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Citizenships: Canada, United States and United Kingdom.

Education

- B.Sc. University of Toronto, 1986: Physics.
- Ph.D. Massachusetts Institute of Technology, 1991: Experimental Physics, "An Interferometer for Atoms", supervised by David Prichard.

Academic Employment

2011–Present: Gordon McKay Professor of Applied Physics in the School of Engineering and Applied Sciences (SEAS) and Professor of Public Policy at the Harvard Kennedy School, Harvard University.

2009–Present: President, Carbon Engineering Ltd.

2004–2011: University of Calgary, Canada Research Chair in Energy and the Environment; Director and Professor, ISEEE Energy and Environmental Systems Group; Professor, Department of Chemical and Petroleum Engineering; Adjunct Professor, Faculty of Environmental Design, 2007-present, Faculty of Physics and Astronomy, 2010-present, and Department of Economics, 2004-2008.

1999– 2011: Carnegie Mellon University, Department of Engineering and Public Policy, Adjunct Professor, 2004-2011; Assistant Professor, 1999-2003; Adjunct Assistant Professor, 1992-1999; Post-Doctoral Fellow, 1991-1992.

1993–1999: Research Scientist, Harvard University, Department of Earth and Planetary Science.

1992–1993: National NOAA Global Change Fellowship, National Center for Atmospheric Research, Climate Modeling Section.

Awards

- Time Magazine, Hero of the Environment, 2009.
- The City of Calgary Award for Environmental Achievement by an Individual, 2008.
- Canadian Geographical Society, Environmental Scientist of the Year, 2006.
- MIT Martin Deutsch Prize, MIT's biennial prize for excellence in experimental physics, 1989.
- Canadian Association of Physicists, National University Prize Exam, First prize, 1986.

Research Foci

My research has spanned four domains: climate-related technology assessment and policy analysis, technology development, atmospheric science, and physics.

- *Climate-related technology and policy assessment*, including:
  - Methods for eliciting and analyzing quantitative expert judgments about climate science and energy technologies from climate sensitivity to solar PV.
  - Environmental impacts of energy technologies including the development of Canada's leading effort to assess the lifecycle impacts of oil sands technologies; the first study of the climate

impact of large-scale wind power; and most recently, the development of new methods for quantifying the land use footprint of energy technologies.
    - Integrated assessment of CO_2 capture and storage (CCS) including early work on its implications for public policy, its risk and costs, the potential for biomass energy with CCS, the factors that determine public perception of these technologies, and the difficulties of managing CCS risks within current regulatory frameworks. In Canada, I served on several high-profile committees that influenced governments to commit $2B to a set of commercial CCS demonstration projects.
    - Technology assessments examining, for example, viability of hydrogen as a transportation fuel and the economics of integrating large-scale wind power into electricity systems.
    - Assessment of geoengineering. In 1990 I wrote one of the first comparative technology and policy assessments of geoengineering, work that grew into a more systematic look at the technology and its historical roots. Over the last few years I have organized interdisciplinary meetings on geoengineering, created an annual summer school, and have worked to develop understanding of the risks, governance and public perception of climate engineering.
- *Technology development*. I lead Carbon Engineering, an angel-funded startup company developing industrial-scale technology for direct capture of CO_2 from ambient air. Carbon Engineering will spend more than ~$6M on process engineering and hardware development over the next three years. In addition, I have developed novel methods for engineering reservoirs to minimize risk by CO_2 leakage by accelerating the dissolution of injected CO_2 in brine and new methods of lofting particles to the upper atmosphere for geoengineering using photophoresis.
- *Atmospheric science*. Working for James Anderson at Harvard, I lead the development of a new high-accuracy infrared spectrometer that flew on the NASA ER-2 high-altitude aircraft, an engineering effort that entailed about 15 scientific and technical personnel along with NASA pilots and engineers as well as Arrhenius, a proposed small satellite mission that was a precursor to CLARREO. In addition to experimental work, I used isotopic measurements to constrain models of water vapor transport and did the first analysis of the climatic impacts of wind power.
- *Physics*. As a graduate student with David Prichard I built the first interferometer for atoms, a high-profile experiment that was named among the 10 "hottest" areas of science by ISI and covered in news stories by *Science* and *Nature*; my publications on this work have been cited over 500 times.

Service

- Lead organizer of an annual transdisciplinary summer school on geoengineering jointly managed and funded by The University of Calgary, the University of Heidelberg, and Carnegie Mellon University.
- Member, Research Advisory Board, Electric Power Research Institute.
- Member, Geoengineering Task Force, National Commission on Energy Policy.
- Member, UK Royal Society's geoengineering study panel, 2009.
- Member, Canada's ecoENERGY Carbon Capture and Storage Task Force, 2007. Note: I was the only academic on this seven member panel that included three CEO's and two deputy ministers.
- Member, InterAcademy Council (IAC) study on Transitions to Sustainable Energy, 2007. Note: The IAC is the union of the world's major science academies. I was one of 15 experts world-wide named to their first energy study.
- Member, Canada's National Advisory Panel on Sustainable Energy Technology, "Bruneau report", 2006. Note: I was the only Canadian academic on this ten member panel.
- Member of the US National Academy of Sciences Panel on Benefits of Sequestration R&D.
- Lead author and chair of crosscutting group on Regulation, Legal Issues and Public Perception, of the IPCC Special Report on Carbon Storage. Note: As chair of one of the three crosscutting groups my responsibility was roughly equivalent to a "Convening Lead Author". I became the *de facto* crosscutting lead for issues related to timescales and the risk of leakage, one of the most crucial issues for policymakers.

- Principal organizer of a major international workshop on Industrial Carbon Management, Aspen Global Change Institute, July 2000. The week-long workshop brought together 33 experts on capture technologies, geological and oceanic sequestration, technology policy, and representatives of major US and European environmental organizations.
- Consulting to a consortium of clients including Environment Canada and the provinces of British Columbia, Alberta and Saskatchewan. Developing protocols for managing the risk of geological sequestration of CO_2.

Testimony

Canadian House of Commons, Standing Committee on Energy, the Environment and Natural Resources (The Current State and Future of Canada's Energy Sector [Including Alternative Energy]). Calgary, AB. December 2011.

Canadian House of Commons, Standing Committee on Natural Resources (Energy Security in Canada). Videocon. November 2010.

UK House of Commons, Science and Technology Committee. London, UK. January 2010.

US House of Representatives, Committee on Science and Technology, Subcommittee on Energy and Environment. Geoengineering II: the Scientific Basis and Engineering Challenges. "Learning to manage sunlight: Research needs for Solar Radiation Management". Washington DC, US. February 2010.

Canadian House of Commons, Standing Committee on Energy, the Environment and Natural Resources (The Current State and Future of Canada's Energy Sector [Including Alternative Energy]). Ottawa, ON. April 2010.

Canadian House of Commons, Standing Committee on Natural Resources (Oil Sands). Ottawa, ON. December 2007.

Canadian House of Commons, Standing Committee (The Environment and Sustainable Development). Ottawa, ON. May 2007.

Canadian Legislative Committee. Bill C-30. Ottawa, ON. February 2007.

Publications

See keith.seas.harvard.edu for a more complete list with PDFs.

Under review

Carr, W., C. Preston, L. Yung, D.W. Keith, B. Szerszynski, A. Mercer. Public Engagement on Solar Radiation Management and Why it Needs to Happen Now. *Climatic Change*.

Hossein Safaei, David W. Keith and Ronald J. Hugo. Compressed Air Energy Storage (CAES) with compressors distributed at heat loads to enable waste heat utilization. *Journal of Applied Energy*.

Justin McClellan, David W. Keith, and Jay Apt. Cost analysis of stratospheric albedo modification delivery systems. *Environmental Research Letters*.

Douglas G. MacMartin, David W. Keith, Ben Kravitz, and Ken Caldeira. Managing tradeoffs in geoengineering through optimal choice of non-uniform radiative forcing. *Nature Climate Change*.

Published or accepted

Geoffrey Holmes and David W. Keith. An Air-Liquid Contactor for Large-Scale Capture of CO_2 from Air. *Philosophical Transactions of the Royal Society A – Mathematical, Physical & Engineering Sciences*.

Juan B. Moreno-Cruz and David W. Keith (2012). Climate Policy under Uncertainty: A Case for Geoengineering. *Climatic Change*, DOI 10.1007/s10584-012-0487-4.

Katharine L. Ricke, Dan Rowlands, William J. Ingram, David W. Keith and M. Granger Morgan (2011). Effectiveness of stratospheric solar radiation management as a function of climate sensitivity. *Nature Climate Change*, **2**: 92-96.

H. Safaei Mohamadabadi, R. Hugo and D. Keith (2011). Enhancing the economics of wind-based compressed air energy storage by waste heat recovery. *ASME Energy Sustainability Conference, Washington DC*.

David Keith (2011). Reshaping the energy landscape. *Physics Today*, **64**: 56-57.

A M Mercer, D W Keith and J D Sharp (2011). Public understanding of Solar Radiation Management. *Environmental Research Letters*, doi: 10.1088/1748-9326/6/4/044006.

G. Doluweera, S. Jordaan, J. Bergerson, M. Moore and D. Keith (2011). Evaluating the Role of Cogeneration for Carbon Management in Alberta. *Energy Policy*, doi:10.1016/j.enpol.2011.09.051.

David Keith, Juan Moreno-Cruz (2011). Pitfalls of coal peak production. *Nature*, **469**: 472.

Eduard Cubi Montanya and David W. Keith (2011). LEED, Energy Savings, and Carbon Abatement: Related but Not Synonymous. *Environmental Science and Technology*, **45**: 1757-1758.

Juan Moreno-Cruz, Katharine Ricke and David W. Keith (2011). A simple model to account for regional inequalities in the effectiveness of solar radiation management. *Climatic Change*, doi: 10.1007/s10584-011-0103-z.

Douglas G. MacMynowski, Ho-Jeong Shin, Ken Caldeira and David W. Keith (2011). Can we test geoengineering? *Energy and Environmental Science*, **4**: 5044-5052.

Ghaderi, S., D. Keith, R. Lavoie and Y. Leonenko (2010). Evolution of Hydrogen Sulfide in Sour Saline Aquifers During Carbon Dioxide Sequestration. *International Journal of Greenhouse Gas Control*, **5**: 347-355.

Sonia Yeh, Sarah M Jordaan, Adam R Brandt, Merritt Turetsky, Sabrina Spatari and David Keith (2010). Land Use Greenhouse Gas Emissions from Conventional and Unconventional Oil Production. *Environmental Science & Technology*, **44**: 8766–8772.

Ken Caldeira and David W. Keith (2010). The Need for Climate Engineering Research. *Issues in Science and Technology*, Fall: 57-62.

Jeffrey R. Pierce, Debra K. Weisenstein, Patricia Heckendorn, Thomas Peter and David W. Keith (2010). Efficient formation of stratospheric aerosol for climate engineering by emission of condensable vapor from aircraft. *Geophysical Research Letters*, **37**: L18805.

Keith, D. W. (2010). Photophoretic levitation of aerosols for geoengineering. *Proceedings of the National Academy of Sciences*, **107**:16428-16431.

Kirsten Zickfeld, M. Granger Morgan, David J. Frame and David W. Keith (2010). Expert judgments about transient climate response to alternative future trajectories of radiative forcing. *PNAS*, **107**: 12451-12456.

Joule Bergerson and David Keith (2010). The truth about dirty oil: Is CCS the answer? *Environmental Science & Technology*, **44**: 6010-6015.

Keith, D. W., E. Parsons and M. G. Morgan (2010). Research on global sun block needed now. *Nature*, **463**: 426-427.

Keith, D. W. (2010). Engineering the Planet. *Climate Change Science and Policy*, S. Schneider and M. Mastrandrea eds, p 494-501. Island Press, Washington DC.

Zeidouni, M., M. Pooladi-Darvish and D. W. Keith (2009). Analytical Solution to Evaluate Salt Precipitation during CO_2 Injection in Saline Aquifers. *International Journal of Greenhouse Gas Control Technologies*, **3**: 600-611.

Sharp, J. D., M. K. Jaccard and D. W. Keith (2009). Anticipating Public Attitudes toward Underground CO_2 Storage. *International Journal of Greenhouse Gas Control*, **3**: 641-651.

Rhodes, J. S. and D. W. Keith (2009). Biomass co-utilization with unconventional fossil fuels to advance energy security and climate policy. *A synthesis report Sponsored by the National Commission on Energy Policy*. Washington DC, Bipartisan Policy Center.

Mahmoudkhani, M. and D. W. Keith (2009). Low-energy sodium hydroxide recovery for CO_2 capture from air. *International Journal of Greenhouse Gas Control Technologies*, **3**: 376-384.
Keith, D. W., K. Heidel and R. Cherry (2009). Capturing CO_2 from the atmosphere: Rationale and Process Design Considerations. *Geo-Engineering Climate Change: Environmental necessity or Pandora's box?* B. Launder and M. Thompson eds, p 107-126, Cambridge University Press.
Keith, D. (2009). Why Capture CO_2 From The Atmosphere. *Science*, **325**: 1654-1655.
Seyyed Ghaderi, David W. Keith and Yuri Leonenko (2009). Feasibility of Injecting Large Volumes of CO_2 into Aquifers. *Energy Procedia*, **1**: 3113-3120.
Mahmoudkhani M., Heidel K.R., Ferreira J.C., Keith D.W. and Cherry R.S. (2009). Low energy packed tower and caustic recovery for direct capture of CO_2 from air. *Energy Procedia*, **1**: 1535-1542.
Keith, D. (2009). Dangerous Abundance. *Carbon Shift: How The Twin Crises Of Oil Depletion And Climate Change Will Define The Future*. T. Homer-Dixon and N. Garrison eds, p 26-57, Random House, Toronto**.**
Jordaan, S. M., D. W. Keith and B. Stelfox (2009). Quantifying land use of oil sands production: a life cycle perspective. *Environmental Research Letters*, **4**.
Eduard Cubi, David Keith and Jim Love (2009). Performance challenges of UFAD. *American Society of Heating, Refrigerating and Air-Conditioning Engineers*, **51**.
Hassanzadeh, H., M. Pooladi-Darvish and D. W. Keith (2009). Accelerating CO_2 Dissolution in Saline Aquifers for Geological Storage--Mechanistic and Sensitivity Studies. *Energy & Fuels*, **23**: 3328-3336.
Hassanzadeh, H., M. Pooladi-Darvish and D. Keith (2009). The Effect of Natural Flow of Aquifers and Associated Dispersion on the Onset of Buoyancy-driven Convection in a Saturated Porous Medium. *American Institute of Chemical Engineers Journal*, **55**: 475-485.
Cubi, E., D. Keith and J. Love (2009). Performance challenges of UFAD. *American Society of Heating, Refrigerating and Air-Conditioning Engineers*, **51**.
Zeman, F. S. and D. W. Keith (2008). Carbon Neutral Hydrocarbons. *Philosophical Transactions of the Royal Society (A)*, **366**: 3901-3918.
Wilson, E. J., M. G. Morgan, J. Apt, M. Bonner, C. Bunting, M. A. D. Figueiredo, J. Gode, C. C. Jaeger, D. W. Keith, S. T. McCoy, R. S. Haszeldine, M. F. Pollak, D. M. Reiner, E. S. Rubin, A. Torvanger, C. Ulardic, S. P. Vajjhala, D. G. Victor and I. W. Wright (2008). Regulating the Geological Sequestration of Carbon Dioxide. *Environmental Science & Technology*, **42**: 2718–2722.
Stolaroff, J. K., D. W. Keith and G. V. Lowry (2008). Carbon dioxide capture from atmospheric air using sodium hydroxide spray. *Environmental Science & Technology*, **42**: 2728-2735.
Stephens, J. C. and D. W. Keith (2008). Assessing Geochemical Carbon Management. *Climatic Change*, **90**: 217-242.
Rhodes, J. S. and D. W. Keith (2008). Biomass with Capture: Negative Emissions Within Social and Environmental Constraints. *Climatic Change*, **87**: 321-328.
Morgan, M. G. and D. W. Keith (2008). Improving the way we think about projecting future energy use and emissions of carbon dioxide. *Climatic Change*, **90**: 189-215.
Leonenko, Y. and D. W. Keith (2008). Reservoir Engineering To Accelerate the Dissolution of CO_2 Stored in Aquifers. *Environmental Science & Technology*, **42**: 2742-2747.
Kirk-Davidoff, D. B. and D. W. Keith (2008). On the climate impact of surface roughness. *Journal of Atmospheric Sciences*, **65**: 2215-2234.
Curtright, A. E., M. G. Morgan and D. W. Keith (2008). Expert Assessments of Future Photovoltaic Technologies. *Environmental Science & Technology*, **42**: 9031-9038.
Zickfeld, K., A. Levermann, D. W. Keith, T. Kuhlbrodt, M. G. Morgan and S. Rahmstorf (2007). Expert judgements on the response of the Atlantic meridional overturning circulation to climate change. *Climatic Change*, **82**: 235-265.
Reinelt, P. and D. W. Keith (2007). Carbon Capture Retrofits and the Cost of Regulatory Uncertainty. *Energy Journal*, **28**: 101-127.

Palmer, A., D. Keith and R. Doctor (2007). Ocean storage of carbon dioxide: piplelines, risers and seabed containment. *The 26th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2007)*. San Diego, CA.

Matthews, H. D. and D. W. Keith (2007). Carbon-cycle feedbacks increase the likelihood of a warmer future. *Geophysical Research Letters*, **34**: L09702.

Hassanzadeh, H., M. Pooladi-Darvish and D. W. Keith (2007). Scaling Behavior of Convective Mixing, with Application to Geological Storage of CO_2. *American Institute of Chemical Engineers Journal AIChE* **53**: 1121-1131.

Hassanzadeh, H., M. Pooladi-Darvish, A. M. Elsharkawy, D. Keith and Y. Leonenko (2007). Predicting PVT data for CO_2–brine mixtures for black-oil simulation of CO_2 geological storage. *International Journal of Greenhouse Gas Control*, **2**: 65-77.

Apt, J., D. W. Keith and M. G. Morgan (2007). Promoting Low-Carbon Electricity Production. *Issues in Science and Technology* **23, 3**: 37-43.

Rao, A. B., E. S. Rubin, D. W. Keith and M. G. Morgan (2006). Evaluation of Potential Cost Reductions from Improved Amine-based CO_2 Capture Systems. *Energy Policy*, **34**: 3765-3772.

M. Granger Morgan, P. J. Adams and D. W. Keith (2006). Elicitation of expert judgments of aerosol forcing. *Climatic Change*, **75**: 195-214.

Keith, D. W., M. Ha-Duong and J. K. Stolaroff (2006). Climate strategy with CO_2 capture from the air. *Climatic Change*, **74**: 17-45.

Hassanzadeh, H., M. Pooladi-Darvish and D. W. Keith (2006). Stability of a Fluid in a Horizontal Saturated Porous Layer: Effect of Non linear Concentration Profile, Initial, and Boundary Conditions. *Transport in Porous Media*, **65**: 193-211.

DeCarolis, J. F. and D. W. Keith (2006). The Economics of Large Scale Wind Power in a Carbon Constrained World. *Energy Policy*, **34**: 395-410.

Stolaroff, J. K., G. V. Lowry and D. W. Keith (2005). Using CaO- and MgO-rich Industrial Waste Streams for Carbon Sequestration. *Energy Conversion and Management*, **46**: 687-699.

Rhodes, J. S. and D. W. Keith (2005). Engineering-economic analysis of biomass IGCC with carbon capture and storage. *Biomass & Bioenergy*, **29**: 440-450.

Keith, D. W., J. A. Giardina and M. G. Morgan (2005). Regulating the Underground Injection of Carbon Dioxide. *Environmental Science & Technology*, **39**: 499A-505A.

Hassanzadeh, H., M. Pooladi-Darvish and D. W. Keith (2005). Modeling of Convective Mixing in CO_2 Storage. *Journal of Canadian Petroleum Technology*, **44**: 42-52.

DeCarolis, J. F. and D. W. Keith (2005). The Costs of Wind's Variability: Is There a Threshold? *The Electricity Journal*, **18**: 69-77.

Palmgren, C. R., M. G. Morgan, W. Bruine de Bruin and D. W. Keith (2004). Initial Public Perceptions of Deep Geological and Oceanic Disposal of Carbon Dioxide. *Environmental Science & Technology*, **38**: 6441-6450.

Keith, D. W., J. F. DeCarolis, D. C. Denkenberger, D. H. Lenschow, S. L. Malyshev, S. Pacala and P. J. Rasch (2004). The influence of large-scale wind-power on global climate. *Proceedings of the National Academy of Sciences*, **101**: 16115-16120.

Johnson, T. L. and D. W. Keith (2004). Fossil Electricity and CO_2 Sequestration: How Natural Gas Prices, Initial Conditions and Retrofits Determine the Cost of Controlling CO_2 Emissions. *Energy Policy*, **32**: 367-382.

Wilson, E. J., T. L. Johnson and D. W. Keith (2003). Regulating the Ultimate Sink: Managing the risks of geologic CO_2 sequestration. *Environmental Science & Technology*, **37**: 3476-3483.

Robinson, A. L., J. S. Rhodes and D. W. Keith (2003). Assessment of Potential Carbon Dioxide Reductions due to Biomass-Coal Cofiring in the United States. *Environmental Science & Technology*, **37**: 5081-5089.

James S. Rhodes and David W. Keith (2003). Biomass energy with geologic sequestration of CO_2: Two for the price of one? *Proceedings of the 6th Greenhouse Gas Control Conference, Kyoto Japan.* J. Gale and Y. Kaya eds., Pergamon, Oxford UK, p 1371-1376.

Keith, D. W. and A. E. Farrell (2003). Rethinking Hydrogen Cars. *Science*, **301**: 315-316.
Ha-Duong, M. and D. W. Keith (2003). Carbon storage: the economic efficiency of storing CO_2 in leaky reservoirs. *Clean Technology and Environmental Policy*, **5**: 181-189.
Farrell, A. E., D. W. Keith and J. J. Corbett (2003). A strategy for introducing hydrogen into transportation. *Energy Policy*, **31**: 1357-1367.
Keith, D. W. and M. Wilson (2002). Developing Recommendations for the Management of Geologic Storage of CO_2 in Canada. Regina, SK, University of Regina**:** 39.
Keith, D. W. and J. S. Rhodes (2002). Bury, burn or both: A two-for-one deal on biomass carbon and energy. *Climatic Change*, **54**: 375-377.
DeCarolis and D.W. Keith (2002). Is the Answer to Climate Change Mitigation Blowing in the Wind? *Proceedings of the first International Doctoral Consortium on Technology, Policy, and Management*. E. F. ten Heuvelhof ed., Delft University, Delft, The Netherlands, p 199-215.
Keith, D. W. (2002). Geoengineering - die technologische Gestaltung des Planeten Erde. *Klima. Das Experiment mit dem Planeten Erde*. W. Hauser. Munich, Germany, Deutsche Museum**:** 352-369.
Keith, D. W. (2002). Towards a Strategy for Implementing CO_2 Capture and Storage in Canada. Prepared by D. W. Keith, Carnegie Mellon University, Pittsburgh, Pennsylvania, for the Oil, Gas and Energy Branch, Environment Canada, Ottawa, Ontario.
Keith, D. W. (2002). Geoengineering. *Encyclopedia of Global Change*. A. S. Goudie. New York, NY, Oxford University Press**:** 495-502.
Keith, D. W. and M. G. Morgan (2001). Industrial Carbon Management: A Review of the Technology and its Implications for Climate Policy. *Elements of Change 2001*. J. Katzenberger. Aspen Global Change Institute, Aspen CO.
Keith, D. W., J. A. Dykema, H. Hu, L. Lapson and J. G. Anderson (2001). An Airborne Interferometer for Atmospheric Emission and Solar Absorption. *Applied Optics*, **40**: 5463-5473.
Keith, D. W. and J. G. Anderson (2001). Accurate Spectrally Resolved Infrared Radiance Observation from Space: Implications for the Detection of Decade-to-Century-Scale Climatic Change. *Journal of Climate*, **14**: 979-990.
Keith, D. W. (2001). Industrial Carbon Management: An Overview. *Carbon Management: Implications for R&D in the Chemical Sciences and Technology*. A. T. Bell and T. J. Marks. Washington, DC, National Academies Press**:** 127-146.
Keith, D. W. (2001). Geoengineering. *Nature*, **409**: 420.
Keith, D. W. (2001). Sinks, Energy Crops, and Land Use: Coherent Climate Policy Demands an Integrated Analysis of Biomass. *Climatic Change*, **49**: 1-10.
Keith, D. and A. Farrell (2001). Regulating Transportation Emissions. *Rx for Regulation*. S. Farrow. Pittsburgh, Center for the Study & Improvement of Regulation, Carnegie Mellon University.
Johnson, T. L. and D. W. Keith (2001). Electricity from Fossil Fuels Without CO_2 Emissions: Assessing the Costs of Carbon Dioxide Capture and Sequestration in US Electricity Markets. *Journal of the Air & Waste Management Association*, **51**: 1452-1459.
Farrell, A. and D. W. Keith (2001). Hydrogen as a transportation fuel. *Environment*, **43**: 43-45.
DeCarolis, J. F. and D. W. Keith (2001). The Real Cost of Wind Energy. *Science*, **294**: 1000-1002.
Keith, D. W. and E. A. Parson (2000). A Breakthrough in Climate Change Policy? *Scientific American*, February: 78-79.
Keith, D. W. (2000). The Earth is Not Yet an Artifact. *IEEE Technology and Society Magazine*, **19**: 25-28.
Keith, D. W. (2000). Stratosphere-troposphere exchange: Inferences from the isotopic composition of water vapor. *Journal of Geophysical Research-Atmospheres*, **105**: 15,167-115,174.
Keith, D. W. (2000). Geoengineering the Climate: History and Prospect. *Annual Review of Energy and the Environment*, **25**: 245-284.
J.J. Corbett, D.W. Keith and A. Farrell (2000). *Towards true zero-emission vehicles in a single step: Air pollution and greenhouse gas reductions through hydrogen fueled ships with carbon management*. Oceans 2000.

Hu, H., J. Dykema, D. Keith, L. Lapson, J. Anderson, R. O. Knuteson and W. L. Smith (2000). Intercomparison of atmospheric radiance measurements by two fourier transform spectrometers flown on the NASA ER-2. *IRS2000: Current Problems in Atmospheric Radiation*. W. L. Smith and Y. M. Timofeyev. Hampton, VA, Deepak Publishing.

Kirk-Davidoff, D. B., E. J. Hintsa, J. G. Anderson and D. W. Keith (1999). The effect of climate change on ozone depletion through changes in stratospheric water vapor. *Nature*, **402**: 399-401.

Parson, E. A. and D. W. Keith (1998). Fossil fuels without CO_2 emissions. *Science*, **282**: 1053-1054.

Keith, D. W. (1998). Geoengineering Climate. *Elements of Change 1998*. S. J. Hassol and J. Katzenberger. Aspen Colorado, Aspen Global Change Institute**:** 83-88.

Keith, D. W. (1996). Energetics. *Encyclopedia of Climate and Weather*. S. H. Schneider. New York, NY, Oxford University Press**:** 278-283.

Keith, D. W. (1996). When is it appropriate to combine expert judgments? *Climatic Change*, **33**: 139-143.

Morgan, M. G. and D. W. Keith (1995). Subjective Judgments By Climate Experts. *Environmental Science & Technology*, **29**: A468-A476.

Keith, D. W. (1995). Meridional Energy Transport - Uncertainty in Zonal Means. *Tellus* **47**: 30-44.

David Keith (1994). Eliciting Expert Judgment about Uncertainty in Climate Prediction. *Elements of Change 1994*. S. J. Hassol and J. Katzenberger eds., Aspen Global Change Institute, Aspen Colorado, p 164-165.

Turchette, Q. A., D. E. Pritchard and D. W. Keith (1992). Numerical model of a multiple-grating interferometer. *Journal of the Optical Society of America A*, **9**: 1601.

Keith, D. W. and H. Dowlatabadi (1992). A Serious Look at Geoengineering. *Eos, Transactions American Geophysical Union*, **73**: 289-293.

Ekstrom, C. R., D. W. Keith and D. E. Pritchard (1992). Atom Optics Using Microfabricated Structures. *Applied Physics B*, **54**: 369-374.

Keith, D. W., R. J. Soave and M. J. Rooks (1991). Free-standing gratings and lenses for atom optics. *Journal of Vacuum Science and Technology B*, **9**: 2846-2850.

Keith, D. W., C. R. Ekstrom, Q. A. Turchette and D. E. Pritchard (1991). An Interferometer For Atoms. *Physical Review Letters*, **66**: 2693-2696.

David W. Keith (1991). *An Interferometer for atoms*. Thesis, Department of Physics, Massachusetts Institute of Technology, Cambridge, MA.

Keith, D. W. and D. E. Pritchard (1990). Atom Optics. *New Frontiers in Quantum Optics*. A. O. Barut. New York, NY, Plenum Press**:** 467-475.

Keith, D. W., M. L. Schattenberg, H. I. Smith and D. E. Pritchard (1988). Diffraction of atoms by a transmission grating. *Physical Review Letters*, **61**: 1580.

Percy, J. R., V. A. Fabro and D. W. Keith (1985). The application of visual observations to the study of a small-amplitude variable star: rho Cassiopeiae. *Journal of the American Association of Variable Star Observers*, **14**: 1-7.

Corkum, P. and D. Keith (1985). Controlled Switching of 10μm Radiation Using Semiconductor Etalons. *Journal of the Optical Society of America B*, **12**: 1873-1879.

Percy, J. R. and D. Keith (1984). The Quasi-Cepheid Nature of Roh-Cassiopeiae. *Journal of the Royal Astronomical Society of Canada*, **78**: 206.

Jointly Authored Reports

M. Granger Morgan, Hadi Dowlatabadi, Max Henrion, David Keith, Robert Lempert, Sandra McBride, Metchell Small, Thomas Wilbanks (2009). *CCSP 5.2, Best Practice Approaches for Characterizing, Communicating and Incorporating Scientific Uncertainty in Climate Decision Making*. US Climate Change Science Program.

Jim Carter, John Brannan, Dave Collyer, Cassie Doyle, Jim Ellis, David Keith, Don Lowry, Art Meyer, Mike Percy, Kathy Sendall, Ian Shugart, Roger Thomas, Peter Watson and Steve Williams. (2009). *Accelerating Carbon Capture and Storage Implementation in Alberta*. Alberta Carbon Capture and Storage Development Council.

John Shepherd, Ken Caldeira, Joanna Haigh, David Keith, Brian Launder, Georgina Mace, Gordon MacKerron, John Pyle, Steve Rayner, Catherine Redgwell, Peter Cox and Andrew Watson. (2009). *Geoengineering the climate - Science, governance and uncertainty*. The Royal Society.

Cheryl Slusarchuk, Shawn Atleo, Donna Barnett, Jeff Burghardt, Lyn Brown, Randy McLeod, Joe Van Belleghem, Teressa Coady, Ian Tostenson, Andrew Weaver, John Robinson, Naomi Devine, Peter Robinson, David Keith, John Walker and Mossadiq Umedaly. (2008). *Climate Action Plan*. The Government of British Columbia.

Charles Christopher, Lester B. Lave, Geroge M. Hidy, W.S. Winston Ho, David Keith, Larry W. Lake, Michael E. Q. Pilson, Jeffrey, J. Siirola, James E. Smith, Robert H. Socolow, John M. Wootten (2007). Report of the Panel on DOE's Carbon Sequestration Program. *Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two)*. United States National Research Council ed, Board on Energy and Environmental Systems, Washington, DC, p 132-151.

Edward A. Parson, Virginia R. Burkett, Karen Fisher-Vanden, David W. Keith, Linda O. Mearns, Hugh M. Pitcher, Cynthia E. Rosenzweig, Mort D. Webster (2007). *CCSP 2.1b, Global-Change Scenarios, Their Development and Use*. US Climate Change Science Program.

Ian Anderson, David Keith, Kathleen Sendall, Steve Snyder, Patricia Youzwa (2007). *Canada's Fossil Energy Future: The Way Forward on Carbon Capture and Storage.* Natural Resources Canada.

Shem Arungu Olende, Steven Chu, Ged Davis, Mohamed El-Ashry, Jose Goldemberg, Thomas Johansson, David Keith, Li Jinghai, Nebosja Nakicenovic, Rajendra Pachauri, Majid Shafie-Pour, Evald Shpilrain, Robert Socolow, Kenji Yamaji and Yan Luguang (2007). *Lighting the way: Toward a sustainable energy future.* InterAcademy Council.

Virginia R. Burkett, Karen Fisher-Vanden, David W. Keith, Linda O. Mearns, Edward A. Parson, Hugh M. Pitcher, Cynthia E. Rosenzweig and Mort D. Webster (2007). *Global-Change Scenarios: Their Development and Use*. U.S. Climate Change Science Program.

Angus Bruneau, Denis Connor, John C. Fox, Daniel Kammen, David Keith, Patrick Lamarre, Jacques G. Martel, Ken McCready, Patrice Merrin Best, Laurier Schramm (2006). *Powerful Connections: Priorities and Directions in Energy Science and Technology in Canada.* Natural Resources Canada.

Juan Carlos Abanades, Makoto Akai, Sally Benson, Ken Caldeira, Peter Cook, Ogunlade Davidson, Richard Doctor, James Dooley, Paul Freund, John Gale, Wolfgang Heidug, Howard Herzog, David Keith, Marco Mazzotti, Bert Metz, Balgis Osman-Elasha, Andrew Palmer, Riitta Pipatti, Koen Smekens, Mohammad Soltanieh, Kelly Thambimuthu and Bob van der Zwaan (2005). *IPCC Special Report on Carbon Dioxide Capture and Storage*. Cambridge University Press.

James A. Edmonds, J. F. Clarke, J. J. Dooley, David C. Thomas, Brian P. Flannery, John C. Stringer, Carol Creutz, Etsuko Fujita, James A. Spearot, John Turner, David W. Keith, Leo E. Manzer, Harold H. Kung, Patrick R. Gruber, John W. Frost, K. M. Draths, David R. Knop, Mason K. Harrup, Jessica L. Barker and Wei Niu. (2001). *Carbon Management: Implications for R&D in the Chemical Sciences and Technology. A Workshop Report to the Chemical Sciences Roundtable*. National Academy Press.

Patents

D. W. Keith and M. Mahmoudkhani (2012), "Carbon Dioxide Capture", *United States Patent*, #8,119,091 B2.

D. W. Keith and J. Rhodes (2011), "Low-Carbon intensity production of hydrocarbon fuels", US Provisional Patent filing #61/524,565.

D. W. Keith, M. Henderson, A. Kainth (2011), "Target Gas Capture", US Provisional Patent filing #61/531,922.

D. W. Keith, M. Mahmoudkhani, A. Biglioli, B. Hart, K. Heidel and M. Foniok (2008), "Carbon Dioxide Capture Method and Facility", US Provisional Patent filing #61/090,867.

Pritchard, D. E. and Keith, D. W. (1989), "Matter wave optical systems in which an atomic beam intersects a diffraction grating at grazing incidence", *United States Patent*, #4,886,964.

Op Ed's

David Keith. (November/December 2011). Dirty Distraction. *Technology Review*.

David Keith. (26 December 2009). The Denial of Climate Science. *The Calgary Herald.*

David Keith and Joule Bergerson (29 November 2008). Smoke, mirrors and carbon. *The Calgary Herald* and *The Edmonton Journal*.

Mark Jaccard, Nic Rivers and David Keith (12 November 2008). Carbon taxes, the economy and the poor. *The Financial Post*.

Thomas Homer-Dixon and David Keith (19 September 2008). Blocking the Sky to Save the Earth. *The New York Times*.

David Keith and Thomas Homer-Dixon (8 March 2008). A win-win-win solution. *The Globe and Mail*.

Outreach

- I give 10-20 invited talks per year ranging from departmental colloquia at various north american universities to public talks at major national or international events to audiences up to 500.
- I often speak to Canadian industry and environmental groups, ranging from briefings for CEOs and environmental leaders to talks at major energy industry conferences.
- I have been interviewed by public media outlets such as the BBC, CBC, NPR, various talk radio, and Canadian and US TV networks as well as by reporters from *Science* and *Nature*.