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44. Bringing new meanings to molecules by integrating green chemistry and the social sciences

by
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The chemical industry, perhaps more than any other, needs to change if it is to be acceptable and viable in a greener, more sustainable world. Chemists and chemical engineers are taking up this challenge through "green chemistry," and social scientists with backgrounds in economics, politics and law, along with environmental health scholars, are increasingly collaborating with them to produce socially robust knowledge through interdisciplinary scholarship.

Green or sustainable chemistry[1] is "the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances" (Anastas and Warner, 1998: 1). It is a "design philosophy" (Mulvihill et al., 2011) that focuses on preventing – at the molecular level – the health and environmental problems associated with industrial chemicals. Green chemistry is the science of developing chemicals and materials that not only require less energy, water and raw materials in their production but also are *inherently* safe for biological and ecological systems. It marks a sharp departure from the current industrially embedded approach to risk assessment and management, which seeks to control risks through controlling exposures rather than eliminating inherent hazards.

Green chemistry is mainly associated with the fields of chemistry and chemical engineering. However, we argue that it will require the efforts of a much broader community, including environmental health scientists, policy and legal scholars, political scientists, economists and others in the social sciences to fully realise its transformative potential. We therefore advocate new research practices that bring social scientists, chemists and environmental health scientists together in interdisciplinary scholarship.

Introducing green chemistry

The origins of green chemistry can be traced back to chemists' critiques of the definition of "success" in chemical processes. Traditionally, success was based on percentage yields and satisfactory costs, with remediation of waste left as an (often costly) afterthought.

Beginning in the 1970s, increasingly stringent environmental regulation led to greater prominence for new voluntary industry criteria, such as input efficiency and zero-waste processes. Following the United States Pollution Prevention Act of 1990, these ideas were codified in *Green Chemistry: Theory and Practice* (Anastas and Warner, 1998). This defined the field and outlined 12 non-regulatory design principles that address the lifecycle of industrial chemicals, focusing primarily on the perspectives of working chemists.

Guided by these principles, green chemistry has found a home in many academic and industrial settings. Because chemistry is central to most economic sectors, green chemistry technologies have potential applications far beyond the chemical industry itself, for example in pharmaceuticals, food processing, energy, electronics, packaging, and consumer products for cleaning and personal care. Examples of green chemistry applications in industry include replacing organic solvents with condensed carbon dioxide in semiconductor manufacturing, doing dry cleaning without the use of perchloroethylene, and developing processes to manufacture plastics from biomass instead of oil as a feedstock (Manley, Anastas and Cue, 2008).

In contrast to the exposure reduction approach which dominates the risk assessment and management paradigm of present-day regulators and business, green chemistry aims to reduce or eliminate any chemical that poses a hazard. Further, within green chemistry the notion of hazard is interpreted broadly. Along with traditional toxicological concerns such as carcinogenicity and mutagenicity, and new ones such as endocrine disruption, it also includes damage to public goods, such as a substance's ozone-depleting and global-warming potential. The principles of green chemistry therefore also aim to maximise efficiency by reducing the consumption of energy, water and non-renewable feedstock materials. As a result, green chemistry is a fundamental component of sustainable development (NRC, 2006; Mulvihill et al., 2011). It provides conceptual integration for a wide range of seemingly disparate global issues, such as occupational and environmental health, energy and resource efficiency, and climate change.

Recognising green chemistry's transformative potential

If every chemical technology that relies on a hazardous substance is a target for a green chemistry solution, how should priorities be established, and how should the success of new green chemistry technologies be defined? Who should make these value-laden decisions? The approach taken in the United States to developing green chemistry has reinforced the autonomy of chemists, chemical engineers and industry actors, while explicitly endorsing market forces and eschewing regulation (Woodhouse and Breyman, 2005; Iles, 2011). "Unlike regulatory requirements for pollution prevention, Green Chemistry is an innovative, non-regulatory, economically driven approach toward sustainability" (Manley et al., 2008: 743).

This approach may have seemed apolitical to chemists, who on average may be less comfortable than social scientists with issues that are regarded as political. However, as social scientists have long noted, choices that deliberately avoid apparently political activities are themselves inherently political because they arise from socially and culturally embedded value judgements.

In this case, green chemists' preferred approach, via voluntary measures decided by industry, is an implicit endorsement of the status quo. It also positions chemists, chemical

engineers and industry actors, inappropriately we argue, as the main arbiters of the direction and pace of change in the mix and distribution of chemical risks.

In contrast, many social scientists and environmental health scientists, who recognise green chemistry's potential to transform, may be sceptical of relying solely on a market-driven approach. They recognise that markets are structured by regulatory frameworks which, in the case of chemicals, are deeply flawed. Some have argued that "Existing policies have produced a United States chemicals market in which the safety of chemicals for human health and the environment is undervalued relative to chemical function, price, and performance" and that this has led to:

> A chemical *data gap*, because producers are not required to investigate and disclose sufficient information on chemicals' hazard traits to government, businesses that use chemicals, or the public; a *safety gap*, because government lacks the legal tools it needs to efficiently identify, prioritize, and take action to mitigate the potential health and environmental effects of hazardous chemicals; and a *technology gap*, because industry and government have invested only marginally in green chemistry research, development, and education.
>
> (Wilson and Schwarzman, 2009: 1202)

As a result, social scientists from a range of disciplines – such as science and technology studies, law, policy studies, and management – along with environmental health scientists, citizens, non-governmental organisations (NGOs) and policymakers, have joined forces "to propose credible tax incentives, regulations, and mandates; foster public debate; and begin to use the state's legitimate coercive role to reshape innovation in line with public purposes" (Woodhouse and Breyman, 2005: 219). States such as California, Washington and Oregon are passing new, if imperfect, regulations to shift the investment and innovation priorities of chemical producers away from known toxic substances and toward greener chemistries. The debate in California, for example, has focused on industrial innovation in green chemistry as a forward-looking strategy to achieve health and environmental protection as well as increased economic competitiveness (Matus, 2010). As a result, "[g]reen chemistry is beginning to emerge as a key battleground for shifting technologies toward greater sustainability," and has become a site for "epistemic politics" (Iles, 2011: 17).

In some ways, these tensions are unsurprising. They are foreshadowed by green chemists' own definition of their field, which emphasises hazard and risk, concepts that are frequently contested and which have a rich social science literature. We do not take a position on the merits of establishing regulatory regimes that would motivate investment in green chemistry. We do, however, believe it is important to recognise the way in which social scientists and environmental health scientists have engaged with green chemistry to investigate the levers available beyond the chemistry laboratory that might speed the adoption of green chemistry technologies.

Engaging social scientists as important stakeholders for advancing green chemistry

Green chemistry can benefit from collaboration between chemists and experts from other sciences and from the social science disciplines, because "sustainability demands the *integration* of multiple forms of knowledge, including natural scientific, health, social scientific, commercial, and policy, across the entire life cycle of chemicals" (Iles and

Mulvihill, 2012: 5644). An awareness of green chemistry's multi-stakeholder community (Iles and Mulvihill, 2012) enables chemists, chemical engineers and industry actors to engage with social scientists, environmental health scientists, workers, NGOs and policymakers to shape the direction of economic activity in a more acceptable and viable form. This type of collaboration has the potential to provide enormous benefits beyond what might be achieved in the laboratory alone.

Knowledge from the social sciences, and from other scientists engaged in advancing sustainability, can inform choices about what kind of research and development to undertake within a chemical enterprise. It can also shape the social parameters within which green chemistry will either flourish or remain on the margins of industrial activity. At the same time, interdisciplinary work of this nature presents inherent challenges which stem from the cultural and epistemological differences that characterise different academic disciplines.

Fruitful initiatives are emerging, however. The Berkeley Center for Green Chemistry at the University of California, in the United States, facilitates interactions among scholars from chemistry, business, engineering, natural resources, public health policy and the environmental health sciences. It continues to work on overcoming historical differences, but has collaborated successfully on joint research grants, academic and public seminars, conferences, and on building a curriculum of interdisciplinary courses. Similarly, the Green Product Design Network at the University of Oregon in the United States brings together academics and practitioners with expertise in green chemistry, business, product design and communication to catalyse innovation and commercialisation of sustainable products. At McGill University in Canada, the Centre for Green Chemistry and Catalysis includes social scientists along with chemists, and the faculties of Management and Chemistry collaborate on a sustainable innovation workshop that brings together students from the two disciplines to evaluate the environmental performance and commercial viability of actual green chemistry technologies. Linking these and similar initiatives, the Interdisciplinary Network for Green Chemistry provides a forum for dialogue among social scientists, public health scholars and chemists who seek to catalyse the implementation of green chemistry principles throughout the global chemical enterprise through innovative research and education (IN4GC, 2012).

Integrating social sciences with green chemistry

These experiences suggest that the emergence of green chemistry in the context of a multi-stakeholder community has a number of potential benefits. The first is that by working more closely with social scientists, green chemists are likely to develop a greater awareness of their own discipline and of its role in shaping the chemical enterprise – one that recognises science as a socially embedded activity permeated with value judgements. Because any technology is a mixture of benefits and risks, none of which is evenly distributed across time, space or social groups (Maguire and Ellis, 2003), chemists must take their design decisions and responsibilities seriously by exposing and questioning the trade-offs and value judgements they make. These judgments can be masked by "taken-for-granted" assumptions, heuristics and routines. Chemists and engineers, working with social scientists, can reveal and critique these assumptions using social scientific knowledge. Such a reflexive stance is especially important given the significant uncertainties and controversies that surround many chemical risks, a situation that increases the scepticism that citizens feel towards experts' claims (Iles, 2011).

Second, significant policy and industrial advances can be attained. A multi-stakeholder community brought together around green chemistry is more likely to produce "socially robust knowledge" (Nowotny, Scott and Gibbons, 2001) that can withstand both scientific *and* societal testing, because it has emerged from a transparent and participatory process (Iles, 2011). Despite its difficulties, we believe that interdisciplinary collaboration which examines problems using multiple perspectives is more likely to enable academics, industry and policymakers to produce successful interventions in sustainable technologies that support a life-affirming economy.

Experience at the University of California suggests that new ties between previously disparate actors can enable the building of new, broad coalitions to support public policies that alter the nature of economic incentives in the chemical industry by addressing demand-side issues – i.e. the data and safety gaps that are so prominent in today's chemicals markets. Such policies would increase the requirements for companies to generate and disclose information about hazards and to take greater responsibility for their products across their full lifecycle. This in turn would encourage action on supply-side issues through increased investment in green chemistry education, research and innovation, thereby eventually closing the technology gap (Wilson and Schwarzman, 2009).

Finally, the inclusion of social scientists in interdisciplinary teams engaged in the design of new chemical technologies can produce superior designs. During the design phase of a new chemical technology, "the scope of possible innovation ranges from incremental or superficial design improvements to completely redesigning the system of production – a much deeper form of innovation" (Mulvihill et al., 2011: 275). Social scientific knowledge can, for example, contribute to a more realistic understanding of how businesses and members of the public use and dispose of products. This can improve lifecycle analyses and ensure more effective priority setting in chemical policy and in green chemistry research and development. Because social scientists are sensitive to the meanings attached to molecules by different social groups, and to the distributive and ethical implications of the trade-offs between various types of hazards, they can make significant contributions to design deliberations.

Final words

Encouraging the emergence and success of green chemistry in the context of a multi-stakeholder community will present challenges and tensions, such as those associated with the debate on the merits of regulatory versus voluntary approaches to greening the chemical enterprise. Debate is healthy, and given the stakes involved in achieving sustainability, appropriate. There is evidence that the challenges of communicating and sharing information across disciplines can be overcome (Iles and Mulvihill, 2012). Green chemistry can realise its potential to transform the global chemical enterprise towards sustainability.

Note

1. Some social actors and scholars distinguish between *green chemistry* and *sustainable chemistry*, while recognising that they overlap significantly: "The term green chemistry is used commonly by academics because of the historical development of the field. The term sustainable chemistry is often preferred by industry as a way to distinguish technological innovation from the potential political overtones of the word green" (Mulvihill et al., 2011: 272). Here, we use "green" as including both.

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