Elson
Advocacy

March 29, 2023

Ms. Nancy Marconi
Registrar
Ontario Energy Board
2300 Yonge Street, 27th Floor
Toronto, Ontario
M4P 1E4

Dear Ms. Marconi:

Re: Enbridge Gas Inc. ("Enbridge") 2024 to 2028 Rates Application
EB-2022-0200

I am writing to provide an update on the evidence that Environmental Defence plans to submit in this proceeding on the implications of decarbonization for gas customers in relation to Enbridge's application.

Environmental Defence plans to submit brief evidence of Professors Robert Howarth and Mark Jacobson on the greenhouse gas footprint of blue hydrogen (i.e. hydrogen derived from fossil gas with carbon capture and storage). This evidence could assist the OEB and parties in assessing Enbridge's proposals regarding hydrogen and in testing the Guidehouse *Pathways to Net Zero Emissions for Ontario* report. Enbridge argues that hydrogen can be used to help counteract the potential "life-shortening effect on Enbridge Gas's system" from climate legislation.[1] The pipeline-focused scenario in the Guidehouse report involves huge volumes of blue hydrogen (an average of 5 billion m3 annually from 2030 to 2050).

It has recently become clear that there are divergent views between the applicant and some parties to this proceeding on the carbon emissions from blue hydrogen. Those emissions could potentially rule out blue hydrogen as a fuel that could counteract the life-shortening effect on gas pipelines from decarbonization and rule out Guidehouse's pipeline-expansion scenario as a realistic pathway to net-zero.

Environmental Defence does not seek any additional costs in relation to this evidence nor a change to the topic areas described in Environmental Defence's original evidence letter of January 16, 2023. The evidence goes to those same topic areas and we expect Mr. Neme will rely on it in his report. Professors Howarth and Jacobson have declined to receive any financial compensation. My firm would also forgo any incremental counsel costs in relation to the preparation of the evidence.

Professors Howarth and Jacobson are foremost experts on the emissions from blue hydrogen as co-authors of peer-reviewed research on the topic. Professor Howarth is a Professor of

[1] Exhibit 1, Tab 10, Schedule 4, Page 17, para. 52.

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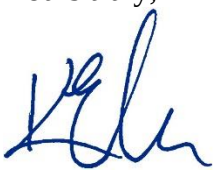
Ecology & Environmental Biology at Cornell University and the Co-Editor in Chief of the journal of Ocean-Land-Atmosphere Research. Professor Jacobson is a Professor of Civil and Environmental Engineering and the Director of the Atmosphere/Energy Program at Stanford University. Their *curricula vitae* are attached.[2]

Please let us know if any further details would be of assistance to the OEB.

Yours truly,



Kent Elson

cc: Parties to the above proceeding

[2] The attached *curriculum vitae* for Professor Jacobson is an abridged version. The full version is 70 pages long and can be found here: https://web.stanford.edu/group/efmh/jacobson/vita/index.html.

ROBERT W. HOWARTH

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http://www.eeb.cornell.edu/howarth/
e-mail: howarth@cornell.edu
Tel.: (1)-607-280-9981

Education

B.A., Amherst College (*Magna cum laude*), 1974
Ph.D., Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Biological Oceanography, 1979

Professional Experience

1993-Present	David R. Atkinson Professor of Ecology & Environmental Biology, Cornell University.
2020-Present	Member, Climate Action Council, State of New York (appointed by the Speaker of the State Assembly).
2021-Present	Co-Editor-in-Chief, *Ocean-Land-Atmosphere Research* (OLAR)
2021-Present	Member of editorial board, *Energy Science & Engineering*
2019-2020	Chair, the University Assembly, Cornell University.
2018-2019	Vice Chair, the University Assembly, Cornell University.
2014-2019	Editor-in-Chief, *Limnology & Oceanography.*
2016-Present	Distinguished Visiting Fellow, Woods Hole Research Center.
2000-Present	Adjunct Senior Scientist, Marine Biological Laboratory, Woods Hole.
1983-Present	Founding Editor, *Biogeochemistry* (Editor-in-Chief, 1983-2004).
2005-2012	Director, Agriculture, Energy, & Environment Program, Cornell University.
2000-2001	Oceans Program Director & Senior Scientist, Environmental Defense Fund.
1995-2000	Director, Program in Biogeochemistry & Environmental Change, Cornell.
1992-1995	Senior Fellow, and coordinator for Initiative in Earth, Atmospheric, & Aquatic Sciences, Center for the Environment, Cornell.
1990-1993	Professor, Section of Ecology & Systematics, Cornell University.
1988-1991	Director, Ecosystems Research Center (US EPA National Center of Excellence), Cornell University.
1985-1990	Associate Professor, Section of Ecology & Systematics, Cornell University.
1980-1985	Assistant and Associate Scientist, Marine Biological Lab, Woods Hole.
1979	Noyes Postdoctoral Fellow, Marine Biological Laboratory, Woods Hole.

Recent Awards and Honors (since 2000)

- One of the ten ever most highly cited marine biologists/aquatic scientists in the world (*PLoS Biol* 18(10): e3000918. https://doi.org/10.1371/journal.pbio)
- One of 50 "Most Influential People" driving energy policy in New York State, City & State New York magazine, three years in a row (2019, 2020, and 2021).
- Invited briefing to US Congress on the Fracking Ban Act (2020)
- Invited briefing to European Parliament on "Fueling the Fracking, Plastics, Methane Emissions and the Gas Lobby" (2020)

- ASLO John Martin Award, Association for Sciences of Limnology & Oceanography (2018).
- Moore Lecturer, University of Virginia (2017).
- ASLO Sustaining Fellow, Association for Sciences of Limnology & Oceanography (2017).
- Invited briefing on methane, shale gas development, and climate change to the Office of Science and Technology Policy, Executive Office of the White House (2016).
- Keynote speaker, Earth Day, State University of New York at Stony Brook (2014).
- Ian Morris Distinguished Scholar, Horn Point Laboratory, University of Maryland (2014).
- Featured plenary speaker, World Water Day, Michigan Technological University (2014).
- Co-Winner, 2013 Atlas Award, "honoring climate heroes worldwide"
- David Schindler Visiting Scholar, Trent University (2013)
- Pritchard Award, best physical oceanography paper published in *Estuaries & Coasts* (2013).
- One of Time Magazine's 50 "People Who Mattered," 2011 Person of the Year issue.
- Zayed International Prize for the Environment (2007), jointly with the other lead authors of the Millennium Ecosystem Assessment.
- Invited briefing on coastal water quality to the Office of Science and Technology Policy, Executive Office of the White House (2006).
- Selected by ISI Web of Science (Scientific Citation Index) as one of 250 most cited scientists globally in ecology and environmental science disciplines (every year, 2006 to the present).
- Biology Faculty of 1,000 (every year, 2005 to the present).
- Lindeman Award in Ecology, University of Minnesota (2003).
- Aldo Leopold Leadership Fellow, Ecological Society of America (2000).
- Eminent Ecologist award, Kellogg Biological Station, Michigan State Univ. (2000).

National and International Committees and Activities

2021	Delegate observer to the UN COP26 negotiations, Glasgow, Scotland.
2017-present	Member, Board of Directors, Food & Water Watch.
2017	Delegate observer to the UN COP23 negotiations, Bonn, Germany.
2017	Chair, Review Panel for Integration of Monitoring and Evaluation into Environmental Restoration Projects to Improve Outcomes in the Gulf of Mexico, National Academy of Sciences.
2015-present	Member, EPA Clean Air Scientific Advisory Committee (CASAC) Secondary National Ambient Air Quality Standards Review Panel for Oxides of Nitrogen and Sulfur, US Environmental Protection Agency.
2015	Delegate observer to the United Nations COP21 negotiations, Paris, France.
2014-2016	Member, National Estuarine Research Reserves Science Collaborative Advisory Board, National Oceanic & Atmospheric Administration.
2010-2014	Member, Working Group on Land and Soils, International Resource Panel, United Nations Environment Programme.
2007-2012	Chair, International SCOPE Biofuels Project: Environmental Consequences of Biofuels (International Council of Science).
2007-2009	President, Coastal & Estuarine Research Federation.
2008-2010	Member, Board of Directors, Council of Scientific Society Presidents.
2007-2011	Co-chair, Committee on Energy & Environment, Council of Scientific Society Presidents.

2005-2013	Representative from the State of New York to the Scientific and Technical Advisory Committee of the Chesapeake Bay Program.
2006-2008	Member, Gulf of Mexico Hypoxia Advisory Panel, US EPA.
2005-2007	Member, Steering Committee, N2007 International N Symposium, Brazil.
2004-2007	Member, Biogeochemistry Rapid Response Team, Ecological Society of America.
2003-Present	Editor, book series on Environmental Management, Springer.
2003-2008	Member, Coast and Oceans Working Group, the Heinz Center.
2003-2006	Director, North American Regional Center, International Nitrogen Initiative.
2003-2014	Member, Advisory Committee, International Nitrogen Initiative.
2002-2005	Coordinating Lead Author, chapter on responses to nutrient pollution, the Millennium Ecosystem Assessment.
2002-2004	Member, Advisory Committee, N2004 International N Symposium, China.
2002-2003	Coordinator and lead author, Working Group to Develop a Federal Interagency Research Plan for Coastal Nutrient Pollution.
2001-2002	Consultant on coastal nutrient pollution, the Pew Oceans Commission.
2000-2003	Member, US Committee for SCOPE, National Academy of Sciences.
2000-2003	Member, Scientific Advisory Board, National Center for Ecological Analysis & Synthesis, University of California at Santa Barbara.
2001-2002	Member, Committee to Evaluate the Water Programs of the US Army Corps of Engineers, National Academy of Sciences.
1992-2002	Co-Chair, International SCOPE Nitrogen Project on Nitrogen: A Regional and Global Analysis (International Council of Science).
2000-2001	Member, Advisory Committee, N2001 Symposium, Potomac, MD.
1998-2001	Member, National Climate Change Assessment (Coastal Marine Sector).
1998-2000	Chair, Committee on Causes and Management of Coastal Eutrophication, National Academy of Sciences.
2000	Chair, Panel on Coastal Nitrogen Pollution, Ecological Society of America.
1996-1998	Member, Board of Scientific Counselors, US Environmental Protection Agency
1994-1995	Member, Panel on Nitrogen Cycling in China, Committee on Scholarly Communication with China, National Academy of Sciences.
1995	Chair, Working group on Scientific Studies in Pristine Areas, National Academy of Sciences.
1994-1997	Member, Steering Committee, Sustainable Biosphere Initiative, ESA.
1994	Member, Committee on High-Priority Science to Meet National Coastal Needs, National Academy of Sciences.
1992-1998	Member, Committee on Ethics, Am. Soc. of Limnol. & Oceanography.
1990-1993	Member, Committee on Opportunities to Improve Wastewater Management for Urban Coastal Areas, National Academy of Sciences.
1991-1995	Member, Advisory Committee for the National Water-Quality Assessment Program, U.S. Geological Survey.
1989-1992	Member, Committee on the Coastal Ocean, National Academy of Sciences.
1991-1993	Member, Governing Board, Estuarine Research Federation.
1988-1990	Member, U. S. National Committee for SCOPE, National Academy of Sciences.

1985-1991	Member, Scientific Advisory Committee, the International SCOPE Sulphur Project (Moscow, USSR), International Council of Science.
1989-1990	Member, Panel on Fluxes of Trace Gases and Nutrients to and from Terrestrial Ecosystems, Committee on Global Change, National Academy of Sciences.
1986-1988	Member, Public Affairs Committee, Am. Soc. of Limnol. & Oceanography.
1981-1984	Member, Panel on Ecological Effects, Committee on Fate and Effects of Oil in the Sea, National Academy of Sciences.

Research Interests

Application of science to sustaining the biosphere; biogeochemistry and aquatic ecosystem science; global and regional nitrogen and phosphorus cycles; global methane cycle; environmental consequences of biofuels; role of trace gases in global warming and climate disruption; life-cycle analysis for greenhouse-gas footprint of energy technologies; influence of land-use, management practices, and climate change on nutrient fluxes from the landscape; atmospheric deposition of nitrogen onto the landscape; controls and consequences of eutrophication in estuaries; biotic, physical, and geochemical controls on nitrogen fixation; environmental management and the effects of pollutants on aquatic ecosystems; alternative energy systems.

Publications:

Editor of eight books and treatises. Author of one textbook: Begon, M., R.W. Howarth, and C. Townsend. 2014. *Essentials of Ecology*, 4th Edition. Wiley. ISBN-13: 978-0470909133

Author or co-author of over 230 peer-reviewed papers. These papers have been cited more than 80,000 times in other peer-reviewed publications. Fifteen of these papers have been cited more than 1,000 times each, seven have been cited more than 3,000 times each, and two have been cited more than 7,500 times each. Howarth is the first author on four of these. All publications are listed chronologically below, with those papers cited at least 1,000 times highlighted in bold.

2023 Howarth, R. W. 2023. Phosphorus in all its forms: Book review of The Devils Element. *Science.*

2022 Howarth, R.W. 2022. Methane emissions from the production and use of natural gas. *EM Magazine*, December 2022, pages 11-16.

Haviland, K. A., R. W. Howarth, R. M. Marino, and M. Hayn. 2022. Variation in sediment and seagrass characteristics reflect multiple stressors along a nitrogen-enrichment gradient in a New England lagoon. *Limnology & Oceanography* doi: 10.1002/lno.12025

Vitousek, P. M, K.K. Tresedor, R.W. Howarth, and D.N.L. Menge. 2022. A "toy model" analysis of causes of nitrogen limitation in terrestrial ecosystems. *Biogeochemistry* https://doi.org/10.1007/s10533-022-00959-z

Howarth, R. W. 2022. Nitrogen. In: Thomas Mehner and Klement Trockner (editors), *Encyclopedia of Inland Waters*, 2nd Edition. Elsevier.

Marino, R. M., and R. W. Howarth. 2022. Nitrogen fixation. In: Thomas Mehner and Klement Trockner (editors), *Encyclopedia of Inland Waters*, 2nd Edition. Elsevier.

Howarth, R. W. 2022. Methane and climate change. In: John F. Stolz, W. Michael Griffin, and Daniel J. Bain (editors), *Environmental Impacts from Development of Unconventional Oil and Gas Reserves*, Cambridge University Press.

Howarth, R. W., and M. Jacobson. 2022. Reply to comment on "how green is blue hydrogen?" *Energy Science and Engineering* doi: 10.1002/ese3.1154

2021 Howarth, R.W., and M. Jacobson. 2021. How green is blue hydrogen? *Energy Science and Engineering* 9: 1676-1687, doi: 10.1002/ese3.956

Howarth, R.W., F. Chan, D.P. Swaney, R.M. Marino, and M. Hayn. 2021. Role of external inputs of nutrients to aquatic ecosystems in determining prevalence of nitrogen vs. phosphorus limitation of net primary productivity. *Biogeochemistry* 154: 293-306, doi: 10.1007/s10533-021-00765-z

Wong, M.Y., S.D. Rathod, R. Marino, L. Li, R.W. Howarth, A. Alastuey, M.A. Alaimo, F. Barraza, M.C. Carneiro, S. Chellam, C. Yu-Cheng, D.D. Cohen, D. Connelly, G. Dongarra, D. Gomez, J. Hand, R.M. Harrison, P.K. Hopke, C. Hueglin, Y. Kuang, F. Lambert, J. Liang, R. Losno, W. Maenhaut, C. Milando, M.I.C. Monteiro, Y. Morera-Gomez, X. Querol, S. Rodriguez, P. Smichowski, D. Varrica, Y. Xiao, Y. Xu, and N.M. Mahowald. 2021. Anthropogenic perturbations to the atmospheric molybdenum cycle. *Global Biogeochemical Cycles*, doi: 10.1029/2020GB006787

2020 Howarth, R.W. 2020. Methane emissions from fossil fuels: Exploring recent changes in greenhouse-gas reporting requirements for the State of New York. *Journal of Integrative Environmental Sciences,* doi: 10.1080/1943815X.2020.1789666.

Wong, M.Y., C. Neill, R. Marino, D. Silverio, and R.W. Howarth. 2020. Molybdenum, phosphorus, and pH do not constrain nitrogen fixation in a tropical forest in the southeastern Amazon. *Ecology* doi: 10.1002/ecy.3211

Wong, M.Y., N.M. Mahowald, R. Marino, E.R. Williams, S. Chellam, and R.W. Howarth. 2020. Natural atmospheric deposition of molybdenum: a global model and implications for tropical forests. *Biogeochemistry*, doi: 10.1007/s10533-020-00671-w

2019 Howarth, R.W. 2019. Ideas and perspectives: is shale gas a major driver of recent increase in global atmospheric methane? *Biogeosciences* 16: 3033–3046, doi:10.5194/bg-16-3033-2019.

Wong, M.Y., C. Neill, R. Marino, D.V. Silvério, P.M. Brando, and R.W. Howarth. 2019. Biological nitrogen fixation does not replace nitrogen losses after forest fires in the southeastern Amazon. *Ecosystems* doi.org/10.1007/s10021-019-00453-y

Swaney, D.P., and R.W. Howarth. 2019. Phosphorus use efficiency and crop production: Patterns of regional variation in the United States, 1987-2012. *Science of the Total Environment*, 685, 174e188.https://doi.org/10.1016/j.scitotenv.2019.05.228

2018 McCrackin, M.L, B.G. Gustafsson, B. Hong, R.W. Howarth, C. Humborg, O.P. Savchuk, A. Svanbäck, and D.P. Swaney. 2018. Opportunities to reduce nutrient inputs to the Baltic Sea by improving manure use efficiency in agriculture. *Regional Environmental Change* doi.org/10.1007/s10113-018-1308-8

McCrackin, M.L, B. Muller-Karulis, B.G. Gustafsson, R.W. Howarth, C. Humborg, A. Svanback, and D.P. Swaney. 2018. A century of legacy phosphorus dynamics in a large drainage basin. *Global Biogeochemical Cycles* 32: 1107-1122. doi.org/10.1029/2018GB005914

Harada, Y., T.H. Whitlow, P.H. Templer, R.W. Howarth, M.T. Walter, N.L. Bassuk, and J. Russell-Anelli. 2018. Nitrogen biogeochemistry of an urban rooftop farm. *Frontiers in Ecology and Evolution.* doi.org/10.3389/fevo.2018.00153

Swaney, D.P., R.W. Howarth, and B. Hong. 2018. Nitrogen use efficiency and crop production: Patterns of regional variation in the United States, 1987-2012. *Science of the Total Environment* 635:498–511. doi.org/10.1016/j.scitotenv.2018.04.027

2017 Zhang, W.S., D. Swaney, B. Hong, R. Howarth, and X. Li. 2017. Influence of rapid rural-urban population migration on riverine nitrogen pollution: perspective from ammonia-nitrogen. *Environmental Science and Pollution Research*, DOI 10.1007/s11356-017-0322-6

Zhang, W.S., D. Swaney, B. Hong, and R.Howarth. 2017. Anthropogenic phosphorus inputs to a river basin and their impacts on riverine phosphorus fluxes along its upstream-downstream continuum. *J. Geophys. Res. Biogeosciences*, 122. https://doi.org/10.1002/2017JG004004

2016 Goyette, J.O., E. Bennett, R.W. Howarth, and R. Maranger. 2016. Changes in anthropogenic nitrogen and phosphorus inputs to the St. Lawrence Basin over 110 years: Impacts on riverine export. G*lobal Biogeochemical Cycles* 30: 1000–1014, doi:10.1002/2016GB005384.

Marino, R.M., and R.W. Howarth. 2016. Why is planktonic nitrogen fixation so rare in coastal marine ecosystems? Insights from a cross-systems approach. Pages 127-139 in P. Glibert and T. Kana (editors), *Aquatic Nutrient Biogeochemistry and Microbial Ecology: A Dual Perspective*. Springer, Dordrecht. doi: 10.1007/978-3-319-30259-1_11

Gao, W., B. Hong, D.P. Swaney, R.W. Howarth, and H. Guo. 2016. A system dynamics model for managing regional N inputs from human activities. *Ecological Modelling* 322: 82-91, doi: 10.1016/j.ecolmodel.2015.12.001

Hong, B., and R.W. Howarth. 2016. Greenhouse gas emissions from domestic hot water: heat pumps compared to most commonly used systems. *Energy Science & Engineering* 4: 123-133, doi: 10.1002/ese3.112

2015 Reynolds, L.K., R. Marino, M.F. Muth, N. McLenaghan, M. Hayn, A.C. Tyler, K.J. McGlathery, and R.W. Howarth. 2015. Evidence of grazer control on nitrogen fixation by eelgrass epiphytes in a temperate coastal bay. *Marine Ecology Progress Series* 526: 11-19, doi: 10.3354/meps11234

Zhang, W.S., D.P. Swaney, B. Hong, R.W. Howarth, H. Han, and X. Li. 2015. Net anthropogenic phosphorus inputs and riverine phosphorus fluxes in highly populated headwater watersheds in China. *Biogeochemistry* 126: 269–283, doi:10.1007/s10533-015-0145-9

Zhang, W.S., D. P. Swaney, X.Y. Li, B. Hong, R.W. Howarth, and S.H. Ding. 2015. Anthropogenic point-source and non-point-source nitrogen inputs into Huai River basin and their impacts on riverine ammonia–nitrogen flux. *Biogeosciences* 12: 4275-4289, doi:10.5194/bg-12-4275-2015

Gao, W., D. P. Swaney, B. Hong, Y. Liu, R. W. Howarth, H. C. Guo. 2015. Evaluating Anthropogenic N inputs to Diverse Lake Basins: A Case Study of Three Chinese Lakes. *Ambio*. 44: 635-646.

Gao, W., R.W. Howarth, D.P. Swaney, B. Hong, and H. Guo. 2015. Enhanced N input to Lake Dianchi Basin from 1980 to 2010: Drivers and consequences. *Science of The Total Environment* 505: 376-384, doi.org/10.1016/j.scitotenv.2014.10.016.

Howarth, R.W. 2015. Perspectives on air emissions of methane and climatic warming risk from hydraulic fracturing and shale-gas development: Implications for policy. *Energy & Emission Control Technologies* 3: 45-54.

Costello, C., X. Xue, and R.W. Howarth. 2015. Comparison of production-phase environmental impact metrics derived at the farm- and national-scale for United States agricultural commodities. *Environmental Research Letters* 10: 114004 doi:10.1088/1748-9326/10/11/114004

Butler, T., R. Marino, D. Schwede, R. Howarth, J. Sparks, and K. Sparks. 2015. Atmospheric ammonia measurements at low concentration sites in the northeastern USA: implications for total nitrogen deposition and comparison with CMAQ estimates. *Biogeochemistry* 122: 191-210.

Howarth, R.W. 2015. Editorial: Misconduct in scientific publications. *Limnology & Oceanography*, 60(#4), doi: 10.1002/lno.10131

Howarth, R.W. 2015. Editorial. *Limnology & Oceanography*, 60(#1), doi:10.1002/lno.10030

2014 Howarth, R.W. 2014. A bridge to nowhere: Methane emissions and the greenhouse gas footprint of natural gas. *Energy Science & Engineering* 2: 47-60, doi:10.1002/ese3.35

Begon, M., R.W. Howarth, and C. Townsend. 2014. *Essentials of Ecology*, 4th Edition. Wiley, Chichester. 480 pages. ISBN-13: 978-0470909133

Bringezu, S, H. Schütz, W. Pengue, M. O´Brien, F. Garcia, R. Sims, R. Howarth, L. Kauppi, M. Swilling, and J. Herrick. 2014. *Assessing Global Land Use: Balancing Consumption with Sustainable Supply.* A Report of the Working Group on Land and Soils of the International Resource Panel. United Nations Environment Program, Paris, France. ISBN: 978-92-807-3330-3

Caulton, D.R., P. B. Shepson, R.L. Santor0, J.P. Sparks, R.W. Howarth, A. Ingraffea, M.O. Camaliza, C. Sweeney, A. Karion, K.J. Davis, B.H. Stirm, S.A. Montzka, and B. Miller. 2014. Toward a better understanding and quantification of methane emissions from shale gas development. *Proceedings of the National Academy of Sciences* 111: 6237-6242. doi/10.1073/pnas.1316546111

Howarth, R.W., M. Hayn, R.M. Marino, N. Ganju, K. Foreman, K. McGlathery, A.E. Giblin, P. Berg, and D. Walker. 2014. Metabolism of a nitrogen-enriched coastal marine lagoon during the summertime. *Biogeochemistry* 118: 1-20, doi:10.1007/s10533-013-9901-x

Gao, W., R.W. Howarth, B. Hong, D.P. Swaney, and H.C. Guo. 2014. Estimating net anthropogenic nitrogen inputs (NANI) in the Lake Dianchi basin of China. *Biogeosciences* 11: 4577 – 4586, doi:10.5194/bg-11-4577-2014

Del Barrio, P., N. Ganju, A. L. Aretxabaleta, M. Hayn, A. Garcia, and R. W. Howarth. 2014. Modeling future scenarios of light attenuation and potential seagrass success in a eutrophic estuary. *Estuarine and Coastal Shelf Science* 149: 13-23, doi 10.1016/j.ecss.2014.07.005

Jacobson, M.Z., M.A. Delucchi, A.R. Ingraffea, R.W. Howarth, G. Bazouin, B. Bridgeland, K. Burkart, M. Change, N. Chowdhury, R. Cook, G. Escher, M. Galka, L. Han, C. Heavey, A. Hernandez, D.F. Jacobson, D.S. Jacobson, B. Miranda, G. Novotny, M. Pellat, P. Quach, A. Romano, D. Steward, L. Vogel, S. Wang, H. Wang, L. Willman, and T. Yeskoo. 2014. A

roadmap for repowering California for all purposes with wind, water, and sunlight. *Energy,* doi.org/10.1016/j.energy.2014.06.099

Howarth, R. W., and A. Ingraffea. 2014. Shale gas: Time to go slow. In *World Energy Monitor, World Energy Forum.* United Nations. New York, NY.

2013 Howarth, R. W., and J. Mohan (editors). 2013. *Biomes and Ecosystems.* Salem Press. 1,440 pages, ISBN 978-1-4298-3813-9

Hayn M., R.W. Howarth, R. Marino, N. Ganju, P. Berg, K. Foreman, A.E. Giblin, and K. McGlathery. 2013. Exchange of nitrogen and phosphorus between a shallow lagoon and coastal waters. *Estuaries & Coasts*, 37: 63–73, doi:10.1007/s12237-013-9699-8

Jacobson, M.Z., R.W. Howarth, M.A. Delucchi, S.R. Scobies, J.M. Barth, M.J. Dvorak, M. Klevze, H. Katkhuda, B. Miranda, N.A. Chowdhury, R. Jones, L. Plano, and A.R. Ingraffea. 2013. Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight. *Energy Policy* 57: 585-601, doi.org/10.1016/j.enpol.2013.02.036i

Jacobson, M.Z., R.W. Howarth, M.A. Delucchi, S.R. Scobies, J.M. Barth, M.J. Dvorak, M. Klevze, H. Katkhuda, B. Miranda, N.A. Chowdhury, R. Jones, L. Plano, and A.R. Ingraffea. 2013. Response to comment on paper examining the feasibility of changing New York State's energy infrastructure to one derived from wind, water, and sunlight. *Energy Policy* 62: 1212-1215, doi.org/10.1016/j.enpol.2013.07.105i

Hong, B., D.P. Swaney, and R.W. Howarth. 2013. Estimating net anthropogenic nitrogen inputs (NANI) to US watersheds: comparison of methodologies. *Environmental Science & Technology* 47: 5199−5207

Gettel, G., A. Giblin, and R.W. Howarth. 2013. Controls of benthic nitrogen fixation and primary production from nutrient enrichment of oligotrophic, arctic lakes. *Ecosystems,* doi 10.1007/s10021-013-9701-0

Tartowski, S.L., and R. W. Howarth. 2013. Nitrogen, nitrogen cycle. *Encyclopedia of Biodiversity*, Elsevier.

Bettez, N., R. Marino, R.W. Howarth, and E.A. Davidson. 2013. Roads as nitrogen deposition hot spots. *Biogeochemistry* 114: 149-163.

Berg, P., M.H. Long, M. Huettel, J.E. Rheuban, K.J. McGlathery, R.W. Howarth, K.H. Foreman, A.E. Giblin, and R. Marino. 2013. Eddy correlation measurements of oxygen fluxes in permeable sediments exposed to varying current flow and light. *Limnology & Oceanography* 58: 1329-1343.

Howarth, R. W. 2013. Shale gas extraction. Pages 354-359 in Craig, R.K., B. Pryd, J.C. Nagle, O. Schmitz, and W. Smith (eds.), *The Berkshire Encyclopedia of Sustainability: Vol. 5, Ecosystem management and Sustainability*. Berkshire, Great Barrington, MA.

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Professional Appointments

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Stanford University Energy Resources Engineering Professor by Courtesy, 2007-2010
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Stanford University Civil & Environmental Engineering Associate Professor, 2001-2007
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Mark Z. Jacobson's scientific career has focused on better understanding air pollution and global warming problems and developing large-scale clean, renewable energy solutions to them. Toward that end, he has developed and applied three-dimensional atmosphere-biosphere-ocean computer models and solvers to simulate air pollution, weather, climate, and renewable energy. He has also developed roadmaps to transition countries, states, and cities to 100% clean, renewable energy for all purposes and computer models to examine grid stability in the presence of high penetrations of renewable energy.

To date, he has published six books and ~180 peer-reviewed journal articles. He has testified four times for the U.S. Congress. In 2005, he received the American Meteorological Society Henry G. Houghton Award for "significant contributions to modeling aerosol chemistry and to understanding the role of soot and other carbon particles on climate." In 2013, he received an American Geophysical Union Ascent Award for "his dominating role in the development of models to identify the role of black carbon in climate change" and the Global Green Policy Design Award for the "design of analysis and policy framework to envision a future powered by renewable energy." In 2016, Jacobson received a Cozzarelli Prize from the *Proceedings of the National Academy of Sciences* for "outstanding scientific excellence and originality" in his paper on a solution to the U.S. grid reliability problem with 100% penetration of wind, water, and solar power for all purposes. In 2018, he received the Judi Friedman Lifetime Achievement Award, "For a distinguished career dedicated to finding solutions to large-scale air pollution and climate problems." In 2019, he was selected as "one of the world's 100 most influential people in climate policy" by Apolitical. In 2022, he received the *Visionary Clean Tech Influencer of the Year* award at the World Clean Tech Awards. He has also served on the Energy Efficiency and Renewables advisory committee to the U.S. Secretary of Energy, was invited to talk about his clean-energy plans on the Late Show with David Letterman, and co-founded the non-profit Solutions Project.

His publication of a dozen papers, starting from a 2009 *Scientific American* article, on transitioning the world, countries, states, cities, and towns to 100% clean, renewable energy for all purposes sparked an international movement; numerous laws in cities, states, and countries worldwide; and commitments by businesses toward that goal. His work also formed the scientific basis of the U.S. *Green New Deal*.

Some Publications

1. Jacobson, M.Z., A.-K. von Krauland, S.J. Coughlin, E. Dukas, A.J.H. Nelson, F.C. Palmer, and K.R. Rasmussen, Low-cost solutions to global warming, air pollution, and energy insecurity for 145 countries, *Energy and Environmental Sciences*, *15*, 3343-3359, doi:10.1039/d2ee00722c, 2022.
2. Jacobson, M.Z., A.-K. von Krauland, S.J. Coughlin, F.C. Palmer, and M.M. Smith, Zero air pollution and zero carbon from all energy at low cost and without blackouts in variable weather throughout the U.S. with 100% wind-water-solar and storage, *Renewable Energy*, *184*, 430-444, doi:10.1016/j.renene.2021.11.067, 2022.
3. Katalenich, S.M., and M.Z. Jacobson, Toward battery electric and hydrogen fuel cell military vehicles for land, air, and sea, *Energy*, 254, 124355, doi:10.1016/j.energy.2022.124355, 2022.
4. Katalenich, S.M., and M.Z. Jacobson, Renewable energy and energy storage to offset diesel generators
5. Jacobson, M.Z., The cost of grid stability with 100% clean, renewable energy for all purposes when countries are isolated versus interconnected, *Renewable Energy*, 179, 1065-1075, doi:10.1016/j.renene.2021.07.115, 2021.
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14. Jacobson, M.Z., M.A. Delucchi, G. Bazouin, Z.A.F. Bauer, C.C. Heavey, E. Fisher, S. B. Morris, D.J.Y. Piekutowski, T.A. Vencill, T.W. Yeskoo, 100% clean and renewable wind, water, sunlight (WWS) all-sector energy roadmaps for the 50 United States, *Energy and Environmental Sciences*, *8*, 2093-2117, doi:10.1039/C5EE01283J, 2015.
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