

# **Annual Report**

**(July 1, 2015 – June 30, 2016)**



**Richard G. Lugar Center for Renewable Energy (LCRE),**  
Purdue School of Engineering and Technology,  
Indiana University-Purdue University Indianapolis

**June 30, 2016**

***The mission of the Richard G. Lugar Center for Renewable Energy is to:***

*Address the societal needs for clean, affordable and renewable energy sources, improve the nation's energy security, and help mitigate the negative impacts of climate change.*

*Promote research excellence in the area of renewable energy through collaborative efforts among faculty in the disciplines of engineering, chemistry, physics, biology, environmental affairs, and public policy.*

*Promote renewable energy applications through teaching, learning, civic engagement, and synergistic partnerships with industry, government labs and local communities.*

Please visit our website at [www.lugarenergycenter.org](http://www.lugarenergycenter.org) There is a **Give Now** button for your convenience in making tax exempt donations to advance the goals and mission of the Center

## **Introduction**

The Richard G. Lugar Center for Renewable Energy (LCRE) is located on the campus of Indiana University Purdue University-Indianapolis (IUPUI), and is administratively housed in the Purdue School of Engineering and Technology, IUPUI. *The LCRE consists of 44 Research Members spanning multiple disciplines, 21 Advisory Board Members, and 13 Entrepreneurs-in-Residence, plus about 60 students, interns and post-doctoral researchers.*

The LCRE is an interdisciplinary research center, and strives to meet the societal and public needs and challenges in these key energy and environmental areas. The Center helps create a collaborative environment for solving these challenges. The following report summarizes these activities and represents the hard work and commitment of our Research Members, Advisory Board, staff, and entire LCRE family.

## **Focus Areas – Renewable Energy**

- Batteries
  - Li-metal, Li-S
  - Anode/cathode/electrolyte chemistry
  - Seawater flow battery
- Fuel Cells
  - Non-Pt catalyst for PEM
  - Hydrogen storage
  - Hydrogen generation
  - SOFC for APU and home energy
- Combustion Engines
  - Advanced gas turbines
  - Internal combustion engines
  - Power and propulsion systems
- MSW Energy from Waste
  - Heat, oils for refining, electricity
  - Advanced gasification
  - Gas-to-liquids biofuels
- Policy & Economics
  - Urban, State, Federal
  - Energy forecasting and land use
  - Environment & Human health
- Commercial/Institutional & Buildings
  - Sustainable institutions
  - Energy and resource recovery
- Traditional Renewables
  - Solar power (including Space Solar)
  - Wind power (including hydraulic)
- Installation & Maintenance
  - Training
  - Automation
  - Diagnostics
- Manufacturing Science
  - Photovoltaic semiconductors
  - Nanotechnology
  - Fuel Cells
  - High temperature ceramics and coatings
- Efficiency
  - Industrial assessment
  - Curriculum development
  - Sustainable Technologies Certificate
- Entrepreneurship
  - Economic pro forma & business plans
  - Incubators and mentoring
  - Raising capital
- Sustainability & Lifecycle Analysis
  - Electric vehicles
  - Energy storage & management
  - Urban environment
- Switchgear, Diagnostics & Cybersecurity
  - Single transistor inverter
  - Synchronous distributed generation (patented)
  - Microgrids
  - Smart grid technology
  - Energy security methods

## **Summary of Research and Educational Activities**

The LCRE is continuing to make progress and achieve results in its core research fields and to establish itself as a leader, especially with regards to fuel cells, lithium ion batteries, electric vehicle research, biomass conversion, and education. Additionally, the capabilities of the LCRE are being expanded in these and new areas as evidenced by the induction of new Research Members.

Below is a summary of the latest updates with regard to existing and new research and educational programs at the LCRE:

### ***Recent Publications***

1. Wirey, M.; Hunt, M.; Blensdorf, T.; Stein, B.D.; Werner-Zwanziger, U.; Hanson, M. A.; Mahmoud, W.E.; Al-Ghamdi, A.A.; Carini, J.; Bronstein, L.M. Induced Microphase Separation in Hybrid Composite Polymer Electrolytes Based on Poly(acrylonitrile-r-butadienes) and Ionic Liquids. *Macromolecular Chemistry & Physics* (2016), 217(6), 794-803.
2. Baird, N.; Losovyj, Y.; Yuzik-Klimova, E. Yu.; Kuchkina, N. V.; Shifrina, Z. B.; Pink, M.; Stein, B. D.; Morgan, D. G.; Wang, T.; Rubin, M.; Sidorov, A.; Sulman, E. M.; Bronstein, L. M. Zinc-containing magnetic oxides stabilized by a polymer: One phase or two? *ACS Applied Materials & Interfaces* (2016), 8(1), 891-899.
3. McCully, AL and JB McKinlay. 2016. Disrupting Calvin cycle phosphoribulokinase activity in *Rhodospseudomonas palustris* increases the H<sub>2</sub> yield and specific production rate proportionately. *Int. J. Hydrogen. Energ.* 41: 4143-4149.
4. Bhargav, A.; Wu, M.; Fu, Y.-Z. "A Graphite-Polysulfide Full Cell with DME-Based Electrolyte", *J. Electrochem. Soc.* 2016, 163, A11543-A1549.
5. Cui, Y.; Wu, M.; Scott, C.; Xie, J.; Fu, Y.-Z. "A Binder-Free Sulfur/Carbon Composite Electrode Prepared by Sulfur Sublimation Method for Li-S Batteries", *RSC Adv.* 2016, 6, 52642-52645.
6. Bhargav, A.; Guo, W.; Fu, Y.-Z. "Chemically Synthesized Lithium Peroxide Composite Cathode for Closed System Li-O<sub>2</sub> Batteries", *Chem. Commun.* 2016, 52, 5678-5681.
7. Liu, M.; Zhou, D.; He, Y.-B.; Fu, Y.-Z.; Qin, X.; Miao, C.; Du, H.; Li, B.; Yang, Q.-H.; Lin, Z.; Zhao, T.S.; and Kang, F. "Novel Gel Polymer Electrolyte for High-Performance Lithium-Sulfur Batteries", *Nano Energy* 2016, 22, 278-289.
8. Cui, Y.; Fu, Y.-Z. "Enhanced Cyclability of Li/Polysulfide Batteries by a Polymer-Modified Carbon Paper Current Collector", *ACS Appl. Mater. Interfaces* 2015, 7, 20369–20376.
9. Bhargav, A.; Wu, M.; Fu, Y.-Z. "A Graphite-Polysulfide Full Cell with DME-Based Electrolyte", 229th ECS Meeting, May 29 – June 2, 2016, San Diego, CA.
10. Bhargav, A.; Fu, Y.-Z. "Chemically Synthesized Li<sub>2</sub>O<sub>2</sub> Composite Cathode for Closed System Li-O<sub>2</sub> Batteries", 229th ECS Meeting, May 29 – June 2, 2016, San Diego, CA.
11. Carley, S., Baldwin, E., MacLean, L. M., Brass, J. N. 2016. Global Expansion of Renewable Energy Generation: An Analysis of Policy Instruments. *Environmental and Resource Economics*.

- a. Winner of the 2014 Best Paper Award for Research in Comparative Policy Analysis, honored by the Association of Public Policy Analysis and Management and the International Comparative Policy Analysis Forum.
12. Carley, S., Nicholson-Crotty, S., Miller, C. 2016. Adoption, Reinvention, and Amendment of Renewable Portfolio Standards in the American States. Forthcoming in the *Journal of Public Policy*.
13. Baldwin, E., Carley, S., Brass, J. N., MacLean, L. M. 2016. Global renewable energy policy: A comparative analysis of countries by economic development status. *Journal of Comparative Policy Analysis*.
14. Krause, R., Lane, B., Carley, S., Sperl J., Graham, J. 2016. Assessing the Demand for Electric Vehicles under Future Cost and Technological Scenarios. Forthcoming in the *International Journal of Sustainable Transportation*.
15. Clark-Sutton, K., Siddiki, S., Carley, S., Wanner, C., Rupp, J., Graham, J.D. 2016. Plug-in electric vehicle readiness: Rating cities in the United States. *The Electricity Journal* 29(1): 30-40 [Editor Reviewed].
16. Carley, S. 2016. Energy programs of the American Recovery and Reinvestment Act of 2009. *Review of Policy Research* 33(2): 201-223.
17. Carley, S. 2016. The American Recovery and Reinvestment Act of 2009: What have we learned? *Review of Policy Research* 33(2): 119-123.
18. Ziogiannis, N., Alcorn, J., Rupp, J., Carley, S., Graham, J. 2016. State regulation of unconventional gas development in the U.S.: An empirical evaluation. *Energy Research and Social Science* 11:142-154.
19. Paydar, N., Schenk, O., Alcorn, J., Bowers, A., Carley, S., Rupp, J., Graham, J.D. 2015. The Effect of Community Reinvestment Funds on Local Acceptance of Unconventional Gas Development. *Economics of Energy & Environmental Policy* 15(1): 1-26.
20. Esposito, D., Rupp, J., Carley, S. 2015. Interaction of risks associated with natural gas and renewable based electricity. *The Electricity Journal* 28(8): 69-84 [Editor Reviewed].
21. Siddiki, S., Dumortier, J., Curley, C., Carley, S., Krause, R. 2015. Regulating for Innovation and Technology Adoption: The Case of Plug-In Vehicles. *Review of Policy Research* 32(6): 649-674.
22. Nicholson-Crotty, S., Carley, S. 2015. Effectiveness, Implementation Capacity, and Policy Diffusion: Or, "Can We Make that Work for Us?" *State Politics and Policy Quarterly*.
23. Ali Ghorbani Kashkooli, Siamak Farhad, Dong Un Lee, Kun Feng, Shawn Litster, Likun Zhu, Zhongwei Chen, "Multiscale modelling of LiFePO<sub>4</sub> cathode based on nano-scale X-ray computed tomography", *Journal of Power Sources*, vol. 307, Pages 496–509, 2016.
24. Bo Yan, Cheolwoong Lim, Zhibin Song, and Likun Zhu, "Analysis of Polarization in Realistic Li Ion Battery Electrode Microstructure Using Numerical Simulation", *Electrochimica Acta*, vol. 185, pp. 125-141, 2015.
25. A. Razban, A. Khatib, D. Goodman, J. Chen, Mechanical modeling of air handling unit subsystem in a commercial building, submitted to *Journal of Energy*, 2016
26. L. Bearden, A. Razban, an Automated Grid-Based Robotic Alignment System for Pick and Place Applications, *Journal of Intelligent and Robotics System*, March, 2016
27. M. Malguarnera and A. Razban, Utility ownership of combined heat and power: an economic model based approach, *International Journal of Research in Engineering and Technology*, Vol 4, issue 11, pp 131-139, Nov. 2015.

28. Wu, T., S.A. Jahan, P. Kumaar, A. Tovar, H. El-Mounayri, Y. Zhang, J. Zhang, D. Acheson, K. Brand, R. Nalim. A framework for optimizing the design of injection molds with conformal cooling for additive manufacturing. *Procedia Manufacturing*, Vol. 1, Pages: 404-415, doi:10.1016/j.promfg.2015.09.049, 2015
29. Bandi, P., D. Detwiler, J. Schmiedeler, and A. Tovar. Design of Progressively Folding Thin-Walled Tubular Components Using Compliant Mechanism Synthesis. *Thin-Walled Structures*, Vol. 37, Issue 2, Pages: 723-735, doi:10.1007/s40430-014-0197-0, 2015
30. Liu, K., A. Tovar, E. Nutwell, and D. Detwiler. Thin-walled compliant mechanism component design assisted by machine learning and multiple surrogates. *SAE Technical Paper 2015-01-1369*, doi:10.4271/2015-01-1369, 2015
31. León, D., N. Arzola, and A. Tovar. Statistical analysis of the influence of tooth geometry in the performance of harmonic drive. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. Vol. 37, Pages: 723-735, 2015, doi:10.1007/s40430-014-0197-0, 2015
32. E. Salcedo, A. J. Berndt, T. Wu, Y. Zhang, J. Zhang, A. Tovar, J. E. Ryu, "Design of highly flexible and elastic electronic substrates using additive manufacturing," *ASME 2016 IMECE*, Abstract accepted
33. Y. Zhang, L. Wu, A. Shankar, J. E. Ryu, A. Tovar, J. Zhang, "Molecular dynamics simulation of silver nanoink sintering in intense pulse light process," *ASME 2016 IMECE*, Abstract accepted
34. Liu, K., Z. Xu, D. Detwiler, A. Tovar. Optimal Design of Cellular Material Systems for Crashworthiness. In *Proceedings of the SAE World Congress*. Detroit, MI, USA, Apr 12-14, 2016.
35. Mehta, P.S., J.S. Ocampo, P. Chaudhari, A. Tovar, Bio-inspired design of lightweight and safe vehicle structures. In *Proceedings of the SAE World Congress*. Detroit, MI, USA, Apr 12-14, 2016.
36. Gokhale V.V., C. Marko, T. Alam, P. Chaudhari, A. Tovar, Design of an advanced layered composite for energy dissipation using a 3D-lattice of micro compliant mechanism. In *Proceedings of the SAE World Congress*. Detroit, MI, USA, Apr 12-14, 2016.
37. Liu, K., D. Detwiler, and A. Tovar, Machine Learning and Metamodel-based Design Optimization of Nonlinear Multimaterial Structures. In *Proceedings of the ASME 2016 International Design Engineering Technical Conferences (IDETC 2016)*. Charlotte, NC, USA, Aug 21-24, 2016.
38. Wu, T., K. Liu, and A. Tovar, Multiscale Thermomechanical Topology Optimization of Functionally Graded Lattice Injection Molds. In *Proceedings of the ASME 2016 International Design Engineering Technical Conferences (IDETC 2016)*. Charlotte, NC, USA, Aug 21-24, 2016.
39. Lischke, F. and A. Tovar, Design of Self-supporting 3D Structures for Fused Deposition Modeling. In *Proceedings of the ASME Additive Manufacturing + 3D Printing Conference (AM3D)*. Charlotte, NC, USA, Aug 21-24, 2016.
40. Hossain, G., P. Ghane, and A. Tovar, Towards an Effective Neuro-Feature Selection Method in Robust Voice Controlled Prosthetic Arm Design. *Cell Symposia: Engineering the Brain – Technologies for Neurobiological Applications (CSFN 2015)*. Chicago, IL, USA, Oct 15-16, 2015.

41. Liu, K., A. Tovar, E. Nutwell, and D. Detwiler. Towards nonlinear multimaterial topology optimization using unsupervised machine learning and metamodel-based multiobjective optimization. In Proceedings of the ASME 2015 International Design Engineering Technical Conferences (IDETC 2015). Boston, MA, USA, Aug 2-5, 2015.
42. Zusack, S.A., Pail, R., Lachenman, S., Johnson, C.A., Schubert, P.J., McDaniel, N., "Capstone Design Project Experience: Lunar Ice Extraction Design," Proceedings of American Society of Engineering Educators, Annual Conference, New Orleans, 23-26 June 2016.
43. Elkhatib, W., Zusack, S.A., Schubert, P.J., Schaffer, B., Akmayeva, E.V., Proctor, P.J., Wiss, G.N., "Problem-based Multidisciplinary Participation in Aerospace Design," Proceedings of American Society of Engineering Educators, Annual Conference, New Orleans, 23-26 June 2016.
44. Schubert, P.J., "Mentored, Unpaid Design Team Internship Experience," Proceedings of American Society of Engineering Educators, Annual Conference, New Orleans, 23-26 June 2016.
45. Schubert, P.J., "Silicon Carbide from Asteroids for Power Electronics," Int'l. Space Development Conf., San Juan, PR, 18-22 May 2016.
46. Schubert, P.J., "Doubly Self-Aligned DMOSFET in SiC for Microgravity Manufacture," Poster session, CS ManTech 2016, Miami, FL, 16-19 May 2016.
47. Schubert, P.J., "Seawater Flow Battery for Clean Cold-ironing & Fleet Vehicle Fueling," Energy, Utility & Environmental Conference 2016, San Diego, 3-5 Feb 2016.
48. McIver, Ann W., and Schubert, P.J., "Research and Commercialization of Renewable Technologies to Support Remediation," Energy, Utility & Environmental Conference 2016, San Diego, 3-5 Feb 2016.
49. Schubert, P.J., "Distributed Bio-Hydrogen Refueling Stations," Energy, Utility & Environmental Conference 2016, San Diego, 3-5 Feb 2016.
50. Schubert, P.J., Pinto, S.M., Pires, B.C., do Nascimento, M., Barks, E., Nderitu, J., Goncalves, G., Tokmo, F., "Analysis of a Novel SPS Configuration Enabled by Lunar ISRU," Proceedings AIAA SPACE 2015, Pasadena, CA, 31 Aug. – 2 Sept. 2015.
51. Schubert, P., "Selection and Re-Selection in Stochastic Democracy," Proceedings AIAA SPACE 2015, Pasadena, CA, 31 Aug. – 2 Sept. 2015.
52. Al-Gwaiz, M., X. Chao, O.Q. Wu, 2016. Understanding How Generation Flexibility and Renewable Energy Affect Power Market Competition. Forthcoming, Manufacturing & Service Operations Management.
53. Dumortier, Jerome, Matthew W. Kent, Seth B. Payton. (2016). "Plug-in vehicles and the future of road infrastructure funding in the United States." Energy Policy 95, 187-195.
54. Book: A Hundred Solved Problems in Power Electronics, 1st Edition, Authored by Euzeli C. dos Santos Jr., Gregory Carlos, ISBN/EAN13: 1508450137/9781508450139.
55. N. Marinus; C. Jacobina; N. Rocha; E. dos Santos, "AC-DC-AC Three-Phase Converter Based on Three Three-Leg Converters Connected in Series," (accepted) in IEEE Transactions on Industry Applications , vol.PP, no.99, pp.1-1
56. Carlos, Gregory; Jacobina, Cursino ; E. C. dos Santos Jr.. "Investigation on Dynamic Voltage Restorers With Two DC-Links and Series Converters for Three-Phase Four-Wire Systems". (accepted) IEEE Transactions on Industry Applications, 2015.

57. G. A. A. Carlos, E. C. dos Santos Jr., C. B. Jacobina, J. P. R. Mello, "Dynamic Voltage Restorer Based on Three-Phases Inverters Cascaded Through an Open-End Winding Transformer". (accepted) IEEE Transactions on Power Electronics, vol.PP, 2015.
58. G. A. de A. Carlos, C. B. Jacobina, E. C. dos Santos Jr., E. L. L. Fabricio, N Rocha. "Shunt Active Power Filter with Open-End Winding Transformer and Series Connected Converters". IEEE Transactions on Industry Applications, Vol. 51, No 4, pp. 3273-3283, July-Aug. 2015.
59. I. S. Freitas, M. M. Bandeira, F. Salvadori, S. A. da Silva, L. Barros, C. B. Jacobina and, E. C. dos Santos Jr. "A Carrier Based PWM Technique for Capacitor Voltage Balancing of Single-Phase Three-level Neutral-Point-Clamped Converters". IEEE Transactions on Industry Applications, vol. 28, No. 3, March 2015.
60. E. C. dos Santos Jr., J. H. G. Muniz, E. R. C. da Silva, C. B. Jacobina, "Nested Multilevel Topologies". IEEE Transactions on Power Electronics, Vol. 30, No. 8, pp. 4058-4068, Aug. 2015.
61. O. Nezamuddin, J. Crespo, E. C. dos Santos Jr., "Design of a Highly Efficient Microinverter," 43rd IEEE Photovoltaic Specialists Conference, Portland, OR.
  - a. Winner of Best Student Presentation Award.
62. B. K. Sabbarapu, O. Nezamuddin, E. C. dos Santos Jr., "Small Signal Analysis Of A Single Input Dual Output Dc-Dc Buck Converter," IEEE Communication Energy Systems (INTELEC), 2016.
63. J. Arruda, E. C. dos Santos Jr., "An optimized VSI for Microgrid Applications," IEEE Communication Energy Systems (INTELEC), 2016.
64. N. Marinus, E. C. dos Santos Jr., C. B. Jacobina, "A Bridgeless Controlled Rectifier for Single Split-Phase Systems," IEEE ECCE - The Energy Conversion Congress and Exposition, 2016.
65. B. K. Sabbarapu, O. Nezamuddin, E. C. dos Santos Jr., "Single-Input Multiple-Output Synchronous Dc-Dc Buck Converter," IEEE ECCE - The Energy Conversion Congress and Exposition, 2016.
66. G. Carlos, E. C. dos Santos Jr., C. B. Jacobina, "Alternative Breed of Three-Phase Four-Wire Shunt Compensator based on Cascaded Transformer with Single Dc-link," IEEE ECCE - The Energy Conversion Congress and Exposition, 2016.
67. G. Carlos, E. C. dos Santos Jr., "Cascaded Open End Winding Transformers based DVR," IEEE ECCE - The Energy Conversion Congress and Exposition, 2016.
68. G. A. A. Carlos, E. C. dos Santos Jr., P.R. R. Sousa, C. B. Jacobina, L. M. Barros; A.C Oliveira. "DVR with five-level converter based on three-and two-level legs connections". In: 2015 IEEE Energy Conversion Congress and Exposition, 2015, Montreal. 2015 IEEE Energy Conversion Congress and Exposition (ECCE), 2015. p. 5474.
69. Maciel, Alvaro M. ; Jacobina, Cursino B.; E. C. dos Santos Jr.; Melo, Victor. M. B. ; Carlos, Gregory A. A. "Three-phase four-wire shunt active power filter with the interconnection of single-phase and three-phase converters". In: 2015 IEEE Energy Conversion Congress and Exposition, 2015, Montreal. 2015 IEEE Energy Conversion Congress and Exposition (ECCE), 2015. p. 6423.
70. A. Karimi, M. R. Nalim, "Ignition by Hot Transient Jets in Confined Mixtures of Gaseous Fuels and Air," Journal of Combustion, Volume 2016, Article ID 9565839, 13 pages, 2016.



71. Md Nazmuzzaman Khan, Kyong-yup Paik, and M Razi Nalim, "Torch-Jet Ignition Of Premixed Methane-Hydrogen-Air Blends in a Constant-Volume Combustor: 3D Computational Modeling," AIAA 2015 Propulsion & Energy Forum, Jul 2015, Orlando, FL.
72. Ravichandra R. Jagannath, Sally P. M. Bane, M. R. Nalim, "Wave Rotor Combustor Turbine Model Development," AIAA 2015 Propulsion & Energy Forum, Jul 2015, Orlando, FL.

### ***Inventions Disclosed, Patents Applied for or Granted***

1. Fu, Y.-Z. "High-Energy Rechargeable Lithium-Sulfur Batteries", U.S. Provisional Patent Application No. 62/210,794 filed on August 27, 2015, IURTC Tech No.: 2015-160.
2. Porous 3D Topology Optimization Design Algorithm: A. Tovar, K. Liu, and T. Wu, 2016.
3. Advanced layered composite for energy dissipation using a 3D lattice of micro compliant mechanism array: A. Tovar and V. Gokhale, 2016.
4. Computational Design Algorithm: Thermo-Mechanical Topology Optimization: A. Tovar, K. Liu, and T. Wu, 2015.
5. Algorithm for Modeling Solids as Porous Materials in CAD: A. Tovar, K. Liu, and T. Wu, 2015.
6. "Process and Apparatus for Preparing Solid-State Hydrogen Storage Media", P. Schubert, 2016.
7. Continuation in Parts part II for "Multi-spectral Electrophoresis System and Method for Using", P. Schubert, April 2016.
8. Continuation in Parts for "Multi-spectral Electrophoresis System and Method for Using", P. Schubert, Jan. 2016.
9. Continuation in Parts for "Apparatus and Method for Butanol Synthesis from Gaseous Feedstock", P. Schubert, 2015.
10. "High-Power Radiation-Hard Microelectronics with Double Self-Alignment," P. Schubert 2015.
11. "Wireless Power Transfer with Low Side-Lobe Levels," P. Schubert, 2015.
12. E. dos Santos, US Patent Application No. 14/468,289; filed August 21, 2014
13. E. dos Santos, US Patent Application No. 14/871,085; filed September 30, 2015
14. E. dos Santos, US Provisional Patent Application IURTC Tech No: 2016-105; filed March 15, 2016.

### ***Conferences attended, Invited Talks, Collaborations featuring LCRE***

1. McKinlay, JB 19th International Congress on Nitrogen Fixation, Asilomar, CA
2. McKinlay, JB ASM Microbe Meeting, Boston, MA
3. McKinlay, JB Dept of Bacteriology, University of Wisconsin, Madison, WI
4. "Studies of Lithium Sulfide and Lithium Peroxide Cathode Materials", The 30th Annual Conference of Chinese Chemical Society, Dalian, China, July 1-4, 2016.
5. "Organosulfide – A High Capacity Cathode Material for Rechargeable Lithium Batteries", 2016 China Energy Materials Chemistry Workshop, Changsha, China, June 14-16, 2016.

6. "Rational Design of Cathodes for Rechargeable Li-S and Li-O<sub>2</sub> Batteries", Department of Chemical Engineering, University of Illinois at Chicago, Chicago, IL 60607, February 25, 2016.
7. "Rational Design of Cathodes for Rechargeable Li-S and Li-O<sub>2</sub> Batteries", East Lake International Forum for Outstanding Overseas Young Scholars, Huazhong University of Science and Technology, Wuhan, Hubei, China, December 26-28, 2015.
8. "Rational Design of Cathodes for Rechargeable Lithium-Sulfur Batteries", Department of Chemistry, Indiana University, Bloomington, IN 47405, October 22, 2015.
9. "Rational Design of Cathode Materials for Rechargeable Li-S and Li-O<sub>2</sub> Batteries", The 4th Emerging Information and Technology Association Young Investigator Conference (EITA-YIC 2015), Massachusetts Institute of Technology, Cambridge, MA, August 6-7, 2015.
10. "Rational Design of Li<sub>2</sub>S Cathodes for Rechargeable Li-S Batteries", International Symposium of Young Scientists on Next-Generation Batteries 2015 (ISYSNGB 2015), Hunan University, Changsha, Hunan, China, August 1-2, 2015.
11. "Exploring renewable energy certificate market dynamics: What role do markets play in renewable energy growth and development?" Paper presented at the International Association of Energy Economics Conference, Bergen, Norway, June, 2016.
12. "Policy Learning in the Context of State Energy Policy." Paper presented at the 74th annual Midwest Political Science Association Conference, Chicago, IL, April, 2016.
13. "Exploring renewable energy certificate market dynamics: What role do markets play in renewable energy growth and development?" Paper presented at the 37th Annual Research Conference, Association for Public Policy Analysis and Management, Miami, FL, November, 2015.
14. "The Electric Vehicle Attitude-Behavior Gap: Moving Beyond the Early Adopters." Paper presented at the 34th Annual Conference, U.S. Association of Energy Economics, Pittsburgh, PA, October, 2015.
15. Carley, S., Duncan, D., Esposito, D., Graham, J. D., Siddiki, S., Zirotiannis, N., 2016. "Rethinking Auto Fuel Economy: Technical and Policy Suggestions for the 2016-17 Midterm Reviews." [Peer-reviewed document]
16. Cheolwoong Lim, Huixiao Kang, Bo Yan, Likun Zhu, "Microstructure evolution of high capacity anode electrode by in-situ and in-operando X-ray nano-CT", the 18th International Meeting on Lithium Batteries, June 19-24, 2016, in Chicago, Illinois, USA.
17. Huixiao Kang, Cheolwoong Lim, Yongzhu Fu, Likun Zhu, "Geometric and Electrochemical Characteristics of NMC Electrodes with Different Calendering Conditions", the 18th International Meeting on Lithium Batteries, June 19-24, 2016, in Chicago, Illinois, USA.
18. Bo Yan, Cheolwoong Lim, Leilei Yin, Likun Zhu, "Analysis of Li Dendrite Formation on Graphite Anode Based on Realistic Electrode Microstructure Using Numerical Simulation", the 18th International Meeting on Lithium Batteries, June 19-24, 2016, in Chicago, Illinois, USA.
19. Rou Chen, Likun Zhu, Whitney Yu, "Bubble dynamics in a micro-channel with a virtual check valve", the 68th Annual Meeting of the APS Division of Fluid Dynamics, November 22-24, 2015; Boston, Massachusetts.
20. Ali Razban, Indiana Energy Management Conference, Indianapolis, IN, Aug. 2015, invited speaker.

21. Ali Razban, Indiana Electric League, Indianapolis, IN, March 2016, invited speaker.
22. Ali Razban, 2nd National Energy Education Summit, Washington, DC., June 2016, invited speaker.
23. “Pi Day” lectures to 5th graders and to 6th graders at Jonathan Jennings Elementary School (IPS #109) and 7th graders at Decatur Township Middle School, Indianapolis: “How to save the world with energy”, P. Schubert.
24. Smart Grid: Historical Point of View, Fundamentals and Trends (UFPB, Brazil) 2015, E. dos Santos.

### ***Research Grants and Milestones***

1. 2012-2017 Office of Science (BER), US Department of Energy Early Career Research Program, DE-SC0008131. Metabolism and evolution of a biofuel-producing microbial coculture. \$750,000 total. JB McKinlay, PI. One of 68 proposals awarded from 850; 8% funding rate.
2. 2016 Community Science Program, US Department of Energy, Joint Genome Institute. Identification of genetic factors for obligate syntrophy and biofuel production in a synthetic bacterial coculture. McKinlay, PI. Service grant. No dollar amount.
3. PI: Yongzhu Fu, Ion Selective Separators for Lithium Batteries Enabled by Anion Binding Macrocycles, Co-PI: Amar H. Flood (IU-Bloomington), Source: Indiana University Collaborative Research Grant of the Office of the Vice President for Research. Total budget: \$75,000 (Dr. Fu’ share 50%). Duration: 6/1/2016 – 5/31/2017.
4. “The U.S. Energy and Climate Transition: Aggregated Impacts of Policy on Vulnerable Populations” Co-PI with Tom Evans and David Konisky. Indiana University Collaborative Research Grant. Office of the Vice Provost of Research, Indiana University. \$63,437. 2016-2017. Sanya Carley.
5. “Consumer Willingness to Pay for Sustainability: The Case of the Brewing Industry” PI. Office of the Vice Provost of Research Award for Research Methods and Collaboration, Indiana University. \$4,942. 2016. Sanya Carley.
6. “Study of the macro-economic impact of the light-duty vehicle corporate average fuel economy, greenhouse gas and zero-emission vehicle standards: Phases II and III” Co-PI with John Graham (PI), Denvil Duncan, Saba Siddiki, and Nikos Ziogiannis. Alliance for Automobile Manufacturers. \$590,000. 2016-2017. Sanya Carley.
7. “Study of the macro-economic impact of the light-duty vehicle corporate average fuel economy, greenhouse gas and zero-emission vehicle standards: Phase I” Co-PI with John Graham (PI), Denvil Duncan, and Saba Siddiki. Alliance for Automobile Manufacturers. \$202,723. 2015-2016. Sanya Carley.
8. “Collaborative Research: Dynamics of chalcogenide-doped high capacity lithium-ion battery anode materials during cycling using in situ imaging”, NSF, PI, 2016 – 2019, \$200,022, Likun Zhu.
9. “Computed tomography image-based study for understanding the impact of electrode microstructure on lithium ion battery”, NSF, PI, 2013 – 2017, \$291,002, Likun Zhu.
10. “Collaborative Research: Self-circulating, self-regulating microreactor for on-chip gas generation from liquid reactants”, NSF, PI, 2013 – 2017, \$196,847. Likun Zhu.

11. “Identification of Lithium Ion Battery Electrode Structural Inhomogeneity and Its Effect on Battery Performance”, American Chemical Society Petroleum Research Fund, PI, 2013 – 2015, \$100,000. Likun Zhu.
12. PI of a \$75k, from CLEAResult Corp. for energy audit, energy consumption evaluation and recommendation implementation of industrial sectors, Ali Razban.
13. PI of a \$7,500, from Horton Corp. for To complete Horton's Utility Sales Tax Exemption with supporting analysis, Ali Razban.
14. General Motors. Title: Structural multiscale, multimaterial topology optimization for crashworthiness using Extended Hybrid Cellular Automata. Amount: \$100,000. Role: PI. Effort: 100%. Dates: May 2016 – Nov 2016, Andres Tovar.
15. IUPUI OVCR Funding Opportunities for Research Commercialization and Economic Success (FORCES). Title: Commercialization of a Topology Optimization Algorithm to Design Lightweight, Multi-Functional Components with Optimized Internal Cellular (Porous) Structure. Amount: \$25,000. Role: PI. Effort: 100%. Dates: May 2016 – Oct 2016, Andres Tovar.
16. IUPUI CRL Multidisciplinary Undergraduate Research Institute (MURI). Title: Development of additive manufacturing technologies to 3D print with recycled mixed shredded plastic. Amount: \$15,000. Role: PI. Effort: 50%. Dates: May 2016 – Aug 2016, Andres Tovar.
17. IUPUI OVCR Release Time for Research (RTR). Title: Improved crashworthiness in lightweight automotive vehicles through material substitution and shape optimization with carbon fiber-reinforced composites. Phase 1: material modeling and simulation, Andres Tovar. Amount: \$10,000. Role: PI. Effort: 100%. Dates: Sep 2016 – Dec 2016, Andres Tovar.
18. Honda R&D Americas. Title: Topology Crash Optimization of Progressively Buckling Thin-walled Structures using Tubular Compliant Mechanisms—Improved Conceptual Design using a Target Dynamic Response. Role: PI. Effort: 100%. Amount: \$120,336. Dates: June 2015 – June 2017, Andres Tovar.
19. Walmart U.S. Manufacturing Innovation Fund. Title: Optimal plastic injection molding tooling design and production through advanced additive manufacturing. Amount: \$291,202. Role: PI. Effort: 35%. Dates: Aug 2014 – Feb 2017, Andres Tovar.
20. IUPUI Curriculum Enhancement Grant (CEG): Blended Presentation Approach (BPA) Promoting Curriculum Enhancement of ECE Power Electronics. Awarded: \$5,400. Principal Investigator, E. dos Santos.
21. National Science Foundation via Aerodyn Combustion LLC, “Wave Rotor Constant-Volume Combustion for Energy Efficiency and Greenhouse Gas Abatement in Gas Turbine Engines,” Small Business Technology Transfer (STTR) project, 2015-16, \$225,000 total (IUPUI share \$100,000), M. Razi Nalim & P. Schubert
22. IUPUI, Multi-Disciplinary Undergraduate Research Institute (MURI), “Investigation of plasma-assisted turbulent jet ignition for rapid combustion applications ignition,” \$10,700, 2015-16, M. Razi Nalim.

### ***Students Graduated (selected)***

1. Yuanzhi Cao (Prof. Likun Zhu)
2. Zhibin Song (Prof. Likun Zhu)
3. Arash Edalatnoor (Dr. Ali Razban)
4. Lischke, Fabian (Prof. Andres Tovar)
5. Timothy James Segó (Prof. Andres Tovar)
6. Vaibhav Gokhale (Prof. Andres Tovar)
7. Arash Jamali (Razi Nalim)

### ***New Equipment or Capabilities***

Created the Additive Manufacturing Lab in SL 009. The lab is equipped with more than 20 3D printers including one AirWolf AW3DXL Deluxe (AirFolF 3D Printers, Costa Mesa, California), three Steam Engine printers (3D Parts Manufacturing, Indianapolis, Indiana), one Form 1+ and one Form 2 (FormLabs, Somerville, Massachusetts), and over 10 RepRap printers.

### ***Service Activities***

- Jake McKinlay, starting July 2016; Division Chair-elect, American Society for Microbiology, Division K – Microbial Physiology and Metabolism
- Jake McKinlay, Editorial board member. Applied and Environmental Microbiology, ASM.
- Jake McKinlay, Ad hoc reviewer for mBio, Appl Microbiol Biotechnol, Biotechnol Bioeng, J Bacteriol, ISME J, PLOS One
- Jake McKinlay, Ad hoc reviewer. ASM Microbe textbook chapter.
- Jake McKinlay, Ad hoc reviewer. NSF Molecular and Cellular Bioscience grant proposal
- Ali Razban, Reviewer for 2015 IEEE International Conference on Automation and Engineering.
- Ali Razban, Reviewer for 2016 ASME International Mechanical Engineering Congress & Exposition.
- Ali Razban, Editor of Lawrence Press publisher.
- Andres Tovar, 2016 Journal of Computational Physics
- Andres Tovar, 2016 Structural and Multidisciplinary Optimization
- Andres Tovar, 2016 Austin Journal of Robotics and Automation
- Andres Tovar, 2016 Multidiscipline Modeling in Materials and Structures
- Andres Tovar, 2015 Engineering Structures
- Andres Tovar, 2015 International Journal of Vehicle Design
- Andres Tovar, 2015 Mathematical Problems in Engineering
- Andres Tovar, 2015 Structural and Multidisciplinary Optimization
- Andres Tovar, 2015 Journal of Aerospace Engineering
- Andres Tovar, 2015 Mechanics Research Communications

- Andres Tovar, 2016 ASME International Design Engineering Technical Conference IDETC: 5 papers
- Andres Tovar, 2016 SAE World Congress: 1 paper
- Andres Tovar, 2016 National Science Foundation CMMI: 8 proposals
- Andres Tovar, 2016 Universidad Antonio Nariño: 1 proposal
- Andres Tovar, Editorial Board Member. Austin Journal of Robotics & Automation. Since May 2014.
- Andres Tovar, Editorial Board Member. Journal of Surfaces and Interfaces of Materials. Since Aug 2011.
- Andres Tovar, Scientific Committee Member: Journal Intekhnia, Saint Thomas Aquinas University. Since Jun 2010.
- Andres Tovar, International Scientific Committee Member of the ISSMO 4th International Conference on Engineering Optimization (EngOpt 2016), Iguassu Falls, Brazil, June 19-23, 2016.
- Andres Tovar, Symposium Co-organizer and Review Coordinator for the ASME 41th Design Automation Conference, Design of Engineering Materials and Structures Session, Charlotte, North Carolina, Aug 21-24, 2016.
- Andres Tovar, Symposium Co-organizer and Review Coordinator for the ASME 40th Design Automation Conference, Design of Engineering Materials and Structures Session, Boston, Massachusetts, August 2-5, 2015.
- Guest Associate Editor - IEEE Transactions on Power Electronics, 2015
- IEEE Student Branch Chapter Advisor, Purdue Univ.-Indianapolis Industry Applications Society Student Branch Chapter (2014 - present)
- Euzeli dos Santos, Reviewer - IEEE Transactions on Power Electronics
- Euzeli dos Santos, Reviewer - IEEE Transactions on Industry Applications
- Euzeli dos Santos, Reviewer - IEEE Transactions on Industrial Informatics
- Euzeli dos Santos, Reviewer - IEEE Industrial Electronics Magazine
- Euzeli dos Santos, Reviewer - IEEE Transactions on Vehicular Technology
- Euzeli dos Santos, Reviewer - IET Power Electronics

## **Outreach**

The 2016 **Spring Forum** topic was “Building an Energy Security Roadmap”, with the following motivation statement, drawn from LCRE Research Members, Advisory Board Members, and Entrepreneurs-in-Residence:

*Energy is fundamental to our society and way of life. We appear to be in a golden age of energy where choices proliferate and expenses are low relative to household incomes. Retirements of legacy power plants squeeze baseload delivery at the same time that new installation of solar and wind are outpacing that of new fossil fuel facilities. Intermittency of renewables is a concern, yet grid-scale storage and energy management using batteries is growing and coming down in price. With more distributed generation, there are more points of vulnerability, but also better capability of containing a breach. Cyber attacks are growing in sophistication and in response, the energy industry and the*

*government are trying to step up to these challenges. What will the future energy mix look like? What are the opportunities and threats that come with them? How can we design policy and develop technology to reap the benefits of cheap, sustainable energy for all while preserving the reliability of supply and protecting against the increasing efforts of bad actors? The 2016 Spring Forum explores these inter-dependent issues broadly, seeking to inform and educate, and to identify good opportunities for research as we build a roadmap to energy security in Indiana.*

The event was held in the IUPUI Campus Center and had 104 registrants. The line-up included 20 speakers starting with former Indianapolis mayor Gregory A. Ballard, followed by representatives of InfraGard, the US EPA, the Indiana Utilities Regulatory Commission, and State Senator Jim Merritt, chair of the Utilities Committee. Break-out sessions were facilitated to solicit a broad range of inputs from all participants. These were then summarized at plenary, and followed-up with panel discussions addressed near-term needs for energy security, and long-term trends. A key goal was to identify relevant areas for research by Lugar Center members. Professional credits were awarded to 11 professional engineers and 3 practicing attorneys. Selected speaker presentation materials are available on our website at:

➤ <http://www.lugarenergycenter.org/index.php/events/>

The LCRE **Annual Retreat** was held at International Medical Group Building, now called Brougner Plaza, in January 2016. Following an introduction by Dean Russomanno, Vice Chancellor for Research Simon Atkinson reviewed center-level and multi-disciplinary opportunities. Connie Neining of the State Department of Agriculture reviewed the many renewable energy projects across Indiana, and Vince Griffin of the Indiana Chamber of Commerce outlined further renewable energy opportunities. The afternoon session developed the topic for the Spring Forum and was followed by networking and brainstorming supportive of the activities of the Lugar Center members in attendance.

**Other recent outreach activities include the following:**

- The DOE's National Renewable Energy Lab (NREL) conducted a study for Crane NSWC on a joint solar and battery storage project for the naval base in southern Indiana. By re-purposing used submarine batteries they can create a microgrid or energy storage system. Three LCRE Research Members contributed comments and edits to the report, with input from Dr. David Goodman, Dr. Dave Baxter, and Dr. Peter Schubert.
- Design in Engineering. Thompson Crossing Elementary, Southeast Marion County, Indiana, Apr 28, 2016 by Dr. Andres Tovar.
- Topology optimization of cellular materials: from lightweight vehicles and porous injection molds to prosthesis and scaffolds. Biomedical Engineering Research Seminar, IUPUI, Apr 8, 2016 by Dr. Andres Tovar.
- Bioinspired design of impact-protective structures: from safer helmets to lightweight automotive structures. International Research Conference on Health Science, Education, and Music (CINVEST), Paipa, Colombia, Nov 19-20, 2015 (keynote speaker. Dr. Andres Tovar)

- Bio-inspired structural design. IUPUI Biology Fall Research Seminar, Sep 11, 2015, by Dr. Andres Tovar.

**Student capstone course participation by LCRE:**

- A team of 10 summer interns began work on three research topics with papers to be submitted to the International Astronautical Congress 2016 in Guadalajara, Mexico (abstracts have been accepted). Each student is paired with a mentor from industry or from NASA to guide their Research Plan and review progress. The all-undergraduate research team members (depicted below) includes: Syiu Chi Chua, Shen Mi Khoo, Xiang En Huang, Issuddin Muhammad Izam, Khairuz Zaki MD Rujhan, Khalil Adli Moktar, Mukish Kumar Munyady, Pravinjit Singh, and Filarius Peter Usop, all of Universiti Tenaga Nasional (UNITEN) in Kajang, Malaysia, and are in a 12 month study abroad program at IUPUI.

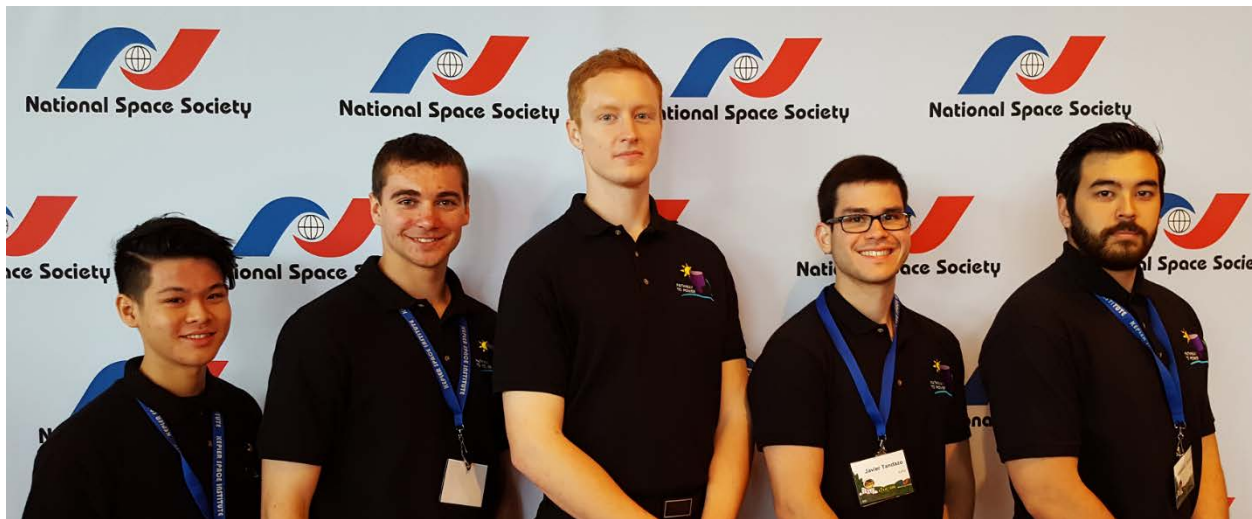


- A capstone design team in Mechanical Engineering pursued an unconventional project and is now one of 12 finalists in a national competition. A five student team entered the RASC-AL competition (Revolutionary Aerospace Systems Concepts – Academic Linkage) on the topic of harvesting water from permanently-shadowed craters on the lunar north and south poles. The competition is managed by the National Institute of Aerospace on behalf of NASA, now in its second year. The IUPUI student team developed a complete system for extracting buried water ice and converting it to liquid oxygen and liquid hydrogen needed for fuel cells, rocket propellant, and for life support. After two rounds of down selection, the ME 462 team will travel to Cocoa Beach in June for the finals. This work builds upon space-related energy research conducted at the Richard G. Lugar Center for Renewable Energy under the supervision of Director Peter Schubert. The student team is led by Steve Zusack, co-founder of SEDS@IUPUI (our “rocket club”) and 3-time NASA intern, together with Raveena Patil, Chanel Johnson, Nathan McDaniel, and Sean Lachenman (not pictured).





- Energy Engineering and Computer Graphics Technology students captured second place and a \$6,000 purse at the International SunSat Design Competition for their video and technical abstract “Pathway to Power”. The finals were held at the 35<sup>th</sup> annual International Space Development Conference held in San Juan, Puerto Rico May 18-22. Representing IUPUI and mentored by the Lugar Center for Renewable Energy the team described a step-wise path by which wireless power transfer can solve today’s energy challenges on earth. This can lead to a future with solar power satellites beaming clean, renewable, baseload power to every nation on earth. From the EEN program came team leader Javier Tandazo, with Alexander Carter, Curtis Waggoner, and John Guggenheim. From CGT came Ethan Wong with support from (not pictured) Andrew Barnhouse, Garrett Ruble and several other classmates. Their final video is available on Youtube at (<https://youtu.be/XvlfdnSPZJQ>). The team was honored at the National Space Society’s ([www.nss.org](http://www.nss.org)) Gala Dinner the last night of the conference, a black-tie affair at which the 8-minute video was presented to leaders in the aerospace community. Space solar power is an area of active research at the Lugar Center for Renewable Energy with a dozen students continuing this excellent work during summer 2016.



- Agricultural Robotics (AgBOT) Challenge (Fall 2015, Spring 2016) by Dr. Andres Tovar.

## **New Personnel at LCRE**

The LCRE continues to rely upon its highly qualified Research Members and external Advisory Board Members to advance its mission and benefit the university, city, state, and world. Below is a list of new personnel at the LCRE and some additional background about each:

## Research Members

### **Owen Q. Wu, Ph.D., Associate Professor of Operations Management, Kelley School of Business, Indiana University**

Research interests of Prof. Wu include operations management of conventional renewable energy resources. A recent publication in the flagship journal for his field is listed at item #52 in the Publications section above. Owen also studies investment strategies in energy supply chains, and incentive issues in energy markets, supply contracts, and demand management. All of these are highly relevant in today's rapidly-changing energy industry. Owen has received many service and teaching awards, and he has worked with several Fortune 50 companies. He joined IU in 2014 and is our most newest Research Member.



## Advisory Board Members

### **Ann W. McIver, QEP, Director, Environmental Stewardship, Citizens Energy Group**

Ms. McIver oversees environmental compliance programs for integrated district energy and natural gas distribution, drinking water and wastewater utility, and oversees the lab services group that provides analytical support. She is on the Board of Directors of the Council of Industrial Boiler Owners, and has served in various roles in the Air & Waste Management Association. Her degrees include B.A. in Mathematics and Criminal Justice from Indiana University and a MPA from SPEA in IUPUI with a concentration in environmental management. In February 2016 she presented a paper at the Energy, Utility & Environment Conference on behalf of the Lugar Center for brownfield remediation using renewable energy.



### **John W. Fassino, Power & Energy Innovation and Engagement Lead, Special Warfare and Expeditionary Systems Department, NSWC, Crane**

Mr. Fassino is an innovation leader in project management and systems engineering recently promoted to Staff Engineer after serving four years as a Division Manager at the Naval Surface Warfare Center, Crane Division located in south-central Indiana. John has been stood up as the representative to the Lugar Center Advisory Board and is actively exploring collaboration opportunities with our research team. John's Bachelor of Science is in Mechanical Engineering from Rose-Hulman Institute of Technology, and he holds a M.P.A. from the IU School of Public and Environmental Affairs (SPEA). He is the recipient of many awards for his service and leadership, and we are proud to have him with the Lugar Center.



**Richard L. Benedict, Director, Project Development, Indianapolis Power & Light Co.**

Mr. Benedict was trained at the University of Chicago and holds a MBA from Harvard Business School with a focus on technology management and business development. He has been the leader in transitioning IPL from a generating capacity mix based predominantly on coal to a portfolio of natural gas, wind, and solar over the last 10 years. He developed the 20 MW lithium-ion battery grid-scale project recently commissioned at the Harding Street location. Thanks in large part to his efforts, Indianapolis ranks #2 in the nation for per-capita solar (behind only Honolulu), and helped the city become recently ranked in the top 8 nationwide for renewable energy overall. Richard is a frequent speaker on these topics at the Indiana Chamber of Commerce's Energy Management Forum.



**Zachary A. Kuznar, Ph.D., Director of Combined Heat & Power, Energy Storage and Microgrid Development, Duke Energy**

Dr. Kuznar studied Chemical Engineering at Purdue University and has both of his advanced degrees from Yale University. With Duke Energy Corp since 2008, his newly-assigned role is far-ranging in the many territories of the largest utility company in the nation. Zak also serves as Advisor to the Electric Power Research Institute (EPRI) on Programs on Solar, Biomass, Energy Storage and Renewable Energy Economics., and a co-advisor on Water Management. In 2013 he was co-chair of the March of Dimes Walk in Charlotte, NC. Zak helped sponsor student research at IUPUI studying solar-plus-storage economic analysis based on the installation of such a system at Clay Terrace, in Carmel.



**Chris Cummings, Business Development, Alternative Energy, MacAllister Power Systems**

Mr. Cummings is involved in many renewable energy projects in Indiana, including CHP, microgrids, biogas, and landfill gas power generation. He helps customers develop business plans for successful implementation drawing on his experience as a private consultant in the solar energy industry. Chris holds a BS in Mechanical Engineering (Magna Cum Laude) from Rose-Hulman Institute of Technology, plus a MS degree from Purdue University. He has spoken on the IUPUI campus to the Energy Club, and has been a speaker at the Indiana Chamber of Commerce's Energy Management Forum.



## **Outlook for AY 2016-2017**

Installation of renewable energy sources outpaced conventional energy sources in 2015 in the US for the first time [USDOE]. Levelized cost of energy (LCOE) for wind is now cheaper than new coal-fired power plants, and solar is on par, yet both are becoming steadily cheaper [Lazard]. Battery technology remains expensive but is likewise on a downward curve, being poised to address the intermittent nature of wind and solar energy. Federal funding for renewables has been largely focused on deployment with the DOE providing loan guarantees for large projects, and helping near-commercial technologies reach full viability. At the same time sustained historically-low prices for natural gas and now oil have softened the investment market for renewables, especially in the US [UNEP]. These trends have put a downward pressure on R&D funding for new renewable sources such as biofuels and biogas. Interest now appears to be turning to developing policies and learning to manage increased adoption of renewables in the energy mix. Locations such as Hawaii and southern California struggle with excess solar generation from rooftop installations, and nationally there is considerable legislative activity around distributed generation, feed-in tariffs, net-metering, and voltage regulation. These are exciting times for renewable energy, and the dynamics are not likely to slow down anytime soon.

At the Conference of Parties 21 in Paris, President Obama joined 19 other countries representing 80% of clean energy R&D pledging to double such investments over five years. In addition, 28 global investors led by Bill Gates committed to support breakthrough energy technologies in countries that have joined Mission Innovation. DOE Secretary Ernest Moniz has been preparing states and regions for the likely implementation of regional centers which match state funds with federal funds as part of the US Mission Innovation approach. Not since the ARRA “stimulus package” has there been such promise for R&D support for renewable energy. A key focus for the Lugar Center this year is preparing for this resurgence, and applying the results to benefit the State of Indiana. We will be working with other universities, corporations, and national labs to bring forward our great capabilities and excellent research practices to help address cost, environment, and national security through renewable energy technologies, policies, and management.

To learn more or to explore partnerships with our research members, visit our website at [www.lugarenergycenter.org](http://www.lugarenergycenter.org) or contact us through the Lugar Center for Renewable Energy e-mail: [lcre@iupui.edu](mailto:lcre@iupui.edu). Your tax-exempt donations, through the web page, will help advance our work.

## **Appendix A**

### **Executive Committee**

1. Alan Jones, Ph.D., Assistant Professor of Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI
2. Rongrong Chen, Ph.D., Research Associate Professor of Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI
3. Steve Rovnyak, Ph.D. Associate Professor of Electrical and Computer Engineering, Purdue School of Engineering and Technology, IUPUI
4. Mark Goebel, Ph.D., Professor of Biochemistry and Molecular Biology, Indiana University School of Medicine
5. M. Razi Nalim, P.E., Ph.D., Professor of Mechanical Engineering, Associate Dean for Research & Graduate Programs, Department of Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI

## **Appendix B**

### **Advisory Board**

The LCRE AB meets quarterly on campus to review progress and provide strategic advice.

1. Dr. Seth W. Snyder, Argonne National Laboratory.
2. Robert Galyen, Chief Technology Officer, Amperex Technology Limited.
3. Keni Washington, Managing Director, Earth Solar Technologies Corporation.
4. Doug Wasitis, Assistant Vice President for Federal Relations, Indiana University
5. Richard Benedict, Director of Project Development, Indianapolis Power and Light
6. Lane Ralph, Private citizen, formerly State Director for Sen. Lugar.
7. Ann McIver, Director, Environmental Stewardship, Citizens Energy Group.
8. Dr. Wayne Eckerle, Vice President, Corporate Research and Technology, Cummins, Inc.
9. Chris Cummings, Business Development: Alternative Energy, MacAllister Power Systems
10. Cary Aubrey, Manager, Bio-energy Development, Indiana State Department of Agriculture.
11. Steve Kozey, General Counsel, Midwest ISO.
12. Todd Colpron, VP of Business Development, IndyPowerSystems.
13. Dr. Maureen McCann, Director, Purdue Energy Center, Purdue University.
14. Dr. Zak Kuznar, Director of Combined Heat & Power, Energy Storage and Microgrid Development, Duke Energy.
15. John Fassino, Power & Energy Innovation and Engagement Lead, Special Warfare and Expeditionary Systems Department, NSWC Crane.
16. Dan M. Martin, Senior Scholar, Woodrow Wilson International Center .
17. Terry Hall, Partner, Faegre Baker Daniels.
18. Jim Wheeler, Co-Founder, PQR Energy.
19. Dustin “Dusty” Wilson, Vice President, SAIC
20. Steve Sherman, Partner, Krieg-DeVault
21. Peter Fellegly, VP-Business Development, Fortune Wireless

## Appendix C

### **Research Members**

1. Dr. Jie Chen, Mechanical Engineering, Purdue School of Engineering and Technology at IUPUI
2. Dr. Hazim El Mounayri, Mechanical Engineering, Purdue School of Engineering and Technology at IUPUI
3. Dr. M. Razi Nalim, Mechanical Engineering, Purdue School of Engineering and Technology at IUPUI
4. Dr. Yaobin Chen, Electrical and Computer Engineering, Purdue School of Engineering and Technology at IUPUI
5. Dr. Sohail Anwar, Mechanical Engineering, Purdue School of Engineering and Technology at IUPUI
6. Dr. David Goodman, Electrical and Computer Engineering Technology, Purdue School of Engineering and Technology at IUPUI
7. Dr. Stephen Hundley, Computer, Information, and Leadership Technology, Purdue School of Engineering and Technology at IUPUI
8. Dr. Afshin Izadian, Electrical and Computer Engineering, Purdue School of Engineering and Technology at IUPUI
9. Dr. Lingxi Li, Electrical and Computer Engineering, Purdue School of Engineering and Technology at IUPUI
10. Dr. Rongrong Chen, Mechanical Engineering, Purdue School of Engineering and Tech at IUPUI
11. Dr. Maher Rizkalla, Electrical and Computer Engineering, Purdue School of Engineering and Tech at IUPUI
12. Dr. Steven Rovnyak, Electrical and Computer Engineering, Purdue School of Engineering and Technology at IUPUI
13. Dr. Alan Jones, Mechanical Engineering, Purdue School of Engineering and Tech at IUPUI
14. Dr. Tamer Wasfy, Mechanical Engineering, Purdue School of Engineering and Technology at IUPUI
15. Dr. Dong Xie, Biomedical Engineering, Purdue School of Engineering and Technology, IUPUI
16. Dr. Jian Xie, Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI
17. Dr. Likun Zhu, Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI
18. Dr. Mark Goebel, Biochemistry and Molecular Biology, IU School of Medicine at IUPUI
19. Dr. Gabriel Filippelli, Professor of Earth Sciences, Director Center For Urban Health, Earth Sciences Department, Purdue School of Science at IUPUI
20. Dr. Asok Sen, Mathematical Sciences, Purdue School of Science at IUPUI
21. Dr. Xianzhong Wang, Biology, Purdue School of Science at IUPUI
22. Dr. Ken Richards, Public and Environmental Affairs/Law, IU School of Public & Environmental Affairs/IU Maurer School of Law
23. Dr. Pierre Atlas, Political Science, Marian University

24. Dr. Carol Rogers, Indiana Business Research Center, Kelley School of Business, IUPUI
25. Patricia Fox, Organizational Leadership and Supervision, Purdue School of Engineering and Technology at IUPUI
26. Dr. Jan Cowan, Architectural Technology Program, Purdue School of Engineering and Technology at IUPUI (through 31 December 2014).
27. Dr. Jerome Dumortier, Public and Environmental Affairs, IU School of Public and Environmental Affairs
28. Dr. Peter J. Schubert, Electrical and Computer Engineering, Purdue School of Engineering and Technology at IUPUI
29. Dr. Jing Zhang, Mechanical Engineering, Purdue School of Engineering and Technology at IUPUI
30. Dr. Stephen K. Randall, Department of Biology, School of Science, IUPUI
31. Andres Tovar, Ph.D., Assistant Professor, Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI
32. Sanya Carley, Ph.D., Associate Professor, School of Public and Environmental Affairs (SPEA), Indiana University
33. Euzeli C. Dos Santos, Jr., Ph.D., Assistant Professor, Electrical and Computer Engineering, Purdue School of Engineering and Technology, IUPUI
34. Huidan “Whitney” Yu, Ph.D., Assistant Professor, Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI
35. Dr. Elaine Cooney, Professor of Electrical and Computer Technology, Department Head, Technology, IUPUI.
36. Dr. E. Jane Luzar, Professor of Economics, Professor of Public and Environmental Affairs, Dean, IUPUI Honors College.
37. Dr. Paul E. Sokol, Professor of Experimental Physics, Department of Physics, IU-Bloomington.
38. Dr. Ali Razban, Senior Lecturer, Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI.
39. Dr. Yongzhu Fu, Assistant Professor, Dept. of Mechanical Engineering, Purdue School of Engineering and Technology, IUPUI.
40. Dr. Lyudmila Bronstein, Research Scientist, IU Dept. of Chemistry
41. Dr. David Baxter, Research Scientist, IU Dept. of Physics
42. Dr. James “Jake” McKinlay, Asst. Prof, Dept. of Biology
43. Dr. Todd Saxton, Associate Professor, Management and Entrepreneurship, Kelley School of Business, Indiana University.
44. Dr. Owen Q. Wu, Associate Professor, Kelley School of Business, Indiana University



## Appendix D

### **Entrepreneurs-in-Residence**

The EIR program was initiated in December 2011 in cooperation with the Indiana University Research and Technology Corporation (IURTC) – the technology transfer organization for the IU system. IURTC's Spin-Up program aids faculty to create business opportunities and funding based on their intellectual property. The most crucial role for the EIRs is to serve as PI for federal Small Business Innovation Research (SBIR) or Small Business Technology Transfer (STTR) grants made by spIn-Up companies which can then subcontract to university faculty. This allows faculty members to retain 100% appointments while benefiting from the entrepreneurial experience of the EIR and avoiding the federal requirement that the PI be 51% or more associated with the small company. Recently the NSF adopted funding opportunity language prohibiting this arrangement, and there is concern this could extend to other federal agencies. In addition to SBIRs, EIRs help develop business plans, often in concert with students from the Kelley School of Business and the School of Public and Environmental Affairs, and they bring networking opportunities to LCRE. The following individuals provide pro bono work on behalf of the university with the hope and expectation that, upon receiving funding, they can begin to draw a salary commensurate with their level of interest and availability, while creating commercially-viable going concerns based on research from LCRE Research Members:

1. Mr. John Craun
2. Dr. Randall Gatz
3. Dr. Shashikala K
4. Dr. James Logsdon
5. Mr. Joe Paganessi
6. Mr. Edward F. Plocharczyk
7. Dr. Clara Deal
8. Mr. Peter Price
9. Dr. Bob Rosenstein
10. Mr. Lee Saberson
11. Mr. Morris Stillabower
12. Ms. Anjali Sarda
13. Dr. Sy Ali

## Appendix E

### **Director's Afterward**

In October I sold my car – the first time I've been without 4 wheels since college. Downtown Indy is bike-friendly to my 2.1 mile commute, and for running errands. During poor weather, or carrying bulky items, I use the **Blue Indy** car-share service ([www.blue-indy.com](http://www.blue-indy.com)), and for trips to the airport there is Uber and Lyft, or regular taxis. For visits around the state and region there are rental cars or ride-sharing with my colleagues. Realizing that going car-free is not possible for all of us, I encourage you to find ways to **green-up** your own transportation. For tips and info visit SustainIndy, and IndyGo - including their public discussions regarding **Red Line Rapid Transit**.

A great many people contribute to the Lugar Center for Renewable Energy. We are privileged to be administratively housed within the School of Engineering and Technology at IUPUI and to have the support of Dean David Russomanno and his staff, plus helpful staffers in the ECE and ME departments. Administrators and facility services people from all across the Indianapolis campus have worked hard in creating an environment conducive to research and learning. Thanks to all of you who help make this important work possible.

