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Designing Nanostructures at the Interface between Biomedical and Physical Systems

Arnold & Mabel Beckman Center, Irvine, California

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Improving Hydrogen Production by Genetic Methods: Designing a Better Nanomachine
Focus Group Description

Background

In our increasingly mobile but always-connected society there is a need for better small energy storage and conversion devices to provide a remote power source exactly where it is needed and only when needed, for example in cell phones, remote sensors or in-body implants such as pacemakers, medical sensing or drug dispersal devices. As our planet's fossil fuel supply diminishes and our concern for global warming, pollution and other environmental costs of our current energy supply system increases, it is essential that we develop cleaner, more environmentally benign power sources as well. Ref 1 gives an overview of challenges in energy technology that could be addressed by nanotechnology. Miniature biofuel cells could be a means of converting stored bioenergy to power, or alternatively of harnessing hydrogen gas from inexpensive, readily available materials such as sea water for a source of fuel when needed.

Unicellular microorganisms are remarkable efficient at catalyzing a wide range of chemical reactions (Ref 2) such as fermentation, respiration and photosynthesis, using a variety of electron donors and acceptors. Recently, researchers have been able to program cells in rudimentary ways to perform tasks not evolved in nature (Refs 3, 4).

Several types of algae and bacteria can produce hydrogen by photosynthesis or fermentation. Photobiological technology holds great promise; however, as oxygen is also produced the technology needs to overcome the limitation of oxygen sensitivity of the hydrogen evolving enzyme systems. Screening for naturally occurring organisms which are more tolerant to oxygen as well as creating new genetic forms of the organisms that can sustain hydrogen production in the presence of oxygen is currently being performed (from Ref 5).

Biofuel cells have been reported (see Ref 6) achieving several hundred nanowatts of power, in which tethered biological enzymes at two electrodes first strip a hydrogen ion off glucose and then combine the H+ with oxygen to create both power and water.

Nanotechnology is currently revolutionizing small battery technology – see for example Ref 7.

The Problem

Given the information provided above (and any other research you choose to do) your task is to provide a scientific plan to create a programmed microorganism or a collection of nanobiomachines that use water or oxygen as an input and creates a local source of hydrogen gas for use as a fuel. Decide on your specific goal, keeping in mind the following questions:

- What will be the power or hydrogen gas generation requirements needed for powering a PDA or a pacemaker 5-10 years from now? (Ref. 8)
- What are the environmental, safety, temperature, longevity, antifouling, or other engineering requirements needed?
- How efficient can this process be? Are there fundamental limits? If so, what are they?
- What are the overall fuel cycle costs of such a proposed technology?
- How would this technology compare (cost, size, efficiency, safety, environmental impact, temperature range, ease of use, robustness and reliability) to competing technologies such as nano fuel cells or nanobatteries?

Initial References

- 1 - Nanoscience Research for Energy Needs, Report of a NSET workshop “Nanoscale Science and our Energy Future”, DOE (2004). A link to the full report is provided on DOE’s Office of Science homepage: http://www.sc.doe.gov/.
- 2 - Newman, D., Microbial Mineral Respiration. The Bridge, winter 2003. National Academy of Engineering, 33 (4) pp 9-13. http://www.nae.edu/TheBridge
- 3 - Weiss, R., ibid, Challenges and Opportunities in Programming Living Cells. pp. 39-46.
- 4 - Kobayashi et al., Programmable Cells: Interfacing Natural and Engineered Gene Networks. Proceedings of the National Academy of Sciences, June 1, 2004. 101 (22) pp: 8414-8419.
- 5 - For an introduction to hydrogen generation, see: The Generation of Hydrogen, The Hydrogen Economy – U. Birmingham. Also see References 1 and 2 of Focus Group 13.
- 6 - Service, R., Shrinking Fuel Cells Promise Power in Your Pocket. Alper, J., The Battery – Not Yet a Terminal Case. Science, May 17, 2002. 296 (5571) pp. 1222 –1226.
- 7 - Nanobatteries - http://radio.weblogs.com/0105910/2004/05/26.html http://www.newswise.com/articles/view/?id=500572.
- 8 - International Technology Roadmap for Semiconductors, 2003 has power requirement projections for handheld devices in the section on RF and analog/mixed signal electronics. A link to the entire document can be found at http://public.itrs.net/