Bio inspired energy:

Biomimicry innovations for energy sustainability

Nature's designs inspire technological innovations with research known as biomimicry, which offers promise for "bio inspired energy" to create more efficient energy production, energy storage, and energy delivery with innovations that replicate the designs of natural systems. This brief introduction into this nascent field, where energy networks and natural systems intersect, synthesizes the current state of science. On-going research is encouraged, as opportunity exists for complexity sciences and network models that exist in nature to advance modern technologies, infrastructure, and policy approaches for the energy sector.

Authors: K. T. Honey[1], G. A. Pagani[2]

With this scoping paper, we explore how biomimicry holds promise for the next frontier in energy for human beings. Biomimicry (also known as biomimetics) is the process of using natural-world mechanisms to inspire man-made designs and technological innovations. Designs and efficiencies of nature have evolved through billions of years of natural selection into intricate systems that can inspire novel scientific thinking and energy efficient systems for long-term sustainable development.

Our contention is that complexity sciences will help develop new tools and techniques to improve grid infrastructure, regulatory design, and energy policy. Complexity sciences use methods for helping us understand distributed energy networks and smart-grid dynamics with bidirectional communication. They can also provide models and guidelines to inform energy developments, emerging behaviors, and future challenges [1]. In 2012, the Joint Research Centre in the EU initiated a large-scale, international effort to integrate these concepts of complexity into smart grids and energy delivery [1,2]. As a sub-component of this complex systems approach to meeting future energy demands, we hypothesize that energy for human beings will benefit from biomimicry research to stimulate new ideas for energy technology innovations, efficient grid designs, and strategies for optimal energy delivery amidst a dynamic environment. The multidisciplinary efforts of the complexity approach can help in tackling the energy-related issues from several points of view and bridging the gap to include concepts far away from the engineering perspective such as biological inspired solutions in the future energy solutions.

Energy is the key factor that enables the modern society, which can today benefit from this systems approach inspired by biomimicry. Energy consumption trends and projections show increasing energy consumption will be required in coming decades (IEA forecasts a 35% increase in energy consumption in the period 2012-2035 [3]). If new technologies could harvest energy in a sustainable way there would be no issues associated to the increasing trend in global energy demands. However, the world's sources of energy today are far from sustainable. The widespread use of fossil fuels increases greenhouse gases in

[1] Kristen T. Honey, Stanford University, Stanford, CA and AAAS Science & Technology Policy Fellow.
[1]email: khoney@stanford.edu
[2] Andrea Pagani, University of Groningen, Groningen, The Netherlands. email: g.a.pagani@rug.nl

***NOTE:** Both authors welcome new collaborations and information sharing on biomimicry for energy systems, but please direct interest in grant writing and funding new research on biomimicry for energy systems to Andrea Pagani.*

the Earth's atmosphere, exacerbating climate change and extreme weather that threatens the survival of many organisms and human societies.

There is immense room for improvement in harvesting, transformation (from one source to another), delivery, and use of energy today. The way society has historically approached—and continues to approach—energy use is far from efficient. From the technical perspective, energy conversions obey to the laws of physics and technical limits of the machines engineered. Economic and political factors play an important role in using some resources instead of others. Solutions on this matter are not easy to achieve and we do not aim to provide them. Rather, we identify promising biomimicry research and ideas, as a novel way of thinking to encourage us to look at the energy world through the lenses of nature. By emulating nature, we will improve efficiency and achieve long-term sustainability.

Today's paradigm of energy and the existing energy grids rest on linear concepts of passive distribution and one-way communications with power flows from large suppliers to final consumers. This model, however, is outdated. It increasingly fails to meet the energy and environmental demands of society. Our existing energy infrastructure and paradigm must evolve into an increasingly efficient, active, and responsive network. Looking at nature can provide us with new source of inspiration.

Examples of biomimicry success in disciplines other than energy abound. For example, biomimicry research has led to novel designs and break-through technologies of system control solutions [4,5], in buildings architecture [6], mechanical engineering [7]. Materials science has already inspired ideas with roots in biology, such as Velcro products [8,9], glues and tissue healing compounds [10,11], and advanced sensing technologies that mimic insect reception systems [12].

The energy domain is ripe for biomimicry innovations, with ideas of a new energy system and future grid inspired by nature [13]. To bring attention to these ideas and encourage biomimicry research for energy, we identified these projects and resources with links for readers to follow for further information:

- **Energy production and harvesting** (e.g., photosynthesis inspired technologies)
    - artificial photosynthesis [14]
    - wind turbine planning [15]
    - black butterfly wing solar collection structure [16]
    - marine and wind turbines that mimic non-smooth surface [17,18,19]
    - heliostat positioning for solar plants from sunflowers [20]

- **Energy storage** (e.g., nature inspired battery technologies)
    - conductors for batteries [21]
    - hydrogen production through hierarchical structure in butterfly wing [22]

- **Energy delivery and grid efficiency** (e.g., efficient natural networks for grid design)
    - more efficient led light from fireflies [23]
    - threats communication mechanism from insects [24]

More efficient and sustainable ways to harvest, transform, deliver, and use energy likely exist in the natural world— human beings have just not yet understood or seen them. The above examples are a

testament to the power of 4.5 billion years of evolution on our planet and its biosphere, now with an estimated 8.7 million species [25], encoding for diverse strategies of optimal energy use (e.g., optimal foraging theory [26, 27]). For human beings, however, energy (other than individual survival) dates back only to the industrial revolution (circa 1750). Human society has not yet had enough time to advance its energy harvesting, conversion and use methods to compare to those of the natural world. Still, we can find inspiration from the engineering efficiencies and abundances of nature, thereby expediting our transition to energy sustainability. Energy efficiency and renewable energy—including wind, solar, tidal, waves, geothermal—are first steps toward the better use of what is endlessly available in nature. This interplay of new bio-inspired ideas for energy, sustainable sources, and novel technologies can only be fully investigated with a multidisciplinary approach that is at the cornerstone of complexity science.

Our ideas are designed as a starting point for bio-inspired energy efforts. We encourage others to use and extend these ideas. An open-source and collaborative approach to science and biomimicry innovation is our preferred approach for solving the "wicked problem" of sustainable energy, which is of utmost societal importance in today's interdependent world with increasing energy demands.

References:

[1] Bompard, E., Connors, S., Fulli, G., Han, B., Masera, M., Mengolini, A., & Nuttal, W. J. (2012). Smart Grids and Complexity Science. *EU Commission JRC Scientific and Policy Reports*.
[2] Joint Research Centre, Institute for Energy and Transport (IET). Workshop Smart Energy Grids and Complexity Science, Petten (NL), 25 Jun 2012 (website accessed 09/15/2013): http://ses.jrc.ec.europa.eu/workshop-smart-energy-grids-and-complexity-science-petten-nl-25-jun-2012
[3] International Energy Agency (2012). World Energy Outlook 2012. *IEA Report*.
[4] Passino, K.M., (2002). Biomimicry of bacterial foraging for distributed optimization and control, *Control Systems, IEEE* , 22(3), 52,67.
[5] Repperger, D. W., Phillips, C. A., Neidhard-Doll, A., Reynolds, D. B., & Berlin, J. (2006). Actuator design using biomimicry methods and a pneumatic muscle system. *Control Engineering Practice*, *14*(9), 999-1009.
[6] Pawlyn, Michael, (2011). *Biomimicry in architecture*. Riba Publishing.
[7] Burrows, M., & Sutton, G. (2013)Interacting Gears Synchronize Propulsive Leg Movements in a Jumping Insect. *Science, 341(6151)*, 1254-1256.
[8] http://en.wikipedia.org/wiki/Velcro
[9] Allen, R. (2010) Bulletproof Feathers How Science Uses Nature's Secrets to Design Cutting-Edge Technology, *Ed. University of Chicago Press*.
[10] Gorb, S., Varenberg, M., Peressadko, A., & Tuma, J. (2007). Biomimetic mushroom-shaped fibrillar adhesive microstructure. *Journal of The Royal Society Interface*, *4*(13), 271-275.
[11] Mohammadreza Mehdizadeh, Hong Weng, Dipendra Gyawali, Liping Tang, Jian Yang. (2012) Injectable citrate-based mussel-inspired tissue bioadhesives with high wet strength for sutureless wound closure. *Biomaterials*, 33(32): 7972
[12] Krijnen, G., Lammerink, T., Wiegerink, R., & Casas, J. (2007). Cricket inspired flow-sensor arrays. In *Sensors, 2007 IEEE* (pp. 539-546). IEEE.

[13] Datta, Shoumen Palit Austin, JrJung Lyu, and Hui-Chiao Jen (2010) Bio-inspired Energy Future: Quest for Efficient Intelligent Mitochondria and New Liquid Fuels. *International Journal of Electronic BusinessManagement* 9(1).
[14] Gust, D., Moore, T. A., & Moore, A. L. (2009). Solar fuels via artificial photosynthesis. *Accounts of chemical research*, *42*(12), 1890-1898.
[15] Whittlesey, R. W., Liska, S., & Dabiri, J. O. (2010). Fish schooling as a basis for vertical axis wind turbine farm design. *Bioinspiration & Biomimetics*, *5*(3), 035005.
[16] Zhao, Q., Guo, X., Fan, T., Ding, J., Zhang, D., & Guo, Q. (2011). Art of blackness in butterfly wings as natural solar collector. *Soft Matter*, *7*(24), 11433-11439.
[17] Murray, M., Gruber, T., & Fredriksson, D. (2010). Effect of leading edge tubercles on marine tidal turbine blades. *Bulletin of the American Physical Society*, *55*.
[18] van Nierop, E. A., Alben, S., & Brenner, M. P. (2008). How bumps on whale flippers delay stall: an aerodynamic model. *Physical review letters*, *100*(5), 054502.
[19] Fish, F. E., Weber, P. W. Murray, M. M. and Howle, L. E. 2011. The humpback whale's flipper: Application of bio-inspired tubercle technology. *Integrative and Comparative Biology* 51: 203-213.
[20] Noone, C. J., Torrilhon, M., & Mitsos, A. (2012). Heliostat field optimization: A new computationally efficient model and biomimetic layout. *Solar Energy*, *86*(2), 792-803.
[21] Lee, Yun Jung, Hyunjung Yi, Woo-Jae Kim, Kisuk Kang, Dong Soo Yun, Michael S. Strano, Gerbrand Ceder, and Angela M. Belcher. "Fabricating genetically engineered high-power lithium-ion batteries using multiple virus genes." *Science* 324, no. 5930 (2009): 1051-1055
[22] Liu, H., Zhou, H., Ding, J., Zhang, D., Zhu, H., & Fan, T. (2011). Hydrogen evolution via sunlight water splitting on an artificial butterfly wing architecture. *Physical Chemistry Chemical Physics*, *13*(23), 10872-10876.
[23] Bay, A., André, N., Sarrazin, M., Belarouci, A., Aimez, V., Francis, L. A., & Vigneron, J. P. (2013). Optimal overlayer inspired by Photuris firefly improves light-extraction efficiency of existing light-emitting diodes. *Optics Express*, *21*(101), A179-A189.
[24] McKinnon, A.D.; Thompson, S.R.; Doroshchuk, R.A.; Fink, G.A.; Fulp, E.W., (2013). Bio-inspired cyber security for smart grid deployments," *Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES*, 1(6), 24-27.
[25] Mora, C, D.P. Tittensor, S. Adl, A. G. B. Simpson, B. Worm. (2011) How Many Species Are There on Earth and in the Ocean? *PLoS Biology*; 9 (8): e1001127
[26] MacArthur, R. H. and Pianka, E. R. (1966). On the optimal use of a patchy environment. *American Naturalist*, 100.
[27] Mangel, M. and C.W. Clark. (1986). Towards a unified foraging theory. Ecology. 67(5):1127-1138.

Recommended Citation for this paper:
Honey, K.T. and G. A. Pagani. (2013). Bio inspired energy: Biomimicry innovations for energy sustainability. Santa Fe Institute 2013 Complex Systems Summer School Proceedings, Santa Fe Institute, Santa Fe, NM. 4pp. Open-source PDF: http://www.santafe.edu/education/schools/complex-systems-summer-schools/2013-csss-proceedings/