# Christopher L. Muhich

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## Education

Ph.D. Chemical Engineering, University of Colorado, Boulder; December 2014

B.S.E. Chemical Engineering (Summa cum Laude), University of Michigan, Ann Arbor; May 2009

## Research and Professional Experience

2018- Assistant Professor of Chemical Engineering
School for the Engineering of Matter, Transport and Energy
Arizona State University, Tempe Arizona

2015-2017 Postdoctoral Research Assistant, Department of Mechanical and Process Engineering
ETH Zurich (Swiss Federal Institute of Technology in Zurich), Zurich Switzerland
Advisor: Aldo Steinfeld

2009-2014 Graduate Student Research Assistant, Department of Chemical and Biological Engineering
University of Colorado at Boulder, Boulder Colorado
Advisors: Alan Weimer and Charles Musgrave

2008 Internship – Ammonia Removal from Biogas Digesters
MT-Energie, Neidersachsen, Germany

## Peer Reviewed Publications

***Publication overview (as of Sept, 2017):***
Total citations: >450
h-index: 9

1. M. Hoes, **C. Muhich*,** R. Jacot, G. Patzke, A. Steinfeld, "Thermodynamic of Paired Charge-Compensating Doped Ceria with Superior Redox Performance for Solar Thermochemical Splitting of $H_2O$ and $CO_2$" in press *Journal of Materials Chemistry A.*
2. **Muhich, C.***, A. Steinfeld, "Principles of Doping Ceria for the Solar Thermochemical Redox Splitting of $H_2O$ and $CO_2$", *Journal of Materials Chemistry A*. 2017, 5 (30), 15578-15590
3. **Muhich, C.*** "Re-evaluating $CeO_2$ Expansion upon Reduction: Non-Counterpoised Forces, Not Ionic Radius Effects, are the Cause", *Journal of Physical Chemistry C*. 2017, 121 (14), 8052-8059
4. Alghannam, A., **C. Muhich,*** C. Musgrave, "Adatom Surface Diffusion of Catalytic Metals on the Anatase $TiO_2$ (101) Surface", *Physical Chemistry Chemical Physics*. 2017, 19, 4541-4552
5. Ehrhart, B., **C. Muhich**, I. Al-Shankiti, A. Weimer "System Efficiency of Two-Step Solid Oxide Solar Thermochemical Hydrogen Production, Part 3: Various Methods for Achieving Low Oxygen Partial Pressures in the Reduction Reaction", *International Journal of Hydrogen Energy*. 2016, 41(44), 19904-11914

6. Ehrhart, B., **C. Muhich**, I. Al-Shankiti, A. Weimer "System Efficiency of Two-Step Solid Oxide Solar Thermochemical Hydrogen Production, Part 2: Impact of Gas Heat Recuperation and Separation", *International Journal of Hydrogen Energy*, 2016, 41(44), 19894-11903
7. Ehrhart, B., **C. Muhich**, I. Al-Shankiti, A. Weimer "System Efficiency of Two-Step Solid Oxide Solar Thermochemical Hydrogen Production, Part 1: Thermodynamic Model and Impact of Oxidation Kinetics", *International Journal of Hydrogen Energy*, 2016, 41(44), 19881-11893
8. Bartel, C., **C. Muhich**, A. Weimer, C. Musgrave "A First Principles Study of the Initial Hydrolysis of Aluminum Nitride", *ACS Applied Materials and Interfaces*. 2016, *8*(28), 18550-18559
9. **Muhich, C.**, B. Ehrhart, I. Al-Shankiti, B. Ward, C. Musgrave, A. Weimer, "A Review and Perspective of Efficient $H_2$ Generation via Solar Thermal Water Splitting", *Wiley Interdisciplinary Reviews Energy and Environment*. 2016, *5*(3), 261-287 *(Invited)*
10. **Muhich, C.**, V. Aston, R. Tottier, A. Weimer, C. Musgrave, "A First Principles Analysis of Cation Diffusion in Mixed Metal Ferrite Spinels", *Chemistry of Materials*. 2016, *28*(1), 214-226
11. **Muhich, C.**, B. Ehrhart, V. Witte, S. Miller, E. Coker, C. Musgrave, A. Weimer. "Predicting the Solar Thermochemical Water Splitting Ability and Reaction Mechanism of Metal Oxides: A Case Study of the Hercynite Family of Water Splitting Cycles", *Energy & Environmental Science*. 2015, *8*(12), 3687-3699
12. **Muhich, C.**, J. Qiu, A. Holder, Y. Wu, A. Weimer, W. D. Wei, L. McElwee-White, C. Musgrave, "Solvent Control of Surface Plasmon Mediated Chemical Deposition of Au Nanoparticles from Alkylgold Phosphine Complexes", *ACS Applied Materials and Interfaces*. 2015, *7*(24), 13384-13394
13. Lubers, A., **C. Muhich**, K. Anderson, A. Weimer, "Mechanistic Studies for Depositing highly dispersed Pt Nanoparticles on Carbon by Atomic Layer Deposition (ALD)", *Journal of Nanoparticle Research*. 2015, *17*(4), 179
14. **Muhich, C.**, K. Weston, D. Arifin, A. McDaniel, C. Musgrave, A. Weimer, "Extracting Kinetic Information from Complex Gas-Solid Reaction Data", *Industrial & Engineering Chemistry Research*. 2015, *54*(16), 4113-4122
15. **Muhich, C.**, J. Westcott, A. Weimer, C. Musgrave, "Increasing the Photocatalytic Activity of $TiO_2$ through B, C and N Doping", *Journal of Physical Chemistry C*. 2014, *118* (47), 27415-27427
16. Deml, A., V. Stevanovic, **C. Muhich**, C. Musgrave, R. O'Hayre, "Oxide Enthalpy of Formation and Band Gap Energy as Accurate Descriptors of Oxygen Vacancy Formation Energetics", *Energy and Environmental Science*. 2014, *7* (6), 1669-2004
17. **Muhich, C.**, B. Evanko, K. Weston, P. Lichty, X. Liang, J. Martinek, C. Musgrave, A. Weimer, "Efficient Generation of $H_2$ by Splitting Water with an Isothermal Redox Cycle", *Science*. 2013, *341 (*6145*)*, 540-542
18. **Muhich, C.**, J. Westcott, T. Morris, A. Weimer, C. Musgrave, "The Effect of N and B Doping on Graphene and on the Adsorption and Migration Behavior of Pt Atoms", *Journal of Physical Chemistry C*. 2013, *117* (20), 10523-10535
19. Lichty, P., X. Liang, **C. Muhich**, B. Evanko, C. Bingham, A. Weimer, "Atomic Layer Deposited Thin Film Metal Oxides for Fuel Production in Solar Cavity Reactor", *International Journal of Hydrogen Energy*. 2012, *37* (22), 16888-16894
20. Zhou, Y., **C. Muhich**, C. Musgrave, B. Neltner, A. Weimer, "Growth of Pt Particles on the Anatase $TiO_2$ (101) Surface", *Journal of Physical Chemistry C*. 2012, *116* (22), 12114-12123
21. **Muhich, C.**, Y. Zhou, A. Holder, C. Musgrave, A. Weimer, "Effect of Surface Deposited Pt on the Photoactivity of $TiO_2$", *Journal of Physical Chemistry C*. 2012, *116* (18), 10138-10149

*****Denotes articles where C. Muhich is the corresponding author

**Submitted and Pending Publications**

1. **Muhich, C.***, M. Hoes, A. Steinfeld, "Mimicking Tetravalent Dopants in Ceria using Paired Charge Compensating Dopants", submitted to *Acta Materialia*.
2. Miller, S., R. Trottier, **C. Muhich,** C. Musgrave, "Understanding Molecular Adsorption on the Anatase $TiO_2$ (101) surface" in preparation
3. **Muhich, C.*,** S. Blaser, A. Steinfeld, "Determining the Solar to Hydrogen Efficiency of Ceria and Perovskite based Solar Thermochemical Water Splitting Cycles" in preparation

*****Denotes articles where C. Muhich is the corresponding author

**Patents**

P. Lichty, **C. Muhich**, D. Arifin, A. Weimer, A. Steinfeld, "Methods and apparatus for gas-phase reduction/oxidation processes" Appl. Num. 13/857,951; April 5 2013

**Teaching Experience**

ETH – Zurich (Zurich, Switzerland)
- Spring 2017: Fuel Synthesis Engineering - Lecturer
- Spring 2016: Fuel Synthesis Engineering - Lecturer and course developer

University of Colorado (Boulder, CO)
- Fall 2011: Energy Fundamentals - Advanced Teaching Assistant
- Fall 2009: Chemistry for Engineers - Teaching Assistant

University of Michigan (Ann Arbor, MI)
- Fall 2008: Chemical Engineering Department "In House" tutor for Materials and Energy Balances

**Invited/Keynote Presentations**

1. **Muhich, C.**, M. Hoes, A. Steinfeld, "Advanced Redox Materials for the Solar-driven Thermochemical Splitting of $H_2O$ and $CO_2$" invited talk at the *Tailor-made Fuels From Production to Propulsion 5th International Conference*, June 2017 (Aachen, Germany)
2. **Muhich C**. "Solar-thermochemical $H_2O$ and $CO_2$ Splitting" Invited talk at the International School on Electrochemical Energy Conversion and Storage, October 2016 (Max Plank Institute for Solid State Research, Stuttgart, Germany)
3. **Muhich, C.**, A. Steinfeld "Fundamental Understanding and Design of Solar-thermal Gas Splitting Materials", Keynote talk at *Fourth Solar Syngas Workshop*¸ June 2016 (Technical University Clausthal, Clausthal-Zellendort, Germany)

**Conference Contributions**

1. **Muhich, C.**, M. Hoes, A. Steinfeld, "Doping Strategies to Alter the $H_2O/CO_2$ Splitting behavior of Ceria Redox Materials" presented at *American Society of Mechanical Engineers Power and Energy Conference*, June 2016 (Charlotte, North Carolina)
2. **Muhich, C.**, A. Steinfeld, "Materials and Components for Thermochemical Syngas Generation: An Overview of the STGS Work at ETH", presented at *Fourth Solar Syngas Workshop*¸ June 2016 (Technical University Clausthal, Clausthal-Zellendort, Germany)
3. **Muhich, C**., B. Ehrhart, S. Miller, V. Witte, B. Ward, C. Musgrave, A. Weimer "Active and Flowable Doped-Hercynite Materials for Solarthermal Redox Processing to Split Water," presented at *The American Institute of Chemical Engineers Annual Meeting*, Nov 2015 (Salt Lake City, UT)
4. Ehrhart, B., **C. Muhich**, I. Al-Shankiti, B. Ward, A. Weimer, "Impact of Reduction of Flowing Particles on System Efficiency for Solar Thermochemical Hydrogen Production" presented at *The American Institute of Chemical Engineers Annual Meeting*, Nov 2015 (Salt Lake City, UT)
5. Miller, S., R. Trottier, **C. Muhich**, C. Musgrave and A. Weimer "Screening of Metal Oxide Materials for Solar Thermochemical Water Splitting," presented at *The American Institute of Chemical Engineers Annual Meeting*, Nov 2015 (Salt Lake City, UT)
6. **Muhich, C**., J. Qiu, A. Holder, Y. Wu, A. Weimer, W. Wei, L. McElwee-White and C. Musgrave "Solvent Control of Surface Plasmon Mediated Chemical Deposition of Au Nanoparticles from Alkylgold Phosphine Complexes," presented at *The American Institute of Chemical Engineers Annual Meeting*, Nov 2015 (Salt Lake City, UT)
7. Weimer, A., V. Aston, **C. Muhich**, C. Musgrave, "Hybrid Chemical Looping Hydrogen Process using Mixed Metal Oxides" Invited talk at *The American Chemical Society Fall National Meeting*, August 2015 (Boston, MA)
8. **Muhich, C.**, B. Ehrhart, S. Miller, V. Witte K. Weston, D. Arifin, A. McDaniel, E. Coker, C. Musgrave, A. Weimer. "The Mechanism of Transition Metal Aluminates in Solar Thermal Water Splitting Reactions" presented at *The American Society of Mechanical Engineers' Power and Energy Conference*, June 2015 (San Diego, CA)
9. **Muhich, C.**, K. Weston, D. Arifin, B. Ehrhart, S. Miller, A. McDaniel, C. Musgrave, A. Weimer. "On the Kinetics of Isothermal and Near Isothermal Solarthermal Gas Splitting using Doped Hercynite Materials" presented at *The American Society of Mechanical Engineers' Power and Energy Conference*, June 2015 (San Diego, CA)
10. Ehrhart, B., **C. Muhich**, I. Al-Shankiti, A. Weimer. "Materials-Specific Effects on Solar Thermochemical Hydrogen Production Efficiency" presented at *The American Society of Mechanical Engineers' Power and Energy Conference*, June 2015 (San Diego, CA)
11. **Muhich, C**., B. Ehrhart, I. Al-Shankitit, B. Ward, C. Musgrave, A. Weimer. "Needed Research Focus for Achieving Cost-effective and Reliable Solar-thermal Water Splitting" Invited talk at *The Electrochemical Society*, May 2015 (Chicago, IL)
12. **Muhich, C**., B. Ehrhart, I. Al-Shankitit, B. Ward, C. Musgrave, A. Weimer. "Near-Isothermal Doped-hercynite Redox Cycle for Solar-thermal Water Splitting" Invited talk presented at *The Electrochemical Society*, May 2015 (Chicago, IL)
13. **Muhich, C.**, K. Weston, D. Arifin, A. McDaniel, E. Coker, B. Ehrhart, V. Witte, C. Musgrave, A. Weimer. "The Mechanism of the Doped-Herycnite Cycle for Solar-thermal Water Splitting" presented at *The American Chemical Society Spring Meeting*, March 2015 (Denver, CO)
14. **Muhich, C.**, Y. Zhou, J. Westcott, A. Holder, A. Weimer, C. Musgrave, "Investigation of the Role of Surface Metal Catalysis and Near Surface Nonmetal Dopants in the Photocatalytic Activity of $TiO_2$" presented at *The American Chemical Society Spring Meeting*, March 2015 (Denver, CO)
15. **Muhich, C.**, J. Qui, A. Holder, A. Weimer, W. D. Wei, L. McElwee-White, C. Musgrave, "Solvent Control of Surface Plasmon Mediated Chemical Deposition of Au Nanoparticles from Phosphorus-based Organo-Au Precursors", presented at *The American Chemical Society Spring Meeting*, March 2015 (Denver, CO)

16. **Muhich, C.**, K. Weston, B. Ehrhart, V. Witte, D. Arifin, A. McDaniel, E. Coker, C. Musgrave, A. Weimer. "The Chemistry and Thermodynamics of the Herycnite Cycle Solar-thermal Water Splitting Reaction" presented at the *American Institute of Chemical Engineers Annual Meeting*, Nov 2014 (Atlanta, GA)
17. **Muhich, C.**, B. Ehrhart, K. Weston, I. Al-Shankiti, D. Arifin, A. McDaniel, C. Musgrave, A. Weimer. "Extracting Kinetic Information from Complex Gas-solid Reaction Data: the Kinetics of Hercynite Materials for Solar Thermal $CO_2$ Splitting" presented at the *American Institute of Chemical Engineers Annual Meeting*, Nov 2014 (Atlanta, GA)
18. Ehrhart, B., **C. Muhich**, I. Alshankitit, A. Weimer. "Effect of Kinetic Limitation on Solar Thermochemical Hydrogen Production Efficiency" presented at the *American Institute of Chemical Engineers Annual Meeting*, Nov 2014 (Atlanta, GA)
19. Lubers, A., **C. Muhich**, K. Anderson, A. Weimer. "Preparation of Carbon Supported Pt Nanoparticles by Atomic Layer Deposition" presented at the *American Institute of Chemical Engineers Annual Meeting*, Nov 2014 (Atlanta, GA)
20. **Muhich C.**, B. Ehrhart, K. Weston, I. Al-Shankiti, C. Musgrave, A. Weimer. "Understanding the Fundamentals of the Hercynite Cycle and its Operational Behavior under Pseudo-Isothermal Water Splitting Conditions" poster at *The American Institute of Chemical Engineers Annual Meeting*, Nov 2014 (Atlanta, GA)
21. Johnson K., Y. Wu, J. Qiu, **C. Muhich**, C. Musgrave, W. Wei, L. McElwee-White, "Surface plasmon mediated chemical solution deposition on nanostructured substrates" poster at *The American Chemical Society Spring Meeting*, March 2014 (Dallas, TX)
22. **Muhich, C.**, B. Evanko, K. Weston, P. Lichty, X. Liang, C. Musgrave, A. Weimer, "Isothermal Water Splitting: A Novel Approach to Efficient $H_2$ Generation through Solar Thermal Energy" presented at the *American Institute of Chemical Engineers Annual Meeting*, Nov 2013 (San Francisco, CA)
23. **Muhich, C.**, J. Westcott, A. Weimer, C. Musgrave "Increasing $O_2$ Reduction on $TiO_2$ via Non-precious-metal Surface Doping" presented at the *American Institute of Chemical Engineers Annual Meeting*, Nov 2013 (San Francisco, CA)
24. **Muhich, C.**, J. Westcott, T. Morris, A. Weimer, C. Musgrave "Fundamentals of N and B Dopants on Graphene and Pt Interactions with Graphene" presented at the *American Institute of Chemical Engineers Annual Meeting*, Nov 2013 (San Francisco, CA)
25. **Muhich C.**, B. Evanko, K. Weston, P. Lichty, X. Liang, C. Musgrave, A. Weimer, "Isothermal Water Splitting using the Two-Step Redox 'Hercynite Cycle'" poster at *The American Institute of Chemical Engineers Annual Meeting*, Nov 2013 (San Francisco, CA)
26. **Muhich C.**, Y. Zhou, D. King, A. Weimer, C. Musgrave, "Pt cluster deposition on $TiO_2$ particles via ALD for improved photocatalytic performance and a fundamental understanding thereof" poster at *Partec – International Congress on Particle Technology*, April 2013 (Nuremberg, Germany)
27. **Muhich, C**., Y. Zhou, A. Holder, A. Weimer, C. Musgrave, "Understanding the Effect of Surface Deposited Pt on the Photoactivity of $TiO_2$" presented at the *American Institute of Chemical Engineers Annual Meeting*, October 2012 (Pittsburg, PA)
28. **Muhich C.**, Y. Zhou, A. Holder, A. Weimer, C. Musgrave, "The Role of Pt on the Photoactivity of $TiO_2$" poster at *The American Institute of Chemical Engineers Annual Meeting*, October 2012 (Pittsburg, PA)
29. Weston K., **C. Muhich**, P. Lichty, X. Liang, A. Weimer, "A Comparison of Two Step Concentrated Solar Thermal Water Splitting Materials" poster at *The American Institute of Chemical Engineers Annual Meeting*, October 2012 (Pittsburg, PA)
30. **Muhich, C.**, B. Evanko, C. Musgrave, A. Weimer, "Green Hydrogen Production using a Nickel Ferrite Based Hercynite Solar Thermal Water Splitting Cycle" presented at *World Renewable Energy Forum*, May 2012 (Denver, CO)

31. **Muhich, C.**, C. Musgrave, A. Weimer, "Theoretical Studies of Ion Transport In Solar Thermal Water Splitting by Mixed Metal Ferrites In Traditional and Hercynite Cycles" presented at the *American Institute of Chemical Engineers Annual Meeting*, October 2011 (Minneapolis, MN)
32. **Muhich, C.**, A. Weimer, C. Musgrave, "Nickel Ferrites in the Hercynite Water Splitting Cycle" presented at the *American Institute of Chemical Engineers Annual Meeting*, October 2011 (Minneapolis, MN)
33. Zhou, Y., **C. Muhich**, C. Musgrave, A. Weimer, "The Enhancement Effect of Pt Clusters on the $TiO_2$ Photoactivity in Solution" presented at the *American Institute of Chemical Engineers Annual Meeting*, October 2011 (Minneapolis, MN)
34. Zhou, Y., **C. Muhich**, C. Musgrave, A. Weimer, "A First-Principle Study of Pt Clusters On Anatase $TiO_2$ (101) Surfaces" presented at the *American Institute of Chemical Engineers Annual Meeting*, October 2011 (Minneapolis, MN)
35. **Muhich C.**, C. Musgrave, A. Weimer, "Theoretical Studies of Ion Transport and Surface Reactions in Solar Thermal Water Splitting by Mixed Metal Ferrites" poster at *The American Institute of Chemical Engineers Annual Meeting*, 2011 (Minneapolis, MN)
36. **Muhich C.**, Y. Zhou, C. Musgrave, A. Weimer, "Theoretical Study of Pt Clusters On Anatase $TiO_2$ (101) Surface and the Effect on Photoactivity" Poster at *The American Institute of Chemical Engineers Annual Meeting*, October 2011 (Minneapolis, MN)
37. **Muhich, C.**, C. Musgrave, A. Weimer, "Theoretical Studies of Solar Thermal Water Splitting by Mixed Metal Ferrites" presented at *The American Chemical Society* Fall National Meeting, August 2011 (Denver, CO)

**Awards and Honors**

2016 Best presentation of Solar Thermochemcial Fuels II, at 2016 AIChE Annual Meeting (Doped Ceria for Solar Thermal Water Splitting: What Works, What Doesn't, and How to Improve It)
2015 University of Colorado Department of Chemical and Biological Engineering Max S. Peters Outstanding Graduate Award
2014 Department of Chemical and Biological Engineering Graduate Student Faculty Leadership Award
2013 Department of Education's Graduate Assistantship in Areas of National Need (GAANN) Fellow
2011 Second Place AIChE Environmental Division Poster Competition (Theoretical Study of Pt Clusters On Anatase $TiO_2$ (101) Surface and the Effect on Photoactivity)
2011 Third Place AIChE Materials Science Division Poster Competition (Theoretical Studies of Ion Transport and Surface Reactions in Solar Thermal Water Splitting by Mixed Metal Ferrites)
2011 National Science Foundation Graduate Fellowship Honorable Mention
2007 Member of Tau Beta Pi Engineering Honor Society
2007 University of Michigan Angell Scholar
2006 University of Michigan's William J. Branstrom Freshman Prize

**Research Students Advised/Supervised**

ETH – Zurich:

PhD students: Marie Hoes (2016- )
Master's Thesis: Pamela Biemmi (2017); Fabienne Muff (2017); Bernhard Pribyl (2016)
Semester Project: Christoph Hurter (2017)
Bachelor's Thesis: Samuel Blaser (2016)

University of Colorado:

Senior Thesis: Kayla Watson, (2011-2014); Jay Westcott (2012-2013); Timothy Morris (2011-2012);

Independent Study: Afnan Alghannam, (2014-2015); Anna Murphy, (2013); Erin Bangert (2013); Brianne Braach (2012); Zach Nager (2012); Kyle Williams (2011)
Professional Research Assistant: James Baker (2013); Brian Evanko (2011-2012)
Summer Research Assistant: Amy Sagastegui (2011 Princeton University)

**Leadership/Service Activities (2009 - present)**

Journal Reviewer: Journal of Physical Chemistry Letters; Journal of Physical Chemistry C; Computational Materials Science; AIChE Journal; Industrial and Engineering Chemistry Research;

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| 2016 | Session chair of Catalytic Hydrogen Generation session at the 2016 AIChE Annual Meeting in San Francisco, California |
| 2016 | Session chair of Solar Thermochemical Fuel Production session at the 2016 ASME 10$^{th}$ International Conference on Energy Sustainability in Charlotte, North Carolina |
| 2013-2014 | Executive of Chemical and Biological Engineering Department Graduate Student Leadership Council |
| 2012-2013 | Graduate Student Representative to the Chemical and Biological Engineering Department |
| 2011-2013 | Member of the University of Colorado Engineering College's BOLD (Broadening Opportunity through Leadership and Diversity) Center Student Leadership Council (SLC) |
| 2010-2014 | Chapter Advisory Team member for the University of Colorado's Theta Tau Professional Engineering Fraternity chapter |
| 2009-2010 | Founder and President of the Student Alliance of GLBT Engineers, University of Colorado Chapter |