The greenhouse impact of unconventional gas for electricity generation. *Environmental Research Letters, 6*(4), 44008.

Ingelfinger, F., & Anderson, S. (2004). Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. *Western North American Naturalist, 64*(3), 385–395.

Initiative, M. I. T. E. (2011). The future of natural gas: An interdisciplinary MIT Study. *Massachusetts Institute of Technology, Cambridge, MA.*

Jackson, R. B., Vengosh, A., Darrah, T. H., Warner, N. R., Down, A., Poreda, R. J., … Karr, J. D. (2013). Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proceedings of the National Academy of Sciences of the United States of America, 110*(28), 11250–5. doi:10.1073/pnas.1221635110

Jackson, R. E., Gorody, A. W., Mayer, B., Roy, J. W., Ryan, M. C., & Van Stempvoort, D. R. (2013). Groundwater Protection and Unconventional Gas Extraction: The Critical Need for Field-Based Hydrogeological Research. *Groundwater, 51*(4), 488–510. doi:10.1111/gwat.12074

Jeong, S., Hsu, Y., Andrews, A. E., Bianco, L., Vaca, P., Wilczak, J. M., & Fischer, M. L. (2013). A multitower measurement network estimate of California's methane emissions. *Journal of Geophysical Research: Atmospheres, 118*(19), 11–339.

Jiang, M., Griffin, W. M., Hendrickson, C., Jaramillo, P., VanBriesen, J., & Venkatesh, A. (2011). Life cycle greenhouse gas emissions of Marcellus shale gas. *Environmental Research Letters, 6*(3), 34014.

Johnson, N., Gagnolet, T., Ralls, R., Zimmerman, E., Eichelberger, B., Tracey, C., … Bearer, S. (2010). Pennsylvania Energy Impacts Assessment Report 1: Marcellus Shale Natural Gas and Wind. *Harrisburg, PA, US: The Nature Conservancy-Pennsylvania Chapter.*

Karion, A., Sweeney, C., Pétron, G., Frost, G., Michael Hardesty, R., Kofler, J., … Conley, S. (2013). Methane emissions estimate from airborne measurements over a western United States natural gas field. *Geophysical Research Letters, 40*(16), 4393–4397. doi:10.1002/grl.50811

Kassotis, C. D., Tillit, D. E., Davis, J. W., Hormann, A. M., & Nagel, S. C. (2013). Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region - en.2013-1697. *Endocrinology,* 1–11. Retrieved from http://press.endocrine.org/doi/pdf/10.1210/en.2013-1697

Katzenstein, A. S., Doezema, L. a, Simpson, I. J., Blake, D. R., & Rowland, F. S. (2003). Extensive regional atmospheric hydrocarbon pollution in the southwestern United States. *Proceedings of the National Academy of Sciences of the United States of America, 100*(21), 11975–9. doi:10.1073/pnas.1635258100

Keranen, K. M., Savage, H. M., Abers, G. A., & Cochran, E. S. (2013). Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 Mw 5.7 earthquake sequence. *Geology, 41*(6), 699–702.

Kim, W. (2013). Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio. *Journal of Geophysical Research: Solid Earth, 118*(7), 3506–3518.

Kresse, T. M., Warner, N. R., Hays, P. D., Down, A., Vengosh, A., & Jackson, R. B. (2012). Shallow groundwater quality and geochemistry in the Fayetteville Shale gas-production area, north-central Arkansas, 2011. *US Geol. Surv. Scient. Invest. Rep, 5273.*

Landon, M. K., & Belitz, K. (2012). Geogenic sources of benzene in aquifers used for public supply, California. *Environmental Science & Technology, 46*(16), 8689–97. Retrieved from http://dx.doi.org/10.1021/es302024c

Litovitz, A., Curtright, A., Abramzon, S., Burger, N., & Samaras, C. (2013). Estimation of regional air-quality damages from Marcellus Shale natural gas extraction in Pennsylvania. *Environmental Research Letters, 8*(1), 014017. doi:10.1088/1748-9326/8/1/014017

Llenos, A. L., & Michael, A. J. (2013). Modeling earthquake rate changes in Oklahoma and Arkansas: possible signatures of induced seismicity. *Bulletin of the Seismological Society of America, 103*(5), 2850–2861.

Love, M. S., Saiki, M. K., May, T. W., & Yee, J. L. (2013). Whole-body ConCentrations of elements in three fish species from offshore oil platforms and natural areas in the southern California bight, usa. *Bulletin of Marine Science, 89*(3), 717–734.

Lustgarten, A. (2012). Injection Wells: The Poison Beneath Us. ProPublica.

Maclean, I. M. D., & Wilson, R. J. (2011). Recent ecological responses to climate change support predictions of high extinction risk. *Proceedings of the National Academy of Sciences, 108*(30), 12337–12342.

Martin, M., & Castle, W. (1984). Petrowatch: petroleum hydrocarbons, synthetic organic compounds, and heavy metals in mussels from the Monterey Bay area of central California. *Marine Pollution Bulletin, 15*(7), 259–266.

Mccawley, M. (2013). *Air, Noise, and Light Monitoring Results For Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD – 10 Project).* Charleston, West Virginia.

McKenzie, L. M., Guo, R., Witter, R. Z., Savitz, D. A., Newman, L. S., & Adgate, J. L. (2014). Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. *Environ Health Perspect, 122*(4), 412–417.

McKenzie, L. M., Witter, R. Z., Newman, L. S., & Adgate, J. L. (2012). Human health risk assessment of air emissions from development of unconventional natural gas resources. *The Science of the Total Environment, 424,* 79–87. doi:10.1016/j.scitotenv.2012.02.018

McMahon, P. B., Thomas, J. C., & Hunt, A. G. (2011). *Use of diverse geochemical data sets to determine sources and sinks of nitrate and methane in groundwater, Garfield County, Colorado, 2009.* US Department of the Interior, US Geological Survey.

Mee, A., Snyder, N. F. R., & Hall, L. S. (2007). California Condors in the 21 st Century—Conservation Problems and Solutions. *California Condors in the 21st Century,* 243–279.

Miller, S. M., Wofsy, S. C., Michalak, A. M., Kort, E. A., Andrews, A. E., Biraud, S. C., … Janssens-Maenhout, G. (2013). Anthropogenic emissions of methane in the United States. *Proceedings of the National Academy of Sciences, 110*(50), 20018–20022.

Myers, T. (2012). Potential contaminant pathways from hydraulically fractured shale to aquifers. *Groundwater, 50*(6), 872–882.

National Research Council. (2013). *Induced Seismicity Potential in Energy Technologies.* Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/openbook.php?record_id=13355

Ohio Department of Natural Resources. (2008). *Report on the Investigation of the Natural Gas Invasion of Aquifers in Bainbridge Township of Geauga County, Ohio.* Retrieved June 24, 2014, from https://s3.amazonaws.com/propublica/assets/natural_gas/ohio_methane_report_080901.pdf

Olaguer, E. P. (2012). The potential near-source ozone impacts of upstream oil and gas industry emissions. *Journal of the Air & Waste Management Association, 62*(8), 966–977. doi:10.1080/10962247.2012.688923

Osborn, S. G., Vengosh, A., Warner, N. R., & Jackson, R. B. (2011). Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences of the United States of America, 108*(20), 8172–6. doi:10.1073/pnas.1100682108

OSHA-NIOSH. (2012). Hazard Alert: Worker Exposure to Silica during Hydraulic Fracturing. OSHA. Retrieved from files/143/1033__OSHA_NIOSH_HazardAlert_WorkerExposureToSilicaDuringHydraulicFracturing.pdf

Ostro, B., Lipsett, M., Reynolds, P., Goldberg, D., Hertz, A., Garcia, C., … Bernstein, L. (2010a). Long-term exposure to constituents of fine particulate air pollution and mortality: results from the California Teachers Study. *Environmental Health Perspectives (Online), 118*(3), 363.

Ostro, B., Lipsett, M., Reynolds, P., Goldberg, D., Hertz, A., Garcia, C., … Bernstein, L. (2010b). Long-term exposure to constituents of fine particulate air pollution and mortality: results from the California Teachers Study. *Environmental Health Perspectives, 118*(3), 363–9. doi:10.1289/ehp.0901181

Papoulias, D. M., & Velasco, A. L. (2013). Histopathological Analysis of Fish from Acorn Fork Creek, Kentucky, Exposed to Hydraulic Fracturing Fluid Releases, *12*(4), 92–111.

Peischl, J., Ryerson, T. B., Brioude, J., Aikin, K. C., Andrews, a. E., Atlas, E., … Parrish, D. D. (2013). Quantifying sources of methane using light alkanes in the Los Angeles basin, California. *Journal of Geophysical Research: Atmospheres, 118*(10), 4974–4990. doi:10.1002/jgrd.50413

Pétron, G., Frost, G., Miller, B. R., Hirsch, A. I., Montzka, S. a., Karion, A., … Tans, P. (2012). Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study. *Journal of Geophysical Research, 117*(D4), D04304. doi:10.1029/2011JD016360

Ramirez Jr, P. (2010). Bird mortality in oil field wastewater disposal facilities. *Environmental Management, 46*(5), 820–826.

Rattner, B. A., Capizzi, J. L., King, K. A., LeCaptain, L. J., & Melancon, M. J. (1995). Exposure and effects of oilfield brine discharges on western sandpipers (Calidris mauri) in Nueces Bay, Texas. *Bulletin of Environmental Contamination and Toxicology, 54*(5), 683–689.

Record of Decision and Resource Management Plan Amendments for the Powder River Basin Oil and Gas Project. (2013). Retrieved from http://www.blm.gov/pgdata/etc/medialib/blm/wy/information/NEPA/prb-rod.Par.71614.File.dat/00rod.pdf

Revised Draft Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program. (2011). Retrieved from http://www.dec.ny.gov/data/dmn/rdsgeisfull0911.pdf

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., & Pounds, J. A. (2003). Fingerprints of global warming on wild animals and plants. *Nature, 421*(6918), 57–60.

Rowe, G., Hurkmans, R., & Jones, N. (2004). Unlocking the Monterey Shale Potential at Elk Hills: A Case Study. In *Proceedings of SPE International Thermal Operations and Heavy Oil Symposium and Western Regional Meeting.* Society of Petroleum Engineers. doi:10.2118/86993-MS

S.S. Papadopulos & Associates Inc. (2008). Phase II Hydrogeologic Characterization of the Mamm Creek Field Area , Garfield County , Colorado, (September). Retrieved from http://s3.amazonaws.com/propublica/assets/methane/garfield_county_final2.pdf

Sawyer, H., Kauffman, M. J., & Nielson, R. M. (2009). Influence of Well Pad Activity on Winter Habitat Selection Patterns of Mule Deer. *Journal of Wildlife Management, 73,* 1052–1061. doi:2

Sawyer, H., Nielson, R. M., Lindzey, F., & McDONALD, L. L. (2006). Winter habitat selection of mule deer before and during development of a natural gas field. *Journal of Wildlife Management, 70*(2), 396–403.

Simons, E. A., & Akin, M. (1987). Dead endangered species in a California oil spill. In *International Oil Spill Conference* (Vol. 1987, pp. 417–418). American Petroleum Institute.

Sloto, R. A. (2013). *Baseline Groundwater Quality from 20 Domestic Wells in Sullivan County, Pennsylvania, 2012.* US Department of the Interior, US Geological Survey.

Sullivan, P. (2012). Endangered earth: Fracking in the Golden State. *Center for Biological Diversity,* 12. Retrieved from http://www.biologicaldiversity.org/publications/earth/newsletter-fall-2012.pdf

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., … Williams, S. E. (2004). Extinction risk from climate change. *Nature, 427,* 145–148. doi:10.1038/nature02121

Thomson, J. L., Schaub, T. S., Culver, N. W., & Aengst, P. C. (2005). Wildlife at a crossroads: energy development in western Wyoming. *Washington, DC: The Wilderness Society.*

Thyne, G. (2008). Review of Phase II Hydrogeologic Study Prepared for Garfield County. Retrieved from http://celdf.org/downloads/Gas - Thyne Study of methane in groundwater 2008.pdf

Timoney, K. P., & Ronconi, R. A. (2010). Annual bird mortality in the bitumen tailings ponds in Northeastern Alberta, Canada. *The Wilson Journal of Ornithology.*

Trail, P. W. (2006). Avian mortality at oil pits in the United States: a review of the problem and efforts for its solution. *Environmental Management, 38*(4), 532–544.

US Energy Information Administration (2012). *Annual Energy Outlook 2012: With Projections to 2035.* Government Printing Office.

U.S. Environmental Protection Agency. (1995). *Response of the U.S. Environmental Protection Agency to Petition for Promulgation of Rule Withdrawing Approval of Alabama's Underground Injection Control Program.* Retrieved June 24, 2014, from http://energyindepth.org/docs/pdf/Browner-Letter-Full-Response.pdf

U.S. Environmental Protection Agency. (2004). *Chapter 4: Hydraulic Fracturing Fluids, In: Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs, EPA 816-R-04-003, Washington, D.C.*

U.S. Environmental Protection Agency. (2012). *Minimizing and Manageing Potential Impacts of Induced-Seismicity from Class II Disposal Wells: Practical Appraoches.* Washington, D.C. Retrieved from http://www.eenews.net/assets/2013/07/19/document_ew_01.pdf

U.S. Environmental Protection Agency. (2013). *EPA Needs to Improve Air Emissions Data for the Oil and Natural Gas Production Sector.* doi:13-P-0161

U.S. Fish and Wildlife Service. (2005). Recovery plan for vernal pool ecosystems of California and southern Oregon. *US Fish and Wildlife Service, Region 1, Portland, Oregon.*

United States Government Accountability Office. (2012). *Information on Shale Resources, Development, and Environmental and Public Health Risks.*

United States House of Representatives Committee on Energy and Commerce. (2011). *Chemicals Used in Hydraulic Fracturing* (pp. 1–30). Washington, DC. Retrieved from http://conservationco.org/admin/wp-content/uploads/2013/02/Final-Rebuttal-Exhibits.pdf-Adobe-Acrobat-Pro.pdf.

US Government Accountability Office. (2012). *Information on the Quantity, Quality, and Management of Water Produced during Oil and Gas Production.* Washington, DC. Retrieved from http://www.gao.gov/assets/590/587522.pdf

US Government Accountability Office. (2010). *Opportunities Exist to Capture Vented and Flared Natural Gas, Which Would Increase Royalty Payments and Reduce Greenhouse Gases.* Washington D.C.: US GAO. Retrieved from files/158/1042__GAO_2010_OpportunitiesToReduce Methane FugitiveEmissions.pdf

USGS. (2012). *Water Quality Studied in Areas of Unconventional Oil and Gas Development, Including Areas Where Hydraulic Fracturing Techniques are Used, in the United States of unconventional oil and gas development. The analysis uses existing national and regional data.* Washington D.C.: US Department of the Interior, US Geological Survey. Retrieved from files/172/1035__USGS 2012_WaterQualityInAreasWithUnconventionalOilAndGasDevelopment_FS12-3049_508.pdf

USR Corporation. (2006). Phase I Hydrogeologic characterization of the Mamm Creek Field area in Garfield County, (22238121.00006). Retrieved from http://www.garfield-county.com/oil-gas/documents/final_report_1.pdf

Vidic, R. D., Brantley, S. L., Vandenbossche, J. M., Yoxtheimer, D., & Abad, J. D. (2013). Impact of shale gas development on regional water quality. *Science (New York, N.Y.), 340*(6134), 1235009. doi:10.1126/science.1235009

Walker, B. L., Naugle, D. E., & Doherty, K. E. (2007). Greater Sage-Grouse Population Response to Energy Development and Habitat Loss. *Journal of Wildlife Management, 71*(8), 2644–2654. doi:10.2193/2006-529

Warner, N. R., Christie, C. a, Jackson, R. B., & Vengosh, A. (2013). Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. *Environmental Science & Technology, 47*(20), 11849–57. doi:10.1021/es402165b

Warren, R., Price, J., Fischlin, A., de la Nava Santos, S., & Midgley, G. (2011). Increasing impacts of climate change upon ecosystems with increasing global mean temperature rise. *Climatic Change, 106*(2), 141–177.

Warren, R., VanDerWal, J., Price, J., Welbergen, J. A., Atkinson, I., Ramirez-Villegas, J., … Williams, S. E. (2013). Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nature Climate Change, 3*(7), 678–682.

Watson, T., & Bachu, S. (2009). Evaluation of the potential for gas and CO_2 leakage along wellbores. *SPE Drilling & Completion, 21*(1), 115–126. Retrieved from http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-106817-PA

Weller, C. (2002). *Fragmenting our lands: the ecological footprint from oil and gas development.* Wilderness Society.

West Virginia Department of Environmental Protection Office of Oil and Gas. (n.d.). *Air Quality Impacts Occurring From Horizontal Well Drilling And Related Activities. 2013.* Retrieved June 24, 2014, from http://www.dep.wv.gov/oil-and-gas/Horizontal-Permits/Documents/Final Air Quality Report June 28, 2013.pdf

White, E. I. (2012). Consideration of Radiation in Hazardous Waste Produced from Horizontal Hydrofracking. October.

Whiteman, G., Hope, C., & Wadhams, P. (2013). Climate science: Vast costs of Arctic change. *Nature, 499*(7459), 401–403.

Williams, D. F., Cypher, E. A., Kelly, P. A., Miller, K. J., Norvell, N., Phillips, S. F., … Colliver, G. W. (1998). *Recovery Plan for Upland Species of the San Joaquin Valley, California.* United States Fish and Wildlife Service.

Wilson, J. R., & Schwank, J. W. (2013). *Hydraulic Fracturing in the State of Michigan: Technology Technical Report* (p. 29). Retrieved from http://graham.umich.edu/media/files/HF-02-Technology.pdf

Witter, R., McKenzie, L., Towle, M., Stinson, K., Scott, K., Newman, L., & Adgate, J. (2010). Health Impact Assessment for Battlement Mesa, Garfield County Colorado. *University of Colorado Denver, Colorado School of Public Health, Denver, Colorado. En Ligne:* http://www.Garfield-County.com/Modules/ShowDocument.aspx.

Wolske, K., Hoffman, A., & Strickland, L. (2013). *Hydraulic Fracturing in the State of Michigan: Public Perceptions Technical Report* (p. 39). Retrieved from http://graham.umich.edu/media/files/HF-08-Public-Perceptions.pdf

Wyoming Game and Fish Department. (2010). *Recommendations for development of oil and gas resources within important wildlife habitats.* Retrieved from http://pbadupws.nrc.gov/docs/ML1108/ML110810642.pdf

Zielinski, R. A., & Otton, J. K. (1999). *Naturally Occurring Radioactive Materials (NORM) in Produced Water and Oil-field Equipment: An Issue for Energy Industry.* US Department of the Interior, US Geological Survey.

Zou, L., Miller, S. N., & Schmidtmann, E. T. (2006). Mosquito larval habitat mapping using remote sensing and GIS: implications of coalbed methane development and West Nile virus. *Journal of Medical Entomology, 43*(5), 1034–1041.

Zullo, R., & Zhang, W. (2013). *Hydraulic Fracturing in the State of Michigan: Economics Technical Report* (p. 24). Retrieved from http://graham.umich.edu/media/files/HF-07-Economics.pdf

Appendix F
Water Chemistry Data Tables

Table AF-1. Typical Hydraulic Fracturing Fluid Components for Michigan (Wilson and Schwank, 2013).

Component	Concentration	Reason	Common Uses
Fresh Water	80.5%	Solvent or carrier	Drinking
Sand or ceramic	10-20%	Proppant – keeps fractures open to permit oil/gas flow	Playground sand, drinking water filtration
Acids (usually HCl)	0.12%	Helps dissolve minerals, initiate fractures in rock	Swimming pool cleaner
Petroleum Distillates	0.088%	Dissolves polymers, reduces friction	Mineral Oil – laxative, makeup remover, candy
Isopropanol	0.081%	Viscosity increaser	Antiperspirant, glass cleaner, first aid antiseptic
Potassium chloride	0.06%	Creates brine carrier fluid	Low-sodium table salt substitute
Guar gum	0.056%	Water thickener for sand suspen-sion	Thickener used in cosmetics, baked goods, ice cream…
Ethylene Glycol	0.043%	Prevents scale deposits in pipe(s)	Automotive antifreeze, household cleansers, deicer, caulk.
Sodium or Potassium Carbonate	0.011%	Improves the effectiveness of other components such as cross-linkers	Washing detergents, soaps, water softeners, glass, ceramics
Sodium chloride	0.01%	Stabilizes gel polymer chains	Table salt
Polyacrylamide	0.009%	Minimizes friction between fluid and pipe	Water treatment, soil conditioner
Ammonium bisulfite	0.008%	Oxygen remover to prevent pipe corrosion	Cosmetics, food and beverage processing, water treatment
Borate salts	0.007%	Maintains fluid viscosity as T increases	Laundry detergents, hand soaps, cosmetics
Citric acid	0.004%	Prevents precipitation of metal oxides	Food additive, foods and bever-ages, lemon juice
N,N-dimethyl formamide	0.002%	Prevents pipe corrosion	Pharmaceuticals, acrylic fibers, plastics
Glutaraldehyde	0.001%	Eliminates bacteria from produced water	Disinfectant, sterilizer for medical or dental equipment

NOTE: Not all components may be used in every well

Table AF-2. Predominant chemicals in hydraulic fracturing fluids in California (>2% occurrence) with associated CAS numbers based on data from FracFocus, part 1of 3 (see text for details).

Chemical / ingredient name	CAS number	Count of occurrence in hydraulic fracturing fluid	% Occurrence in fracturing fluid	Count of occurrence as additive	Average conc. in fracturing fluid (% mass)	Average additive conc. (% mass)	Oral toxicity (LD_{50}), rat (mg/kg)	Oral toxicity (LD_{50}), mouse (mg/kg)	Oral toxicity (LD_{50}), rabbit (mg/kg)
Quartz (SiO2)	14808-60-7	1384	99.9	4032	23.988	34.1	500	Not Found	Not Found
Guar gum	9000-30-0	1334	96.2	1339	0.198	55.0	6770	8100	7000
Water	7732-18-5	1209	87.2	2047	73.879	94.2	>90000	Not Found	Not Found
Diammonium peroxodisulphate	7727-54-0	1182	85.3	1205	0.012	88.0	495-820	Not Found	Not Found
Sodium hydroxide	1310-73-2	1147	82.8	1148	0.010	10.8	140-340	Not Found	Not Found
Diatomaceous earth, calcined	91053-39-3	1068	77.1	1702	0.014	75.2	Not Found	Not Found	Not Found
Ethylene glycol	107-21-1	1052	75.9	1049	0.029	28.1	4700	7500	Not Found
Cristobalite	14464-46-1	1022	73.7	1022	0.009	1.1	Not Found	Not Found	Not Found
Magnesium nitrate	10377-60-3	1015	73.2	1015	0.000	9.8	5440	Not Found	Not Found
5-Chloro-2-methyl-3(2H)-isothiazolone	26172-55-4	1015	73.2	1015	0.000	9.8	481	Not Found	Not Found
2-Methyl-3(2H)-isothiazolone	2682-20-4	1015	73.2	1015	0.000	4.9	Not Found	Not Found	Not Found
Magnesium chloride	7786-30-3	1015	73.2	1015	0.000	4.9	2800	4700	Not Found
Isotridecanol, ethoxylated	9043-30-5	1014	73.2	959	0.016	5.0	Not Found	Not Found	Not Found
Distillates, petroleum, hydrotreated light	64742-47-8	1000	72.2	1003	0.097	30.2	>15000	Not Found	Not Found
Hemicellulase enzyme concentrate	9025-56-3	992	71.6	658	0.002	3.0	Not Found	Not Found	Not Found
Distillates, petroleum, hydrotreated light paraffinic	64742-55-8	973	70.2		0.098	30.4	>5000	Not Found	Not Found
2-butoxypropan-1-ol	15821-83-7	962	69.4		0.000		Not Found	Not Found	Not Found
1-butoxypropan-2-ol	5131-66-8	962	69.4	966	0.016	5.3	5.66mL/kg~4920mg/kg	Not Found	Not Found
1,2-Ethanediaminium	138879-94-4	939	67.7	943	0.057	60.0	Not Found	Not Found	Not Found
Phosphonic acid	13598-36-2	680	49.1	680	0.000	1.0	1500-1895	1700-2172	Not Found
Boron sodium oxide	1330-43-4	676	48.8	677	0.030	27.6	2660	Not Found	Not Found
Methanol	67-56-1	368	26.6	485	0.068	52.5	5628 - 6970	7300	14400
Borax	1303-96-4	364	26.3	364	0.033	25.3	5660	2000	Not Found
Carbonic acid, dipotassium salt	584-08-7	245	17.7	252	0.191	59.2	1870	2570	Not Found
Sodium chloride	7647-14-5	223	16.1	92	0.005	6.3	3000	4000	Not Found
Potassium hydroxide	1310-58-3	201	14.5	179	0.015	0.6	273 - 1230	Not Found	Not Found
Phenol, polymer with formaldehyde	9003-35-4	197	14.2	199	0.529	3.1	>5000	Not Found	Not Found
Glycerin, natural	56-81-5	160	11.5	108	0.037	0.2	5570-12600	4100	27000
Acetic acid	64-19-7	157	11.3	101	0.008	49.8	3310-3530	4960	1200
Silica	7631-86-9	149	10.8	139	0.174	1.7	>20000	Not Found	Not Found
Isopropanol	67-63-0	148	10.7	150	0.072	18.3	4710-5840	3600-4475	5030-7990
Alcohols, C11-14-iso-, C13-rich, ethoxylated	78330-21-9	114	8.2	109	0.003	0.0	Not Found	Not Found	Not Found
Naphthalene	91-20-3	114	8.2	76	0.001	0.8	490-2600	350 - 710	Not Found
Potassium chloride	7447-40-7	113	8.2	111	0.003	100.0	2600	383	Not Found
Talc	14807-96-6	109	7.9	109	0.000	0.0	Not Found	Not Found	Not Found
Tetrakis(hydroxymethyl)phosphonium sulfate	55566-30-8	109	7.9	109	0.003	0.0	248-333	Not Found	Not Found
Vinylidene chloride/methylacrylate copolymer	25038-72-6	105	7.6	105	0.004	0.0	Not Found	Not Found	Not Found
Alcohols, C7-9-iso-, C8-rich, ethoxylated	78330-19-5	103	7.4	103	0.056	0.2	Not Found	Not Found	Not Found
Ethoxylated C14-15 alcohols	68951-67-7	99	7.1	99	0.018	18.9	Not Found	Not Found	Not Found
Zirconium oxychloride	7699-43-6	94	6.8	94	0.017	0.1	2950-3500	1227	Not Found
Glutaraldehyde	111-30-8	91	6.6	80	0.008	35.3	134-1470	100	1.59 ml/kg (50% aqueous solution) ~ 843 mg/kg
Methenamine	100-97-0	90	6.5	92	0.118	0.6	Not Found	569-1853	Not Found
Quaternary ammonium compounds, bis(hydrogenated tallow alkyl)dimethyl, salts with bentonite	68953-58-2	90	6.5	4	0.015	0.1	>8000	Not Found	Not Found
Solvent naphtha, petroleum, heavy arom.	64742-94-5	83	6.0	86	0.010	8.9	7050	Not Found	Not Found
Acetic anhydride	108-24-7	81	5.8	82	0.015	100.0	1780	Not Found	Not Found

Table AF-2. Continued, part 2 of 3.

Chemical / ingredient name	CAS number	Count of occurrence in hydraulic fracturing fluid	% Occurrence in fracturing fluid	Count of occurrence as additive	Average conc. in fracturing fluid (% mass)	Average additive conc. (% mass)	Oral toxicity (LD_{50}), rat (mg/kg)	Oral toxicity (LD_{50}), mouse (mg/kg)	Oral toxicity (LD_{50}), rabbit (mg/kg)
Poly(oxy-1,2-ethanediyl), alpha-hexyl-omega-hydroxy	31726-34-8	81	5.8	81	0.017	0.1	Not Found	Not Found	Not Found
Glyoxal	107-22-2	79	5.7	80	0.065	30.0	200-7070	400-1280	>3175
D-Glucitol	50-70-4	79	5.7	80	0.022	10.0	15900	17800	Not Found
Monoethanolamine borate (1:x)	26038-87-9	78	5.6	78	0.041	60.0	Not Found	Not Found	Not Found
2,2-Dibromo-3-nitrilopropionamide	10222-01-2	77	5.6	77	0.004	100.0	178-235	Not Found	118
2-Bromo-3-nitrilopropionamide	1113-55-9	77	5.6	77	0.000	5.0	Not Found	Not Found	Not Found
Triethanolamine	102-71-6	74	5.3	74	0.042	0.2	4200-11300	5400-7800	2200
Boric acid	10043-35-3	70	5.1	71	0.016	30.0	2660-4000	3450	Not Found
Diethylene glycol	111-46-6	70	5.1	68	0.000	0.1	12565-16600	13300-26500	26900
Trimethyl borate	121-43-7	70	5.1	70	0.015	30.0	6140	1290	Not Found
Sodium persulfate	7775-27-1	70	5.1	70	0.005	100.0	Not Found	Not Found	Not Found
2-ethylhexan-1-ol	104-76-7	69	5.0	69	0.000	0.0	2049-3730	2500	1180-1470
Oleic acid	112-80-1	69	5.0	69	0.000	0.0	25000-74000	28000	Not Found
Potassium acetate	127-08-2	69	5.0	68	0.000	0.0	3250	Not Found	Not Found
Potassium cis-9-octadecenoic acid	143-18-0	69	5.0	69	0.000	0.0	>5000	>5000	Not Found
Propylene glycol	57-55-6	69	5.0	69	0.000	0.0	20000-37000	22000-31800	18000-19000
Bis(2-ethylhexyl) sodium sulfosuccinate	577-11-7	69	5.0	69	0.001	0.0	1900-4620	2640	Not Found
Dicoco dimethyl ammonium chloride	61789-77-3	69	5.0	69	0.001	0.0	960	Not Found	Not Found
Alcohols, C10-14, ethoxylated	66455-15-0	69	5.0	69	0.002	0.0	Not Found	Not Found	Not Found
Phenol, 4,4'-(1-methylethylidene)bis-, polymer with 2-(chloromethyl)oxirane, 2-methyloxirane and oxirane	68123-18-2	69	5.0	69	0.007	0.0	Not Found	Not Found	Not Found
Poloxalene	9003-11-6	69	5.0	69	0.002	0.0	5700	3000-45000	Not Found
Calcium chloride anhydrous	10043-52-4	68	4.9	66	0.001	0.0	1000-4179	1940-2045	100-1000
2-Propenoic acid, polymer with sodium phosphinate (1:1), sodium salt	129898-01-7	66	4.8	66	0.011	0.1	Not Found	Not Found	Not Found
2-Butoxyethanol	111-76-2	62	4.5	32	0.028	40.9	470-3000	1200-1519	320
Acetyltriethyl citrate	77-89-4	59	4.3		0.024		7000	1150	Not Found
Citric acid	77-92-9	56	4.0	58	0.022	60.9	3000- 6730	5040	7000
Boric acid, dipotassium salt	1332-77-0	53	3.8	53	0.099	0.4	Not Found	Not Found	Not Found
Tryptones	73049-73-7	47	3.4	6	0.002	5.0	Not Found	Not Found	Not Found
Extract of yeast	08013-01-2	47	3.4	6	0.002	5.0	Not Found	Not Found	Not Found
Teflon	9002-84-0	47	3.4	47	0.000	0.0	Not Found	Not Found	Not Found
Polyethylene glycol	25322-68-3	44	3.2	44	0.001	0.0	600-51310	28915-36000	14000-76000
Formaldehyde, polymer with 4-nonylphenol and oxirane	30846-35-6	44	3.2	44	0.005	0.0	Not Found	Not Found	Not Found
Quaternary ammonium compounds, benzyl-C10-16alkyldimethyl, chlorides	68989-00-4	44	3.2	44	0.003	0.0	400-900	Not Found	Not Found
Alcohols, C9-11-iso-, C10-rich, ethoxylated	78330-20-8	44	3.2	44	0.006	0.0	Not Found	Not Found	Not Found
Cellulase	9012-54-8	44	3.2	58	0.008	21.2	Not Found	Not Found	Not Found
Sodium sulfate	7757-82-6	43	3.1		0.001		5989	193-6346	Not Found
Naphtha, petroleum, hydrotreated heavy	64742-48-9	42	3.0	42	0.304	60.0	>15000	Not Found	Not Found
Mannanase, endo-1,4-beta-	37288-54-3	41	3.0		0.001		Not Found	Not Found	Not Found
Ampicillin	69-53-4	41	3.0		0.001		10000	15200	Not Found
Cellulose, microcrystalline	9004-34-6	41	3.0		0.001		>5000	Not Found	Not Found
Ethanol	64-17-5	39	2.8	41	0.031	27.7	7060-10600	3450	63000
Hydrogen peroxide	7722-84-1	39	2.8	39	0.000	0.3	376-1617	2000	820
Decyldimethylamine	1120-24-7	38	2.7	38	0.000	0.0	Not Found	Not Found	Not Found
N,N-Dimethyldecylamine oxide	2605-79-0	38	2.7	38	0.020	0.1	Not Found	Not Found	Not Found
Ammonium chloride	12125-02-9	37	2.7	30	0.061	50.3	1650	1300	Not Found
Solvent naphtha, petroleum, light arom.	64742-95-6	33	2.4	33	0.012	16.8	3500-14000	Not Found	Not Found
Hydrogen chloride	7647-01-0	33	2.4	46	0.799	22.5	238-277	Not Found	900
Sodium bicarbonate	144-55-8	32	2.3		0.065		4220	3360	Not Found
Poly(oxy-1,2-ethanediyl), alpha-tridecyl-omega-hydroxy	24938-91-8	31	2.2				Not Found	Not Found	Not Found
1,2,4-Trimethylbenzene	95-63-6	31	2.2	33	0.001	2.8	3280-6000	Not Found	Not Found

Table AF-2. Continued, part 3 of 3.

Chemical / ingredient name	CAS number	Count of occurrence in hydraulic fracturing fluid	% Occurrence in fracturing fluid	Count of occurrence as additive	Average conc. in fracturing fluid (% mass)	Average additive conc. (% mass)	Oral toxicity (LD_{50}), rat (mg/kg)	Oral toxicity (LD_{50}), mouse (mg/kg)	Oral toxicity (LD_{50}), rabbit (mg/kg)
Propargyl alcohol	107-19-7	29	2.1	31	0.001	7.7	20 -110	50	Not Found
Thiourea, polymer with formaldehyde and 1-phenylethanone	68527-49-1	29	2.1	20	0.003	19.5	Not Found	Not Found	Not Found

Oral Toxicity: LD_{50} ($mg_{chemical}/kg_{animal}$)
Category 1: x<5
Category 2: 5<x<50
Category 3: 50<x<300
Category 4: 300<x<2000
Category 5: 2000<x<5000
Category >5: x>5000

Table AF-3. Constituents without CAS numbers reported in hydraulic fracturing fluids in California (>2% occurrence) based on data from FracFocus (see text for details).

Chemical / ingredient name	Count of occurrence in hydraulic fracturing fluid	% Occurrence in fracturing fluid	Count of occurrence as additive	Average conc. in fracturing fluid (% mass)	Average additive conc. (% mass)
Amino Alkyl Phosphonic Acid	679	49.0	679	0.006	30.0
Contains non-hazardous ingredients which are listed in in the non-MSDS section of the report	253	18.3	182	0.068	100.0
No Hazardous Ingredients	135	9.7	136	0.048	100.0
Water (Including Mix Water Supplied by Client)	131	9.5	n/a	74.680	n/a
Petroleum Distillate Blend	127	9.2	127	0.549	70.0
Hemicellulase Enzyme	111	8.0	111	0.010	100.0
N.A.	89	6.4	89	0.069	100.0
Mixture of Surfactants	80	5.8	80	0.081	60.0
EDTA/Copper chelate	62	4.5	62	0.008	30.0
Carbohydrates	44	3.2	58	0.035	97.1
Non-hazardous Ingredients	41	3.0	41	0.067	100.0
Cured Acrylic Resin	38	2.7	n/a	0.001	n/a
Alkanes / Alkenes	33	2.4	33	0.291	45.0
Proprietary	33	2.4	33	0.030	61.2
Sulfonate	29	2.1	29	0.007	9.8
Ethoxylated nonylphenol	28	2.0	38	0.104	35.8
Non-Hazardous Ingredient	28	2.0	31	0.040	100.0

Table AF-4. Chemicals listed on matrix acidizing notices in California, part 1 of 2 (see text for details).

Chemical / ingredient name	CAS number	# of wells	% of wells	Oral toxicity (LD_{50}), rat (mg/kg)	Oral toxicity (LD_{50}), mouse (mg/kg)	Oral toxicity (LD_{50}), rabbit (mg/kg)
2-Ethyl hexanol	104-76-7	36	100%	2049-3730	2500	1180-1470
Ethylene glycol	107-21-1	36	100%	4700	7500	Not Found
2-butoxyethanol	111-76-2	36	100%	470-3000	1200-1519	320
Dodecylbenzene sulfonic acid	27176-87-0	36	100%	500-2000	Not Found	Not Found
Methanol	67-56-1	36	100%	5628 - 6970	7300	14400
Isopropanol	67-63-0	36	100%	4710-5840	3600-4475	5030-7990
Hydrochloric Acid	7647-01-0	36	100%	238-277	Not Found	900
Water	7732-18-5	36	100%	>90000	Not Found	Not Found
Poly(oxy-1,2-ethanediyl), alpha-hexyl-omega-hydroxy(C2H4O)n(C6H14O) or Polyethylene glycol monohexyl ether	31726-34-8	36	100%	Not Found	Not Found	Not Found
Acetic acid	64-19-7	29	81%	3310-3530	4960	1200
Benzaldehyde	100-52-7	19	53%	800-1600	28-1600	Not Found
Cinnamaldehyde	104-55-2	19	53%	2220-3400	200-3400	Not Found
Diethylene glycol	111-46-6	19	53%	12565-16600	13300-26500	26900
Ammonium bifluoride	1341-49-7	19	53%	130	Not Found	Not Found
Hydroxylamine hydrochloride	5470-11-1	19	53%	141	408	Not Found
Amine oxides, cocoalkyldimethyl	61788-90-7	19	53%	Not Found	Not Found	Not Found
Formic Acid	64-18-6	19	53%	1100	700	Not Found
Ethoxylated hexanol	68439-45-2	19	53%	Not Found	Not Found	Not Found
Alcohols, C12-16, ethoxylated	68551-12-2	19	53%	Not Found	Not Found	Not Found
Copper dichloride	7447-39-4	19	53%	140-584	190-233	Not Found
Ethylene oxide	75-21-8	19	53%	72-330	280-365	Not Found
Silica, amorphous - fumed	7631-86-9	19	53%	>20000	Not Found	Not Found
Sodium iodide	7681-82-5	19	53%	4340	1000	Not Found
Citric Acid	77-92-9	19	53%	3000- 6730	5040	7000
Poly(oxy-1,2-ethandiyl), a-(nonylphenyl)-w-hydroxy-	9016-45-9	19	53%	1310-16000	>50000	Not Found
Magnesium nitrate	10377-60-3	17	47%	5440	Not Found	Not Found
Prop-2-yn-1-ol	107-19-7	17	47%	20 -110	50	Not Found
Oleic acid	112-80-1	17	47%	25000-74000	28000	Not Found
Dodecylbenzene (impurity)	123-01-3	17	47%	>5000	Not Found	Not Found
Linear/branched alcohol ethoxylate (11eo)	127036-24-2	17	47%	Not Found	Not Found	Not Found
Acetic acid, potassium salt	127-08-2	17	47%	3250	Not Found	Not Found
Sodium hydroxide	1310-73-2	17	47%	140-340	Not Found	Not Found
Disodium ethylene diamine tetra acetate (impurity)	139-33-3	17	47%	2000-3700	400-2050	2300
Potassium oleate	143-18-0	17	47%	>5000	>5000	Not Found
Cristobalite	14464-46-1	17	47%	Not Found	Not Found	Not Found
Crystalline silica	14808-60-7	17	47%	500	Not Found	Not Found
Trisodium ethylenediaminetetraacetate (impurity)	150-38-9	17	47%	2150	2150	Not Found
Poly(oxy-1,2-ethanediyl)	25322-68-3	17	47%	600-51310	28915-36000	14000-76000
5-chloro-2-methyl-2h-isothiazolol-3-one	26172-55-4	17	47%	481	Not Found	Not Found
2-methyl-2h-isothiazol-3-one	2682-20-4	17	47%	Not Found	Not Found	Not Found
Sodium glycolate (impurity)	2836-32-0	17	47%	7110	6700	Not Found
Ethoxylated propoxylated 4-nonylphenol-formaldehyde resin	30846-35-6	17	47%	Not Found	Not Found	Not Found
Alcohol, C11 linear, ethoxylated	34398-01-1	17	47%	Not Found	Not Found	Not Found
Trisodium nitrilotriacetate (impurity)	5064-31-3	17	47%	1100-3500	681-3160	>3500
Glycerol	56-81-5	17	47%	5570-12600	4100	27000
Propylene glycol	57-55-6	17	47%	20000-37000	22000-31800	18000-19000
Dioctyl sulfosuccinate sodium salt	577-11-7	17	47%	1900-4620	2640	Not Found
Dicoco dimethyl quaternary ammonium chloride	61789-77-3	17	47%	960	Not Found	Not Found
Fatty acids, tall-oil	61790-12-3	17	47%	3200-74000	4600	Not Found
Sodium erythorbate	6381-77-7	17	47%	>5000	Not Found	Not Found
Tetrasodium ethylenediaminetetraacetate	64-02-8	17	47%	1658-4500	20.5-30	Not Found
Heavy aromatic naphtha	64742-94-5	17	47%	7050	Not Found	Not Found
Alkenes, C>10 a-	64743-02-8	17	47%	Not Found	Not Found	Not Found
Alkyl (C10-C14) alcohols, ethoxylated	66455-15-0	17	47%	Not Found	Not Found	Not Found
Crosslinked PO/EO-block polymer	68123-18-2	17	47%	Not Found	Not Found	Not Found
Coco-amido-propylamine oxide	68155-09-9	17	47%	Not Found	Not Found	Not Found
Alcohol, C9-C11, Ethoxylated	68439-46-3	17	47%	1378	Not Found	Not Found
Thiourea, polymer with formaldehyde and 1-phenylethanone	68527-49-1	17	47%	Not Found	Not Found	Not Found
Alcohols, C14-15, ethoxylated (7EO)	68951-67-7	17	47%	Not Found	Not Found	Not Found

Table AF-4. Continued, part 2 of 2 (see text for details).

Chemical / ingredient name	CAS number	# of wells	% of wells	Oral toxicity (LD_{50}), rat (mg/kg)	Oral toxicity (LD_{50}), mouse (mg/kg)	Oral toxicity (LD_{50}), rabbit (mg/kg)
Quaternary ammonium compounds chlorides derivatives	68989-00-4	17	47%	400-900	Not Found	Not Found
Hydrofluoric acid	7664-39-3	17	47%	Not Found	Not Found	Not Found
Sulfuric acid (impurity)	7664-93-9	17	47%	2140	Not Found	Not Found
Magnesium chloride	7786-30-3	17	47%	2800	4700	Not Found
Alcohol, C7-9-iso, C8, ethoxylated	78330-19-5	17	47%	Not Found	Not Found	Not Found
Alcohol, C9-11-iso, C10, ethoxylated	78330-20-8	17	47%	Not Found	Not Found	Not Found
Alcohol, C11-14, ethoxylated	78330-21-9	17	47%	Not Found	Not Found	Not Found
Methyl oxirane polymer with oxirane	9003-11-6	17	47%	2300-5700	1830-45000	35000
Diatomaceous earth, calcined	91053-39-3	17	47%	Not Found	Not Found	Not Found
Naphthalene (impurity)	91-20-3	17	47%	490-2600	350 - 710	Not Found
Ammonium chloride	12125-02-9	1	3%	1650	1300	Not Found

Oral Toxicity: LD_{50} ($mg_{chemical}/kg_{animal}$)
Category 1: x<5
Category 2: 5<x<50
Category 3: 50<x<300
Category 4: 300<x<2000
Category 5: 2000<x<5000
Category >5: x>5000

Appendix G
Mammalian Toxicity

Acute mammalian toxicity is a measurement commonly made for many industrial chemicals that allows comparison of toxicity between chemicals (United Nations 2003). In an acute oral toxicity test, characteristics of chemicals are described in terms of the median lethal dose (LD_{50} value) after ingestion by mice, rats, or other animals. The LD_{50} value is the amount of a chemical required to kill half of the members of a tested population after a specified test duration. Toxicologists use the toxic effects observed in mice and rats as a surrogate for toxicological impacts on humans. In some cases oral toxicity in rabbits may be reported. Furthermore, rodent toxicity tests are highly standardized, affording a comparison between chemicals.

Values for the acute oral toxicity of hydraulic fracturing compounds, with reported CAS numbers and that occur in more than 2% of operations, are reported in Table AF-2. Acute oral toxicity values for matrix acidizing compounds are reported in Table AF-4. Acute oral toxicity information for rat, mouse, and rabbit was compiled from a number of data sources (National Library of Medicine, 2013 and 2014; European Chemicals Agency, 2000; Lewis and Sax, 1996; US EPA, 2013). In order to simplify interpretation of the results and allow comparison between compounds, the oral toxicity data were classified according to the Globally Harmonized System of Classification and Labeling of Chemicals (GHS), which has five levels or categories of toxicity (United Nations, 2003). In the GHS system, Category 1 chemicals have lowest LD_{50} doses and so are the most toxic, and Category 5 compounds have the highest LD_{50} doses and so are the least toxic (see footnote to Table 5-3 for toxicity ranges for GHS categories). For example (Table 5-3), 2,2-dibromo-3-nitrilopropionamide (DBNPA, CAS 10222-01-2) is a biocide with a reported rat oral LD_{50} of between 178 and 235 mg/kg, which places it in GHS Category 3. In contrast, ethylene glycol (CAS 107-21-1) is a solvent, commonly used in anti-freeze, that has a reported rat oral LD_{50} of 4,700 mg/kg, which places it in GHS Category 5. By most interpretations, in relation to potential oral toxicity, DBNPA would be of greater potential concern than ethylene glycol, however the actual hazards associated with the various chemicals depend on many other factors as well as acute oral toxicity.

Appendix H California Council on Science and Technology Study Process

The reports of the California Council on Science and Technology (CCST) are viewed as being valuable and credible because of the institution's reputation for providing independent, objective, and nonpartisan advice with high standards of scientific and technical quality. Checks and balances are applied at every step in the study process to protect the integrity of the reports and to maintain public confidence in them.

Study Process Overview—Ensuring Independent, Objective Advice

For over 25 years, CCST has been advising California on issues of science and technology by leveraging exceptional talent and expertise.

CCST can enlist the state's foremost scientists, engineers, health professionals, and other experts to address the scientific and technical aspects of society's most pressing problems. All serve without pay.

CCST studies are funded by state agencies, foundations and other private sponsors. CCST provides independent advice; external sponsors have no control over the conduct of a study once the statement of task and budget are finalized. Study committees gather information from many sources in public and private meetings but they carry out their deliberations in private in order to avoid political, special interest, and sponsor influence.

Stage 1: Defining the Study

Before the committee selection process begins, CCST staff and members work with sponsors to determine the specific set of questions to be addressed by the study in a formal "statement of task," as well as the duration and cost of the study. The statement of task defines and bounds the scope of the study, and it serves as the basis for determining the expertise and the balance of perspectives needed on the committee.

The statement of task, work plan, and budget must be approved by CCST's Board chair. This review often results in changes to the proposed task and work plan. On occasion, it results in turning down studies that CCST believes are inappropriately framed or not within its purview.

Stage 2: Committee Selection and Approval

Selection of appropriate committee members, individually and collectively, is essential for the success of a study. All committee members serve as individual experts, not as representatives of organizations or interest groups. Each member is expected to contribute to the project on the basis of his or her own expertise and good judgment. A committee is not finally approved until a thorough balance and conflict-of-interest discussion is held, and any issues raised in that discussion are investigated and addressed. Members of a committee are anonymous until this process is completed.

Careful steps are taken to convene committees that meet the following criteria:

An appropriate range of expertise for the task. The committee must include experts with the specific expertise and experience needed to address the study's statement of task. A major strength of CCST is the ability to bring together recognized experts from diverse disciplines and backgrounds who might not otherwise collaborate. These diverse groups are encouraged to conceive new ways of thinking about a problem.

A balance of perspectives. Having the right expertise is not sufficient for success. It is also essential to evaluate the overall composition of the committee in terms of different experiences and perspectives. The goal is to ensure that the relevant points of view are, in CCST's judgment, reasonably balanced so that the committee can carry out its charge objectively and credibly.

Screened for conflicts of interest. All provisional committee members are screened in writing and in a confidential group discussion about possible conflicts of interest. For this purpose, a "conflict of interest" means any financial or other interest which conflicts with the service of the individual because it could significantly impair the individual's objectivity or could create an unfair competitive advantage for any person or organization. The term "conflict of interest" means something more than individual bias. There must be an interest, ordinarily financial, which could be directly affected by the work of the committee. Except for those rare situations in which CCST determines that a conflict of interest is unavoidable and promptly and publicly disclose the conflict of interest, no individual can be appointed to serve (or continue to serve) on a committee of the institution used in the development of reports if the individual has a conflict of interest that is relevant to the functions to be performed.

Point of View is different from Conflict of Interest. A point of view or bias is not necessarily a conflict of interest. Committee members are expected to have points of view, and CCST attempts to balance these points of view in a way deemed appropriate for the task. Committee members are asked to consider respectfully the viewpoints of other members, to reflect their own views rather than be a representative of any organization, and to base their scientific findings and conclusions on the evidence. Each committee member has the right to issue a dissenting opinion to the report if he or she disagrees with the consensus of the other members.

Other considerations. Membership in CCST and previous involvement in CCST studies are taken into account in committee selection. The inclusion of women, minorities, and young professionals are additional considerations.

Specific steps in the committee selection and approval process are as follows:

Staff solicit an extensive number of suggestions for potential committee members from a wide range of sources, then recommend a slate of nominees. Nominees are reviewed and approved at several levels within CCST. A provisional slate is then approved by CCST's Board. The provisional committee members complete background information and conflict-of-interest disclosure forms. The committee balance and conflict-of-interest discussion is held at the first committee meeting. Any conflicts of interest or issues of committee balance and expertise are investigated; changes to the committee are proposed and finalized. Committee is formally approved. Committee members continue to be screened for conflict of interest throughout the life of the committee.

Stage 3: Committee Meetings, Information Gathering, Deliberations, and Drafting the Report

Study committees typically gather information through:

1) meetings;

2) submission of information by outside parties;

3) reviews of the scientific literature; and

4) investigations by the committee members and staff.

In all cases, efforts are made to solicit input from individuals who have been directly involved in, or who have special knowledge of, the problem under consideration.

The committee deliberates in meetings closed to the public in order to develop draft findings and recommendations free from outside influences. The public is provided with brief summaries of these meetings that include the list of committee members present. All analyses and drafts of the report remain confidential.

Stage 4: Report Review

As a final check on the quality and objectivity of the study, all CCST reports whether products of studies, summaries of workshop proceedings, or other documents must undergo a rigorous, independent external review by experts whose comments are provided anonymously to the committee members. CCST recruits independent experts with a range of views and perspectives to review and comment on the draft report prepared by the committee.

The review process is structured to ensure that each report addresses its approved study charge and does not go beyond it, that the findings are supported by the scientific evidence and arguments presented, that the exposition and organization are effective, and that the report is impartial and objective.

Each committee must respond to, but need not agree with, reviewer comments in a detailed "response to review" that is examined by one or two independent report review "monitors" responsible for ensuring that the report review criteria have been satisfied. While feedback from the peer reviewers and report monitors is reflected in the report, neither group approved the final report before publication. The steering committee and CCST take sole responsibility for the content of the report. After all committee members and appropriate CCST officials have signed off on the final report, it is transmitted to the sponsor of the study and is released to the public. Sponsors are not given an opportunity to suggest changes in reports. All reviewer comments remain confidential. The names and affiliations of the report reviewers are made public when the report is released.

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