2nd Annual National Academies Keck *Futures Initiative* Conference

Designing Nanostructures at the Interface
between Biomedical and Physical Systems
Arnold & Mabel Beckman Center, Irvine, California
November 18-21, 2004

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

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Summary:

Tiny solutions for big problems

Focus Group 8 proposed a novel, two-part approach to improving biological hydrogen production for local, off-grid energy generation. The overall goal was to use clean, renewable, and biodegradable resources and methods to reduce dependence on hydrocarbon fuels at a scale useful to small, remote villages.

The general idea was to develop first "a better bug" to convert solar energy to harvestable hydrogen gas. The proposed approach draws on contributions from Mother Nature's protozoans, bacteria and photosynthetic algae, assisted by high-tech methods from the biological, chemical, genetic, and pharmaceutical sciences. The improved, more robust organisms would then be put to work on-site within a nearly closed system aimed not only at hydrogen production, but also optimal utilization and recycling of by-products and end-products.

The social process that generated this proposal over the course of 7-1/2 hours together was a rather nonlinear, synergistic one. It entailed periods of whirlwind group discussion – with topics ranging from bovine flatulence to melting igloos – punctuated by occasional retreat for individual or small-group research and reflection. It began with groping for problem definition on Friday. It culminated Saturday with a surprising emergence of the final proposal – a "weird hybrid" incorporating many "crazy" and initially disconnected ideas from the preceding far-ranging conversations.

"I'm astounded," said one group member in the immediate wake of the final session. "I called my wife and said, 'I just saw an amazing two days.'"

What's the problem?
Initially charged with designing and growing "a bacterial or cellular factory to perform electrolysis of seawater to create hydrogen gas," Focus Group 8 devoted Friday's initial 1-hour session to surveying the group's range of expertise and defining the exact problem to be tackled.

On board were representatives from biochemistry, biophysics, chemistry, economics, electrical engineering, entrepreneurial enterprise, environmental chemistry/engineering, nanotechnology, physical chemistry, and physics. (Longed for by weekend's end were biologists of various stripes.)

"What's the problem?" became the morning's mantra as the group struggled to define which pieces of the hydrogen-production maze to address. To help frame the conversation, the group considered scales ranging from cityscape (100s kW/day) to microscales appropriate for space applications or human implantation (μW/day).

A variety of hydrogen-producing approaches were tossed up, ranging from the "pure biology" of hydrogen-producing green algae to the photoelectrochemistry of titania (titanium dioxide) semi-conducting nanoparticles. One "crazy, intriguing proposal" was to assemble a collection of hydrogen-producing enzymes, like biological "spare parts," to crank away within a tiny liposome pouch.

The group mused that significant contributions might come ultimately from developing a systems approach to hydrogen production and by-product utilization, rather than focusing on any single part of the production process.

By lunchtime and session's end, the group had decided to work on the problem of: *local production of hydrogen gas on a moderate scale (on the order of 10 kW)) based on a non-hydrocarbon source*. A backyard in Somalia or remote Texas might be typical deployment sites.

Crazy thoughts and cow parts
Having narrowed the focus to moderate-scale hydrogen production – means yet to-be-determined – Focus Group 8 re-convened Friday afternoon to identify current bottlenecks that might yield to innovative approaches. Envisioning eventual depletion of hydrocarbon fuel resources, the group focused on methods driven ultimately by sunlight.

The pros and cons of a variety of approaches were considered in a 10-way, ping-pong-style group discussion with frequent contributions from the World Wide Web. "Purely biological systems are self-replicating." Good. "But, accumulated waste products eventually shut down the system." Not so good. "But, wastewater treatment plants manage to keep such systems going." Good. "But, biological 'spare parts' don't have to be kept alive." Even better. "But, biological parts in isolation don't tend to function for very long." Not so good.

Occasional long silences and contributions prefaced by, "Here's a crazy thought." were characteristic of the afternoon's conversation.

The bottleneck issue of oxygen toxicity cropped up repeatedly. Hydrogenase, the enzyme responsible for biological hydrogen production, is inactivated by oxygen – which is typically co-generated during the hydrogen production process. It is the Achilles' heel of biologically based hydrogen-generation methods.

By afternoon's end, two persistent notions had earned summary diagrams on the whiteboard. One included the novel use of hydrogenosomes, organelles found in some anaerobic protists and fungi. The other was larger in scale, laying out in concept a complete, nearly closed system powered by sun and wind energy, and generating usable hydrogen, oxygen, and fresh water. It incorporated the novel use of reusable cobalt salen to capture the problematic oxygen. One participant likened this approach to "dissembling a cow and selling every part."

At day's end, the group disbanded with lingering questions about many practical issues, such as component stability, production capacity, and system efficiency.