

## Eric Toberer

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### Education:

- 2002 – 2006: Ph.D. in Materials, University of California, Santa Barbara, CA.  
1997 – 2002: B.S. in Chemistry, Harvey Mudd College, Claremont, CA.

### Employment:

- 2011 – present: Assistant Professor, Dept. of Physics, Colorado School of Mines, Golden, CO  
2006 – 2011: Postdoctoral Fellow, Materials Science, Caltech, Pasadena, CA  
2005: School of Chemistry, University of Bristol, UK.  
2001: Los Alamos Neutron Science Center, LANL, Los Alamos, NM.  
2000: Dept. of Physics, University of Patras, Patras Greece

### Awards:

- 2011: International Thermoelectric Society Young Investigator Award  
2007 – 2010: Beckman Foundation Postdoctoral Fellowship  
2003 – 2006: NSF IGERT Fellowship  
1997 – 2002: Harvey Mudd Merit Fellowship

### Research Contributions:

Assistant Professor 2011 – present  
Colorado School of Mines Physics Dept.  
Our goal is to understand the relationship between material structure and properties to such accuracy that we can predict the properties of unexplored materials. We find this goal to be particularly rewarding when applied to the development of advanced inorganic materials for energy applications such as thermoelectric and photovoltaic materials (in collaboration with NREL). To this end, we have developed strengths in synthesis, materials characterization, and modeling/computation.

Postdoctoral research 2006 – 2011  
California Institute of Technology Advisors: Jeff Snyder and Sossina Haile  
I pursued fundamental research on the transport properties of thermoelectric materials. This work focused on: (a) the first experimental demonstration of the Mahan-Sofa theory to enhance thermoelectric performance using resonant states at the Fermi level, (b) the synthesis of endotactically oriented thermoelectric nanocomposites via spontaneous, bulk routes and (c) a combination of experimental and computational studies designed to reveal structure/electronic property relationships in Zintl compounds.

Graduate research 2002 – 2006  
University of California, Santa Barbara Advisor: Ram Seshadri  
My graduate research emphasis was on the development of new template-free routes to porous materials for fuel cells and photovoltaics. Through this work, I developed a class of reactions which yield mesoporous single crystals, permitting the formation of hierarchically porous materials such as TiO<sub>2</sub>. This work led to redox coupled systems in which catalytic nanoparticles and hierarchical porosity form simultaneously.

**Publications:**

Total of 55 peer-reviewed publications. H-index of 23 and a citation count of 1,978 (not including self-citation) as of March 2014. Citation count determined from Web of Science.

**Review articles:**

6. **E. S. Toberer**, L. L. Baranowski, C. Dames, Advances in thermal conductivity, *Annual Rev. Mater. Res.* 42, 179-209 (2012). [\[DOI\]](#)
5. **E. S. Toberer**, A. Zevalkink, and G. J. Snyder, Phonon engineering through crystal chemistry, *J. Mater. Chem* 21, 15843-15852 (2011).[\[DOI\]](#)
4. **E. S. Toberer**, A. F. May, and G. J. Snyder, Zintl chemistry for designing high efficiency thermoelectric materials, *Chem. Mater.* 22 (2010) 624 - 634 [\[DOI\]](#)
3. S. A. Corr, D. P. Shoemaker, **E. S. Toberer**, R. Seshadri, Spontaneously formed porous and composite materials, *J. Mater. Chem.* 20 (2010) 1413 - 1422. [\[DOI\]](#)
2. G. J. Snyder, **E. S. Toberer**, Complex thermoelectric materials, *Nature Mater.* 7 (2008) 105-114. [\[DOI\]](#)
1. **E. S. Toberer**, R. Seshadri, Template-free routes to porous inorganic materials, *Chem. Commun.* (2006) 3159-3165. [\[DOI\]](#)

**Journal articles:**

49. L. Krishna, L. L. Baranowski, A. D. Martinez, A. C. Tamboli, C. A. Koh, P. C. Taylor, **E. S. Toberer** Efficient route to scalable, phase selective synthesis of type II silicon clathrates with low sodium occupancy *Crys. Eng. Comm.* (2014)
48. L. L. Baranowski, L. Krishna, A. D. Martinez, T. Raharjo, V. Stevanovic, A. C. Tamboli, **E. S. Toberer**, Synthesis and optical band gaps of alloyed Si-Ge type II clathrates, *J. Mater. Chem C* in press (2014) [\[DOI\]](#).
47. P. Zawadzki, L. L. Baranowski, H. Peng, E. S. Toberer, D. S. Ginley, W. Tumas, A. Zakutayev, S. Lany, Evaluation of photovoltaic materials within the Cu-Sn-S family, *Appl. Phys. Lett.* 103, 253902 (2013) [\[DOI\]](#)
46. L. Krishna, L. L. Baranowski, M. T. Lusk, **E. S. Toberer**, A. C. Tamboli, Synthesis of Group IV clathrates for photovoltaics, *J. Photovolt.*, 3, 1305-1310 (2013) [\[DOI\]](#).
45. W. Seifert, G. J. Snyder, **E. S. Toberer**, C. Goupil, K. Zabrocki, E. Muller, The self-compatibility effect in graded thermoelectric cooler elements, *Phys. Stat. Sol. A* 210, 1407-1417 (2013) [\[DOI\]](#).
44. L. L. Baranowski, G. J. Snyder, **E. S. Toberer**, Effective thermal conductivity in thermoelectric materials, *J. Appl. Phys.* 20, 204904, (2013) [\[DOI\]](#).
43. L. L. Baranowski, G. J. Snyder, **E. S. Toberer**, Concentrated solar thermoelectric generators, *Energy Env. Sci.* 5, 9055-9067 (2012) [\[DOI\]](#).
42. K. A. Borup, **E. S. Toberer**, L. D. Zoltan, G. Nakatsukasa, M. Errico, J. P. Fleurial, B. B. Iversen, G. J. Snyder, Measurement of the electrical resistivity and Hall coefficient at high temperatures, *Rev. Sci. Inst.* 83, 123902, (2012) [\[DOI\]](#).
41. Y. Wu, A. P. Litvinchuk, **E.S. Toberer**, G. J. Snyder, N. Newman, A. Fischer, E. W. Scheidt, W. Scherer, U. Haussermann, Thermoelectric properties of  $Zn_5Sb_4In_2 - \delta$  ( $\delta = 0.15$ ), *J. Appl. Phys.* 111, 123712 (2012) [\[DOI\]](#)
40. G. J. Snyder, **E. S. Toberer**, R. Khanna, W. Seifert, Improved thermoelectric cooling based on the Thomson effect, *Phys. Rev. B*, 86, 045202 (2012). [\[DOI\]](#)

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39. G. S. Pomrehn, **E. S. Toberer**, G. J. Snyder, A. van de Walle, Predicted electronic and thermodynamic properties of a newly discovered  $\text{Zn}_8\text{Sb}_7$  phase, *J. Amer. Chem. Soc.*, 133, 11255-11261 (2011). [\[DOI\]](#)
38. S. K. Bux, M. T. Yeung, **E. S. Toberer**, G. J. Snyder, R. B. Kaner, and J. -P. Fleurial, Mechanochemical synthesis and thermoelectric properties of high quality magnesium silicide, *J. Mater. Chem.* 21, 12259-12266 (2011). [\[DOI\]](#)
37. S. Iwanaga, **E. S. Toberer**, A. Lalonde, and G. J. Snyder, A high temperature apparatus for measurement of the Seebeck coefficient. *Rev. Sci. Inst.* 82 063905 (2011). [\[DOI\]](#)
36. A. Zevalkink, **E. S. Toberer**, T. Bleith, E. Flage-Larsen, G. J. Snyder, Improved carrier concentration control in Zn-doped  $\text{Ca}_5\text{Al}_2\text{Sb}_6$ . *J. Appl. Phys.* 110, 013721 (2011). [\[DOI\]](#)
35. J. H. Roudebush, **E. S. Toberer**, H. Hope, G. J. Snyder, and S. M. Kauzlarich, Crystal structure, characterization and thermoelectric properties of the Type-I clathrate  $\text{Ba}_{8-y}\text{Sr}_y\text{Al}_{14}\text{Si}_{32}$  ( $0.6 \leq y \leq 1.3$ ) prepared by aluminum flux, *J. Sol. State Chem.* 184 1176-1185 (2011). [\[DOI\]](#)
34. P. Rauwel, O. M. Martin, E. Rauwel, **E. S. Toberer**, G. J. Snyder, and J. Taftø, Nanostructuring in  $\beta\text{-Zn}_4\text{Sb}_3$  with variable starting Zn concentrations, *Phys. Stat. Solidi A* 208 1652 (2011). [\[DOI\]](#)  
Selected as “Best of PSS 2011”.
33. G. S. Pomrehn, **E. S. Toberer**, G. J. Snyder, A. van de Walle, Entropic Stabilization and Retrograde Solubility in  $\text{Zn}_4\text{Sb}_3$ , *Phys. Rev. B* 83 (2011) 094106. [\[DOI\]](#) Associated poster won Best Graduate Student Poster at TMS Spring 2011
32. Ø. Prytz, E. Flage-Larsen, **E. S. Toberer**, G. J. Snyder, and J. Taftø, Reduction of lattice thermal conductivity from planar faults in the layered Zintl compound  $\text{SrZnSb}_2$ , *J. Appl. Phys.* 109 (2011) 043509. [\[DOI\]](#)
31. A. Zevalkink, **E. S. Toberer**, W. Zeier, G. J. Snyder,  $\text{Ca}_3\text{AlSb}_3$ : An inexpensive, non-toxic thermoelectric material for waste heat recovery. *Energy Envir. Sci.* 4 (2011) 510-518. [\[DOI\]](#)
30. Y. Pei, J. Lensch-Falk, **E. S. Toberer**, D. L. Medlin, G. J. Snyder, High Thermoelectric Performance in  $\text{PbTe}$  due to Large Nanoscale  $\text{Ag}_2\text{Te}$  Precipitates and La Doping, *Adv. Funct. Mater.* 21 (2011) 241-249. [\[DOI\]](#)
29. B. Gault, E. A. Marquis, D. W. Saxey, G. M. Hughes, D. Mangelinck, **E. S. Toberer**, G. J. Snyder, High-resolution nanostructural investigation of  $\text{Zn}_4\text{Sb}_3$  alloys, *Scripta Mater.* 63, (2010) 784-787. [\[DOI\]](#)
28. **E. S. Toberer**, P. Rauwel, S. Gariel, J. Taftø, G. J. Snyder, Composition and the thermoelectric performance of  $\beta\text{-Zn}_4\text{Sb}_3$ , *J. Mater. Chem.* 20 (2010) 9877-9885. [\[DOI\]](#)
27. **E. S. Toberer**, A. Zevalkink, N. Crisosto, G. J. Snyder, The Zintl compound  $\text{Ca}_5\text{Al}_2\text{Sb}_6$  for low cost thermoelectric power generation, *Adv. Funct. Mater.* 20 (2010) 4375-4380. [\[DOI\]](#)
26. E. Flage-Larsen, **E. S. Toberer**, A. F. May, S. Diplas, Valence band study of thermoelectric Zintl  $\text{SrZn}_2\text{Sb}_2$  and  $\text{YbZn}_2\text{Sb}_2$ , *Phys. Rev. B* 81 (2010) 205204. [\[DOI\]](#)
25. J. F. Rauscher, **E. S. Toberer**, C. A. Cox, T. Yi, P. Klavins, G. J. Snyder, S. M. Kauzlarich, Synthesis, structure, magnetism, and high temperature thermoelectric properties of Ge doped  $\text{Yb}_{14}\text{MnSb}_{11}$ , *Dalton Trans.* 39 (2010) 1055-1062. [\[DOI\]](#)
24. C. R. I. Chrisholm, **E. S. Toberer**, M. W. Louie, S. M. Haile, Engineering the next generation of solid state proton conductors: Synthesis and properties of  $\text{Ba}_{3-x}\text{K}_x\text{H}_x(\text{PO}_4)_2$ , *Chem. Mater.* 22 (2010) 1186 - 1194. [\[DOI\]](#)
23. T. Yi, C. A. Cox, **E. S. Toberer**, G. J. Snyder, S. M. Kauzlarich, High temperature transport properties of the Zintl phases  $\text{Yb}_{11}\text{GaSb}_9$  and  $\text{Yb}_{11}\text{InSb}_9$  *Chem. Mater.* 22 (2010) 935-941. [\[DOI\]](#)

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22. **E. S. Toberer**, A. F. May, B. Melot, E. Flage-Larsen, G. J. Snyder, Electronic structure and transport in thermoelectric compounds  $AZn_2Sb_2$  ( $A = Sr, Ca, Yb, Eu$ ), *Dalton Trans.* 39 (2010) 1046 - 1054. [\[DOI\]](#)
21. A. F. May, **E. S. Toberer**, A. Saramat, G. J. Snyder, Characterization and analysis of thermoelectric transport in  $n$ -type  $Ba_8Ga_xGe_{46-x}$ , *Phys. Rev. B* 80 (2009) 125205. [\[DOI\]](#)
20. A. F. May, **E. S. Toberer** and G. J. Snyder, Transport properties of the layered Zintl compound  $SrZnSb_2$ , *J. Appl. Phys.* 106 (2009) 013706. [\[DOI\]](#)
19. C. A. Cox, **E. S. Toberer**, A. Levchenko, S. Brown, A. Navrotsky, G. J. Snyder, and S. M. Kauzlarich, Structure, heat capacity and high temperature thermal properties of  $Yb_{14}Mn_{1-x}Al_xSb_{11}$ , *Chem. Mater.* 21 (2009) 1354 - 1360. [\[DOI\]](#)
18. A. Saramat, **E. S. Toberer**, A. F. May and G. J. Snyder, Thermal stability and phase purity in polycrystalline  $Ba_8Ga_xGe_{46-x}$ , *J. Elect. Mater.* 38 (2009) 1423. [\[DOI\]](#)
17. **E. S. Toberer**, A. F. May, C. Scanlon, and G. J. Snyder, Thermoelectric properties of  $p$ -type  $LiZnSb$ : Assessment of *ab initio* calculations, *J. Appl. Phys.* 105 (2009) 063701. [\[DOI\]](#)
16. O. Prytz, A. E. Gunnaes, O. B. Karlsen, T. H. Breivik, **E. S. Toberer**, G. J. Snyder, and J. Taftø, Nanoscale inclusions in the phonon glass thermoelectric material  $Zn_4Sb_3$ , *Phil. Mag. Lett.* 43 (2009) 362 - 369. [\[DOI\]](#)
15. T. Ikeda, **E. S. Toberer**, V. A. Ravi, G. J. Snyder, S. Aoyagi, E. Nishibori and M. Sakata, In situ observation of eutectoid reaction forming a  $PbTe-Sb_2Te_3$  thermoelectric nanocomposite by synchrotron X-ray diffraction, *Scripta Mat.* 60 (2008) 321-324. [\[DOI\]](#)
14. **E. S. Toberer**, C. A. Cox, S. R. Brown, T. Ikeda, A. F. May, S. M. Kauzlarich and G. J. Snyder, Traversing the metal-insulator transition in a Zintl phase: Rational enhancement of thermoelectric efficiency in  $Yb_{14}Mn_{1-x}Al_xSb_{11}$ , *Adv. Funct. Mater.* 18 (2008) 2795 - 2800. [\[DOI\]](#)
13. **E. S. Toberer**, S. R. Brown, T. Ikeda, S. M. Kauzlarich, and G. J. Snyder, High thermoelectric efficiency in lanthanum doped  $Yb_{14}MnSb_{11}$ , *Appl. Phys. Lett.* 93 (2008) 062110. [\[DOI\]](#)
12. J. P. Heremans, V. Jovovic, **E. S. Toberer**, A. Saramat, K. Kurosaki, A. Charoenphakdee, S. Yamanaka, G. J. Snyder, Enhancement of thermoelectric efficiency in  $PbTe$  by distortion of the electronic density of states, *Science* 321 (2008) 554 - 557. [\[DOI\]](#)
11. S. Brown, **E. S. Toberer**, T. Ikeda, C. Cox, F. Gascoin, S. M. Kauzlarich, and G. J. Snyder, Improved thermoelectric performance in  $Yb_{14}Mn_{1-x}Zn_xSb_{11}$  by the reduction of spin-disorder scattering, *Chem. Mater.* 20 (2008) 3412 - 3419. [\[DOI\]](#)
10. **E. S. Toberer**, M. Christensen, B. B. Iversen, and G. J. Snyder, High temperature thermoelectric efficiency in  $Ba_8Ga_{16}Ge_{30}$ , *Phys. Rev. B* 77 (2008) 075203. [\[DOI\]](#)
9. **E. S. Toberer**, K. A. Sasaki, C. R. I. Chisholm, S. M. Haile, and G. J. Snyder, Local structure of interstitial Zn in  $\beta$ - $Zn_4Sb_3$ , *Phys. Stat. Sol. RRL* 19 (2007) 4833-4838. [\[DOI\]](#)
8. **E. S. Toberer**, M. Grossman, T. Schladt, F. F. Lange, and R. Seshadri, Epitaxial manganese oxide thin films with connected porosity: Topotactic induction of crystallographic pore alignment, *Chem. Mater.* 19 (2007) 4833-4838. [\[DOI\]](#)
7. R. Tackett, G. Lawes, B. C. Melot, M. Grossman, **E. S. Toberer**, and R. Seshadri, Magnetodielectric coupling in  $Mn_3O_4$ , *Phys. Rev. B* 76 (2006) 024409(1-6). [\[DOI\]](#)
6. **E. S. Toberer**, J.-D. Epping, B. F. Chmelka, and R. Seshadri, Hierarchically porous rutile titania: Harnessing spontaneous compositional change in mixed metal oxides, *Chem. Mater.* 18 (2006) 6345-6351. [\[DOI\]](#)

5. **E. S. Toberer**, J. P. Lofvander, and R. Seshadri, Topochemical formation of mesoporous MnO crystals, *Chem. Mater.* 18 (2006) 1047-1053. [\[DOI\]](#)
4. **E. S. Toberer**, T. Schladt, and R. Seshadri, Macroporous manganese oxides with regenerative mesopores, *J. Am. Chem. Soc.* 128 (2006) 1462-1463. [\[DOI\]](#)
3. **E. S. Toberer** and R. Seshadri, Spontaneous formation of macroporous monoliths of mesoporous manganese oxide crystals, *Adv. Mater.* 17 (2005) 2244-2246. [\[DOI\]](#)
2. **E. S. Toberer**, A. Joshi, and R. Seshadri, Template-free routes to macroporous monoliths of nickel and iron oxides: Toward porous metals and conformally coated pore walls, *Chem. Mater.* 17 (2005) 2142-2147 [\[DOI\]](#)
1. **E. S. Toberer**, J. C. Weaver, K. Ramesha and R. Seshadri, Macroporous monoliths of functional perovskite materials through assisted metathesis, *Chem. Mater.* 16 (2004) 2194-2200. [\[DOI\]](#)