BY RANDY WEDIN

Sustainability and Green Chemistry—Not Just Buzzwords

"Green chemistry" and "sustainability" are not just sound bites, but a new paradigm that promises to have a deep and lasting impact on the science of chemistry.

Buzzwords, trends, fads…They strut proudly onto the stage of business, fashion, and politics—even the chemical industry. And then they fade just as quickly.

Sometimes, however, a new idea takes the stage and captures our imaginations, transforming everything and everyone. Across the chemical enterprise, we've reached just such a pivotal moment with the twin concepts of sustainability and green chemistry.

Here are three indicators heralding the arrival of this new paradigm:

- Green chemistry has emerged as a core theme at recent ACS National Meetings. In 2005 alone, 10 technical divisions sponsored a total of 19 symposia on the topic.
- The Dow Jones Sustainability Index (DJSI) was released in September. This is the first time Dow Jones has ever devoted a report exclusively to the sustainability of companies based in the United States. DuPont, 3M, and Pfizer rank among U.S. companies receiving high marks as leaders in corporate sustainability. Other chemistry-related companies on the list (www.sustainability-index.com) include Air Products, Praxair, Abbott, Bristol-Myers Squibb, Genzyme, Kodak, and Procter & Gamble.
- The National Research Council of the National Academies, through its Board on Chemical Sciences and Technology, recently published a report titled *Sustainability in the Chemical Industry: Grand Challenges and Research Needs* (http://dels.nas.edu/bcst/reports.shtml).

The new paradigm of sustainability and green chemistry has clearly arrived. But what exactly are these concepts? And how will they change the way industrial chemists do their jobs?

Defining Sustainability and Green Chemistry

The concept of sustainability first gained attention in 1987, when the United Nations' World Commission on Environment and Development published *Our Common Future,* defining sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Another definition calls it the "triple bottom line of twenty-first century business," with three concurrent goals—economic prosperity, environmental quality, and social justice.

The goal of sustainability involves all sectors of our economy—from agriculture to computers, from housing to transportation, from energy to pharmaceuticals. When tackling the individual challenges in each of these sectors, said Paul Anastas (ACS '95), director of the American Chemical Society's Green Chemistry Institute (GCI), "We'll need to drill down to the molecular level, where you can have the most influence."

That's where green chemistry enters the picture. "Green chemistry is one of the most fundamental and powerful tools to use on the path to sustainability. In fact, without green chemistry and green engineering, I don't know of a path to sustainability," Anastas said.

Green chemistry rests on 12 principles, such as safer solvents, design for energy efficiency, and use of renewable feedstocks. A closely related field, green engineering, has its own set of 9 principles, such as using life-cycle thinking and minimizing depletion of natural resources. More detailed descriptions of these principles can be found on the GCI and EPA websites (chemistry.org/greenchemistryinstitute and www.epa.gov/opptintr/greenengineering).

Together, the principles of green chemistry and green engineering are bringing change to all segments of the chemical industry. One of the sectors seeing especially big changes is the pharmaceutical industry.

Green Chemistry in the Pharmaceutical Industry

Until recently, the most important metric for managing process development in the pharmaceutical industry was "yield." The amount of waste produced in synthesizing and purifying the product was of secondary concern.

In the past decade, however, pharmaceutical companies have started designing manufacturing processes to reduce dramatically the amount of waste produced. With this change in focus, managers are tracking additional metrics, including those for green chemistry such as atom economy, energy efficiency, carbon efficiency, and E-factors. ("E-factor" is defined as the amount, in kilograms, of waste generated per kilogram of product produced.) For bulk chemicals, typical E-factors are <1–5. For pharmaceuticals, however, typical E-factors range from 25 to over 100.

One green chemistry success story comes from Pfizer, where the manufacturing process now used for sildenafil citrate (Viagra) has a very low E-factor of six. Key innovations in the development of this environmentally benign synthesis were (i) discovering a convergent, efficient synthetic route; (ii) designing seven process steps so that there was no extractive work-up in any step; and (iii) implementing efficient solvent recovery early in the product's commercial lifetime. This process earned Pfizer a U.K. Award for Green Chemical Technology in 2003.

Other pharmaceutical companies are also using the principles of green chemistry, which some scientists prefer to call "sustainable chemistry." Here in the United States, Lilly (1999), Roche (2000), Pfizer (2002), Bristol-Myers Squibb (2004), and Merck (2005) have all won EPA Presidential Green Chemistry Awards.

Berkeley ("Buzz") Cue (ACS '69) has been a leader in the pharmaceutical industry's adoption of green chemistry. Since retiring from Pfizer in 2004 as vice president of Global Research and Development, he's remained active in the field. Currently a member of the GCI Governing Board, he also served on the NRC Committee that wrote *Sustainability in the Chemical Industry.*

"It's pretty easy to make the economic case for applying green chemistry principles in manufacturing processes," Cue said. Without sustainable manufacturing processes, companies suffer a double economic penalty—purchasing raw materials that don't wind up in the final product and incurring significant costs for waste disposal.

Encouraged by the many benefits emerging from green chemistry, 11 companies earlier this year joined forces, under the GCI umbrella, to establish the Pharmaceutical Industry Roundtable. The Roundtable plans to develop a toolbox of greener synthetic methods, foster stronger industry–academe partnerships, set standards for green chemistry metrics, and sponsor conferences and educational programs.

What's Next for the Pharmaceutical Industry?

Anastas, Cue, and other green chemistry advocates believe the next step is to apply the principles at earlier stages of the R&D process—to use green chemistry in the lab, not just the manufacturing plant.

"Case studies show that applying green chemistry principles in the lab stage can save as much as a couple kilograms of raw materials for every gram of active drug that's manufactured," Cue pointed out. With R&D budgets so tight, those potential cost savings are catching the attention of more and more scientists.

And for the heavily regulated pharmaceutical industry, there's an additional reason for using green chemistry earlier in the process. "If you change the chemistry at the manufacturing stage, you can't change the quality profile of the drug without jumping through all kinds of regulatory hoops," Cue said. "You have to guarantee that the profile stays the same for patient safety and product performance considerations."

Cue's solution? "Many of us believe that all chemists should understand green chemistry principles and incorporate them into the design of the syntheses of the molecules at the earliest possible stages. Green chemistry doesn't cost extra time. They're not hard principles to learn. It's just a question of changing your mind-set."

The New Paradigm

"It's just a question of changing your mind-set." Those words from Buzz Cue aren't just buzzwords. They reflect a new vision for chemistry that's going to affect each of us in the chemistry enterprise.

Ready to shift your paradigm? A good place to get started, right now, is to read *Sustainability in the Chemical Industry: Grand Challenges and Research Needs.* ⬢

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