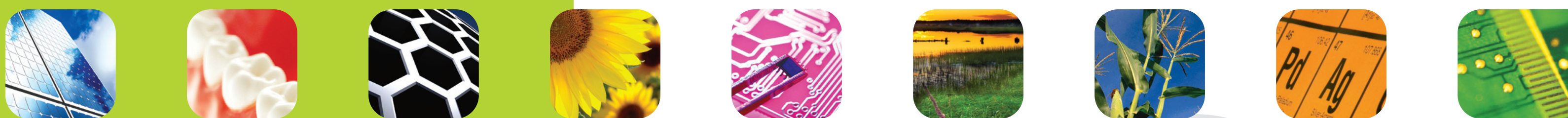
Research Frontiers
FOR THE CHEMICAL INDUSTRY

report on

THE FIFTH ANNUAL
CHF–SCI INNOVATION DAY
WARREN G. SCHLINGER SYMPOSIUM



INNOVATION DAY 08

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Innovation Frontiers in Industrial Chemistry

A Report on the Fourth Annual CHF-SCI Innovation Day 18 September 2008

Introduction

Now in its fifth year the CHF-SCI Innovation Day and Warren G. Schlinger Symposium has had the most successful event in its short history. Although only a few of the younger scientists and researchers are return participants, the group now seems to have a good idea about what to expect and how to interact with each other. Most participants realize that the key concern of Innovation Day is to exchange and debate broad viewpoints on innovation in the chemical industry rather than to discuss scientific and technical details. Innovation Day has evolved into a unique forum where new ideas on technological innovation, science policy, and corporate strategies are brought to the table, where they are open to discussion and critique by all participants. We at the Chemical Heritage Foundation are pleased to report that Innovation Day is beginning to show signs of maturity.

As we have repeatedly stressed in the past, the purpose of Innovation Day is to expose young investigators in chemistry and related sciences and industries to issues on the cutting edge of the innovation frontier. In this age of complexity and global interconnectedness it is no longer sufficient for industrial chemists to concern themselves only with technical matters. Being aware of the broader implications of their work will become increasingly critical for continued success. The proceedings of the annual Innovation Day provide a unique opportunity for young industrial chemists to take a step back from their day-to-day operations to contemplate the bigger picture, expanding their outlooks into the broader social, economic, and political contexts that impinge on contemporary innovative activities in the chemical and molecular science industries.

Frontier Areas for Industrial Chemistry

At the core of the Innovation Day proceedings are conversations captured during six breakout sessions that serve as incubators for more in-depth discussions. The session topics and speakers are selected by the Innovation Day Steering Committee, composed of chief technology officers and top scientists of leading chemical companies. In 2007 the breakout sessions covered the following topics:

1. Sustainable Chemistry and Engineering
2. Electronic Materials
3. Chemistry of Energy Sources
4. Health Materials
5. Emerging Global Economies

Rather than reproduce the presentations, in what follows, we attempt to offer a sense of the conversations that took place, guided by session presenters but participated in by all present.

SUSTAINABLE CHEMISTRY AND ENGINEERING

Moderator: *Gary Kozerski (Dow Corning Corporation)*
Speakers: *Eric J. Beckman (Cohera Medical)*
D. Tyler McQuade (Florida State University)

To institute eco-innovation in the chemical industry, researchers, managers, and executives must overcome the conventional wisdom that says "green" processes and products will necessarily be of lower quality or more expensive. That is the message delivered by panelists and participants in the 2008 Innovation Day breakout section on Sustainable Chemistry and Engineering. Panelists and participants covered much ground in their discussion, but focused attention was given to four areas: measuring greenness; sites for change; laying the foundations for eco-innovations; and the future of the chemical enterprise.

How do we measure the "greenness" of a process or product, and how do we prevent abuses of green labels? These issues are related, as panelists noted, and both can be resolved by establishing accurate and reliable green metrics. But while the concept is clear—"green" must stand for something—in practice metrics have eluded those working in sustainable sciences, including chemistry. Participants noted that metrics have received much attention in recent years, but results have been limited. This limitation may be a natural result of such concepts as green, which require a standard base to measure against. Because the standard itself is susceptible to change, green becomes a pursuit—developing greener processes and products—which makes something stable like metrics difficult to establish.

Where and how eco-innovation occurs play a tremendous role in establishing how change may take place. Panelists explored two issues in particular. In the first they discussed how innovation varies in big companies versus smaller, focused companies. In larger firms resources can be mobilized, but change can be thwarted by the institutional momentum that characterizes such companies. Smaller firms lack these resources but remain flexible because of their lack of built and conceptual infrastructure. Events of recent years have also demonstrated that government is not the only agent of change for eco-innovation. Indeed, the role of governments, both big and small, have been overshadowed by the role that large corporations with long supply chains, such as Walmart, have played in driving eco-innovation.

How do we get from here, our current state of operations, to a place where eco-innovation becomes the norm? One suggestion would be to develop eco road maps, an attempt to borrow the road-map concept that has been successful in the semiconductor industry. Road maps might help make the transition simpler by showing a route from here to there and by coordinating the efforts of researchers: the map makes visible the successive hurdles to be overcome. While details of such a map might take many forms, one thing should hold constant: eco concerns must become a part of the innovation cycle at a much earlier stage in the molecular and industrial design processes.

At stake is more than simply the future of innovation: the future of the enterprise and what it means to be a chemist are also in question. Participants tried to imagine what that future chemist might look like. But road maps and visions will not get us there. To help clear the path, participants identified and discussed what they perceived to be the most challenging obstacles.

The biggest and broadest obstacle to eco-innovation is momentum, which comes in a variety of forms: educational, institutional, cultural, material. All these will need to be addressed by the chemical enterprise in a concerted effort. More specifically, on the macro level, participants worried about the difficulties related to green labeling and greenwashing. How do you prevent companies from making inaccurate claims? How do you police a globalized marketplace to ensure accuracy and transparency? On the micro level, eco-design strategies need to find their way into the origin of the innovation process, which will involve retooling the practices (educationally and culturally) of chemists and chemical engineers.

Panelists and participants set an agenda for making eco-innovation common practice in the chemical industries. First, a set of metrics must be developed and put to use that can help verify the "greenness" of practices and products and that fights the growing practice of greenwashing. A network of external certifications administered by third-party organizations might be necessary. Second, we need to understand the role of the Walmarts of the world as agents of change. That is, how do product distribution channels provide an alternative means for consumers to demand change? Finally, participants called for a new ethic to complement a new metric that asks researchers to be personally responsible *and* accountable for the development of their research programs.

ELECTRONIC MATERIALS

Moderator: *Susan Fitzwater (Rohm and Haas Company)*
Speakers: *Nick Pugliano (Rohm and Hass Electronic Materials)*
Rao Varanasi (IBM Corporation)

Moore's law and complementary metal-oxide semiconductor (CMOS) scaling have formed the backbone of semiconductor electronics during the last forty years or so. As early as the 1980s prescient scientists and engineers were predicting the "limit" of CMOS scaling. Until today, however, the semiconductor industry has been extremely effective in pushing back the "limit" by coming up with novel design schemes, advanced materials, and improved instrumentation to continue the trajectory along Moore's curve of electronic miniaturization. At the core of traditional silicon CMOS scaling was the manufacturing technique of photolithography. Since the 1960s the building blocks of integrated circuits have been fashioned by using photolithography to pattern thin films deposited atop a silicon wafer substrate. By using various diffusion, implantation, and film deposition techniques, the chemical composition of this silicon substrate and the patterned thin films could be altered to perform various functions.

The semiconductor industry is taking very seriously the idea that traditional silicon CMOS scaling is approaching a period of fundamental change in the near term: within the next decade. There are two strands to this developing conversation within the semiconductor community—technical and economic. Within the technical strand the atomistic nature of silicon is viewed as posing a limit to continued traditional CMOS scaling within the next decade or two. Researchers are beginning to explore alternative materials and technologies to provide a new path of technological development for electronic devices. Many of these approaches currently involve the use of novel materials and nanotechnology. Within the economic strand commentators and analysts see the great challenges of continued materials innovation and capital investments for production tools as factors leading to the end of Moore's law. That is, the economic investment required for new plants based on new manufacturing technology will not be justified by returns, and increasingly firms will direct their resources elsewhere. With these developing beliefs about the near-term end of Moore's law and traditional CMOS scaling, the semiconductor community is focusing its R&D investments on new materials investigations and development. Thus, it is highly probable that material innovations will take on even greater importance for the semiconductor industry in the next several decades.

Both of the speakers in the electronics session—Nick Pugliano of Rohm and Haas and Rao Varanasi of IBM—focused their attention on perhaps the most important area in which chemical and material innovations have been absolutely crucial: photolithography. The fabrication process of photolithography requires a series of photoresists and coatings. Both speakers discussed the enormous amount of innovation that occurred over the last forty-plus years to create successive generations of photoresists and coatings resulting in ever-smaller features on integrated circuits. In particular, both speakers discussed various aspects of the chemical advances required for bringing to the production floor the next generation of photolithographic technology: "double patterning" with 193-nanometer immersion lithography. A host of chemical innovations is currently being pursued in order to develop and stabilize this process.

Both speakers pointed to the very real possibility that the next generation or two of photolithographic technology may be the endpoint of the developmental path of the last forty years. Beyond immersion lithography with double patterning—and later perhaps, high index of refraction fluids—the "next big step" in semiconductor component manufacturing technology is "unclear." Both speakers described a variety of the contenders for this next big step, all of which require a significant amount of chemical and materials development. Varanasi concentrated on the "bottom-up" approach in contrast to the "top-down" approach to making devices represented by traditional photolithography. He believes that a form of "directed self-assembly" may very well be the post-lithographic approach to creating leading-edge electronic components. In such an approach lithographic methods, among others, may be used to set a template for new materials systems to self-assemble on, thereby creating electronic devices. Pugliano, however, pointed to the emerging area of new three-dimensional device structures and also three-dimensional integration of devices and circuits. In this move to three-dimensional as opposed to essentially planar structures, new materials will be required as substrates and for new fabrication approaches. In essence the imagined possibilities for finding the "next big step" are threefold—the new method for miniaturization, the new approach to integration, and the new game-changing device structure.

CHEMISTRY OF ENERGY SOURCES

Moderator: *Thomas Upton (ExxonMobil Chemical Company)*
Speakers: *Rakesh Agrawal (Purdue University)*
Jeffrey S. Beck (ExxonMobil Research and Engineering Company)

Global energy demand is projected to increase significantly over the next twenty-five years, especially with the continued economic growth of countries in the developing world, such as China and India. Hence, it is no surprise that young industrial researchers have reached a consensus, by a large margin, that the cost, availability, and environmental impact of energy sources would have the largest effect on innovation for the next twenty years. (See Appendix I for more details on the final results of the Innovation Day pre-session, organized by the Institute for the Future.) Continued innovations in chemistry and engineering are critically necessary to increase the supply, quality, and efficient use of all available energy sources from coal, gas, and oil ("traditional" sources) to wind, solar, biomass, and nuclear ("alternative" sources).

Jeffrey Beck presented a forecast for growth in worldwide energy demand and its implications for the supply side. Demand is projected to increase at 1.3 percent a year over the next two decades, which adds up to 30 percent over the period. Even if the use of solar, wind, and biofuel grew at 10 percent a year, these three renewables will supply less than 2 percent of global needs. Carbon-dioxide emissions will increase essentially at the rate of energy demand unless carbon-capture technologies are introduced into coal plants, use of renewable energy sources grow faster than currently projected, or coal plants are replaced with nuclear energy. Meeting these challenges will require significant chemical and engineering efforts.

In discussing solutions Beck and his group first turned to efficiency in refining and chemical processing. The importance of catalysis research was highlighted by successes in desulfurization and paraxylene processes. Advanced modeling and high-throughput screening techniques are important tools. Further, significant increases in plant efficiency are being realized using advanced analytical tools to identify high-molecular-weight hydrocarbons combined with powerful computation techniques applied to reaction models and process control. Work is also under way on emerging vehicle and fuel technologies, such as on-board hydrogen generation from a range of liquid fuels and lithium-ion battery separators for hybrid electric vehicles.

Rakesh Agrawal identified the need to find alternatives to current transportation fuels as the most critical aspect of an overall energy solution, a theme he emphasized in his opening plenary speech earlier in the day. The group first discussed interim emerging vehicle technologies, including on-board hydrogen generation and research currently under way to develop more efficient lithium-ion batteries. He described a number of ways that solar energy could be converted into liquid transportation fuels—from biomass gasification or fermentation to biomass pyrolysis coupled with electrolytic hydrogen addition. A process that had the highest carbon efficiency and highest yield per ton of biomass involved biomass gasification (with electrolytic hydrogen) to produce synthetic gas. The mixture of carbon monoxide and hydrogen is then fed to a liquid reactor to give the biofuel, with appropriate recycling of carbon dioxide, water, and unreacted carbon monoxide and hydrogen. No estimates were made as to the comparison of the capital costs for each route.

While advanced solar technologies could be a final solution, nuclear energy seems to be one of the few large-scale alternatives in the near and intermediate terms. In order to exploit the potential of nuclear energy we will need to use some of the newer technologies, such as pebble-bed reactors and the thorium technology currently under development in Russia (which can be operated in a way not to produce "bomb-ready" materials).

Given the trillion-dollar investment that the United States has made in infrastructure for petrochemical refining, we have a major task in replacing this as we move to alternative-energy sources. There are currently over 150 refineries in the United States, which is double the number operational in 1980. The technological momentum of this vast investment and the associated lack of government policies to support alternative energy have caused the relative lag of American companies in wind and solar—think Vestas of Denmark in wind energy and Sharp of Japan in solar energy. More supportive government policies will be required if the United States is to make major advances in the field of renewable energy.

Health Materials

Moderator: *William Fraser (The Dow Chemical Company)*
Speakers: *Leonard J. Buckley (Naval Research Laboratory)*
Alan Rudolph (Adlyfe)

We have discussed in past years' reports the difficulty of defining the field of "health materials." The difficulty is perhaps due to the panoply of scientific and technical areas that impinge on the issues surrounding human health and well-being. The field encompasses items from medical devices to such vanity products as cosmetics and involves professionals from the areas of biology, chemistry, physics, engineering, materials science, and medicine.

Participants in this year's breakout session focused on the barriers and constraints that impede and inhibit the commercialization of innovation. Most of the discussion focused on the inadequacies and inefficiencies of excessive government regulation, especially that of the U.S. Food and Drug Administration (FDA). Within the broader context of an increasingly interconnected world, national regulations sometimes lack international harmonization, which leads to further confusion about scientific and business practices. Pushed to an extreme, the lack of international harmonization could lead to a significant "regulatory risk" within the field of health materials. In turn, this risk creates disincentives for firms to invest further in innovations for new product areas. Instead, firms tend to focus their research on reformulating existing technologies so that they do not have to go through such rigorous testing. The increasing regulatory risk, together with the length of commercialization, caused firms to focus more on innovation through modification of existing technologies. The session participants agreed that inefficient government regulation sets up a bias toward incremental innovations over radical ones. To overcome this problem we would need to find a way to more quickly filter out inefficacious or unsafe products, which would cut down significantly on regulatory risk and costs.

Within this force field of barriers and constraints scientists and engineers are resorting to "bioinspiration" as a source of innovative ideas. Leonard Buckley described the research that the Naval Research Laboratory (NRL) is doing in the area of biocides. He described the "unmet need" the NRL was trying to address with this work (i.e., the need for antimicrobial surface coating that is antifouling, self-cleaning, and nontoxic), the research problem to be solved, and the technical challenges to be faced. To overcome these challenges and solve the problem, Buckley's team turned to natural biocides (such as sponges, the lotus leaf, and naturally occurring microcidal peptides) for "bio-inspiration." They did this because natural biocides are usually antifouling, they do not need additional reagents to work, and they are self-decontaminating (or self-cleaning). Buckley briefly described the technology transfer strategies (licensing of patents and cooperative R&D arrangements) the NRL uses in their efforts to commercialize these bio-inspired innovations.

Alan Rudolph's presentation focused on his start-up company's research on the identification of brain biomarkers for early diagnosis of Alzheimer's disease. In particular, Adlyfe has sought to develop objective, standardizable, and measurable endpoints to be used in therapeutic innovations and diagnosis, replacing the current cognitive endpoints, which are subjective and unstandardizable. Through protein chemistry and the study of protein folding the company has identified specific protein conformations that correlate to disease state. The source of "bio-inspiration" for Adlyfe's research has been the study of the disease process to identify proteins that might be implicated in the disease mechanism. Once these possible target proteins were identified, the company developed techniques for tracking the folding events of specific peptide sequences within these proteins, eventually identifying specific sequences that correlated to the disease state. Through this work the company has identified specific peptide sequences that serve as diagnostic markers and as endpoints in the development of therapeutic innovations for amyloid and prion diseases.

EMERGING GLOBAL ECONOMIES

Moderator: *James Alder (Celanese Corporation)*
Speakers: *Yoguo Ma (Peking University)*
Zhengang Xu (Beijing Research Institute of Coal Chemistry)

Globalization is a multifaceted phenomenon that brings different challenges to different countries. To the multinational companies it means dealing with international competition, managing supply chains across national boundaries, adapting their organizational culture to the local conditions, and so forth. But for the emerging economies in Asia it means adjusting their national innovation system to make the most out of the globalization phenomenon.

This was the second year in which Innovation Day featured a breakout session on emerging global economies. In 2007 we had invited two technology managers from multinational chemical companies (Dow Chemical and Rohm and Haas) with R&D operations in China and India, who discussed the many challenges of establishing their presence within the sociocultural context of these emerging economies. This year we had an opportunity to examine this phenomenon from the other side, namely that of the Chinese scientists and engineers. Both of this session's speakers were from China, where Western firms are increasingly tapping the rapidly growing Chinese R&D capability.

Yuguo Ma presented on the efforts in Peking University's College of Chemistry and Molecular Engineering (CCME) to forge close partnerships with industry. In recent years (2001–2007) the CCME faculty members have swiftly increased the quantity and quality of their publications. The bulk of the R&D funding for this university department comes from the Chinese government, largely through the National Science Foundation of China. With lavish funding from the public sector the quality of research performed by CCME faculty members is on par with that of elite universities in the United States and Europe. This is an impressive feat, especially given the large-scale purge of academics during the Cultural Revolution of the 1960s, which created a long hiatus in high-level R&D.

The main concern of Peking University is the relative lack of practical applications that come out of CCME's scientific research. As an indicator of this phenomenon, Ma cited two statistics. First, out of a total of 216 research projects conducted in 2007, only 14 involved industrial concerns as collaborators. Second, the number of patent applications filed by CCME faculty members was extremely low. In 2007, for example, only 27 Chinese and 3 international patents were applied for by CCME professors. In short, the university is heavily biased toward basic research and lacks close interaction with industrial researchers.

In order to amend this problem the CCME began a new campaign in 2006 called "Partnership on Polymer Science." This campaign was designed to foster collaborations with industrial partners. As a result the CCME has managed to forge links with several key Western firms, such as Rohm & Haas, P&G, DuPont, General Electric, Degussa, 3M, Dow Chemical, Bayer, Celanese, and BASF. It is worth noting that virtually all the university-industry links are between a select few elite Chinese universities and Western multinationals with local R&D facilities. Chinese domestic firms were not considered equal partners in this scheme, as their level of technical expertise was perceived to be below that of the level of research performed by elite Chinese university researchers. A serious mismatch exists between Chinese universities and industrial firms.

This quandary facing the Chinese innovation system represents a unique challenge as the country is coming of age in scientific research, just as the forces of globalization are in full swing in the twenty-first century. Whether the continuation of current practice would benefit the Chinese innovation system in the long run is the key question. It is understandable that faculty members at top academic institutions, such as Peking University, would wish to continue their research agenda. After all, most of the CCME faculty members have received their professional training in elite U.S. institutions. However, top Chinese universities would need to make efforts to nurture and upgrade the domestic industry, as well as forge links with Western multinational companies. Government intervention to set up appropriate incentive systems would be necessary to guide elite scientists and engineers into diverse directions.

APPENDIX I: MAPPING THE FUTURE OF SCIENCE AND INNOVATION

As a new feature for Innovation Day 2008, we invited Alex S. Pang, research director of the Institute for the Future (IFTF), to lead an exercise to map major trends in the natural sciences, information technology, and the organization of innovation essential to understanding science in the twenty-first century.

Maps and visualizations have always been important in scientific research and thinking. More recently, maps of science have emerged as tools for understanding how the sciences have developed and where they may go. The IFTF has been conducting road-mapping exercises with groups of scientists around the world. Building maps allows groups to develop a common vision of how science may progress over the coming decades, to see what trends are going to be especially important in different disciplines or regions, and to explore how different futures can emerge at the intersection of different trends.

The session, attended by more than thirty participants, resulted in a visualized map on the future of science and innovation, collectively produced by the participants with guidance from IFTF researchers). After the session Pang provided us with some rumination on what characterized the future as envisioned by participants of Innovation Day 2008.—Editor

Several major challenges will drive research agendas and funding in chemistry in the 2010s: energy (in particular the fallout from declining oil supplies); resources (e.g., growing scarcity of natural resources, efforts to create renewable substitutes); health (in particular the challenges of aging populations); global problems like climate and population change; and regulation (especially around environmental protections and manufacturing processes). At the center of the map was green chemistry, which the session participants argued had the capacity to contribute innovations across all these areas. If energy, resources, health, and regulation present major challenges in the coming decade, green chemistry—which includes efforts to develop environmentally low-impact (low-energy and low-water) manufacturing processes, renewable sources for synthetic products, and cradle-to-cradle processes—may represent the solution.

The growth of green chemistry will be accelerated by the growing number of students trained to look for environmentally responsible practices in the design, manufacture, and disposal of chemicals. Green chemistry may also invigorate the chemicals industry, which in advanced nations is feeling pressure from new companies (particularly in Asia and to a smaller degree in Latin America) and is constantly looking for new innovations and competitive advantage. One major task-force report noted that "the incorporation of green chemistry and related approaches into the training of current and potential science students increases the effectiveness of recruitment and retention efforts in this crucial field."

It is a commonplace that the twenty-first century will be (or already is) the century of biology. Just as the twentieth century was dominated by the physical sciences (think of the electronics revolution, nuclear power, the preeminence of physics in the popular imagination), the thinking goes, science in the twenty-first century will be driven by the life sciences. However, if these experts are right, then green chemistry could define a service role for itself that would rival genetic engineering, genomics, and environmental science, and help establish its centrality in the applied sciences.

About Innovation Day

To promote early career innovation, the Chemical Heritage Foundation and the Society of Chemical Industry jointly organize an annual Innovation Day, consisting of the Warren G. Schlinger Symposium, Gordon E. Moore Medal presentation, and Perkin Medal award ceremony. The Schlinger Symposium brings together promising young scientists and technology leaders from across the chemical industries with a focus on frontiers of chemical R&D. Plenary and breakout sessions are oriented to areas where the chemical industry interfaces with other emerging business sectors. In combination with the award ceremonies, the Schlinger Symposium offers attendees the opportunity to learn about cutting-edge science and technology, exchange ideas with peer industrial researchers and entrepreneurs, and prepare to be innovation leaders.

About the Chemical Heritage Foundation

The Chemical Heritage Foundation (CHF) fosters an understanding of chemistry's impact on society. An independent nonprofit organization, we strive to

- Inspire a passion for chemistry;
- Highlight chemistry's role in meeting current social challenges; and
- Preserve the story of chemistry across centuries.

CHF maintains major collections of instruments, fine art, photographs, papers, and books. We host conferences and lectures, support research, offer fellowships, and produce educational materials. Our museum and public programs explore subjects ranging from alchemy to nanotechnology.

About CHF's Center for Contemporary History and Policy

The Center for Contemporary History and Policy offers historically grounded perspectives on issues related to the molecular sciences and technologies. The center's programmatic initiatives draw on diverse historical and contemporary source materials to provide knowledge, perspective, and advice to stakeholders from industry, academia, government, and citizen groups.

About the editor

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