COLUMN Romance between scientists is not just about the two-body problem **p.127**

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CHEMISTRY

Greener pastures

For chemists with an interest in the environment, making a move into green chemistry can be fruitful.

BY NEIL SAVAGE

One night in spring 2005, Laura Muollo stayed up late trying to choose which chemistry graduate programme to attend. Although she had been accepted by big-name universities including Yale, Johns Hopkins and Northwestern, she settled on the lesser-known University of Massachusetts Lowell — even though she would receive a lower stipend. Lowell offered her something that the other institutions could not at the time: the opportunity to focus heavily on green chemistry. "I decided that the name of the school couldn't make me happy, but doing what I wanted would," she says.

By 2009, Muollo had gained a PhD in organic chemistry, with a green-chemistry option that catered to her interest in the environment. Her classes included toxicology, environmental law, and energy and the environment. And even before she graduated, Muollo had found a job at the Warner Babcock Institute for Green Chemistry in Wilmington, Massachusetts, which was founded and is helmed by John Warner, one of the pioneers of green chemistry. The institute designs and develops materials and processes that reduce the use and generation of hazardous substances in industry.

Now one of the directors of research programmes at Warner Babcock, Muollo is working on, among other things, a chemical method for recovering metals from used electronics that is less energy-intensive than conventional means.

Green chemists not only create new molecules, but also take particular account of how those molecules will behave in the environment — whether they will be toxic or otherwise undesirable. When designing a new product, green chemists consider all the stages of its life cycle, from the raw materials to its production and use and what happens when the discarded product breaks down in the environment.

Green chemistry is not so much a separate job track as an addition to general chemistry training. "You can't make a career being a green chemist," says Warner. "You do green chemistry in a career." Aspiring chemists hoping to pursue a career with a green emphasis need to acquire some training in areas beyond conventional chemistry, but relatively few formal master's or PhD programmes in the subject exist. The American Chemical Society (ACS) in Washington DC currently lists 26 institutions around the world that have some sort of green focus (see go.nature.com/keja5h).

CLEAN CHEMISTRY

One aspect of green chemistry involves designing chemical production processes that are more environmentally friendly than those currently available. This does not necessarily mean achieving complete non-toxicity. The aim may be to use less-hazardous solvents or safer methods of synthesis, to produce less waste, to use renewable feedstocks or to develop a more energy-efficient process. And to be acceptable to industry, the greener version has to work as well as — or better than — any existing version, and be no more expensive.

Training in green chemistry is rarely a formal requirement for an industry post. But industrial interest in the field is growing. Chemical manufacturers are likely to look favourably on applicants who are trained to consider the health and environmental impacts of chemical processes and products. Experts in the field say that this view is partly attributable to an increase in government rules, such as the European Union's Registration, Evaluation, Authorisation and Restriction of Chemical Substances (REACH) regulation. REACH, which came into effect in 2007, requires industry to evaluate the risks posed by the chemicals that it uses, and to seek safer alternatives.

Green chemistry has many potential benefits for industry. In principle, safer processes can mean reduced expense for the disposal of ▶

hazardous waste and lower liability costs, as workers and consumers get less exposure to toxic substances. Many consumers are becoming increasingly concerned about the environmental effects of the products they buy, so companies also see green as a means of increasing their share of the market. Employing scientists who can recognize, and correct, problems of toxicity or environmental hazard early in the cycle of research and development can save time and money (see 'Green chemistry in action'). "Having people work for us who have a background understanding and knowledge of green-chemistry process cycles gives us an advantage," says Karen Koster, executive vice-president for environmental health and safety at Momentive, a chemical manufacturer based in Columbus, Ohio.

Koster says that Momentive looks for people who have green-chemistry training as well as some experience in a market that the company deals with, so that they understand the products that the chemicals will go into. Much of the company's work is for the automotive industry — creating speciality coatings for composite materials that serve as lightweight alternatives to metal parts, and helping car makers to meet new emissions standards. Other clients include the construction industry and suppliers of parts for turbines. Someone in a chemical-engineering graduate programme who has had an internship in one of these industries would be an attractive hire, says Koster. "There's more of a focus on applications and markets and less of a focus on 'OK, I need an expert in polymer chemistry and they're going to come in and design molecules,'" she says.

Some companies offer training on the job. At the multinational company 3M, based in St Paul, Minnesota, which has about 80,000 employees worldwide, developmental chemists and engineers can take six two-hour training sessions on toxicology. It is important for the company to train employees who went through graduate education before green chemistry made it into academic programmes, says Robert Skoglund, senior laboratory manager in 3M's medical department. "We're trying to give them an understanding of the hazards of chemicals."

SUCCESS STORIES

Green chemistry in action

Green chemistry encompasses anything that renders a process or product more environmentally friendly, whether by reducing waste, replacing toxic solvents with less toxic ones, using renewable feedstocks such as biomass, or making more efficient use of inputs such as energy or water. Here are a few examples of green-chemistry successes, some taken from past winners of the US Environmental Protection Agency's Presidential Green Chemistry Challenge.

- Momentive in Columbus, Ohio, has produced a coupling agent for silica-containing tyres that eliminates most of the ethanol released during manufacture. It also improves the tyre's resistance and traction, thus reducing fuel consumption.
- Nike in Beaverton, Oregon, has changed the rubber formulation it uses for making its shoes, reducing, for example, the total zinc content by 80% and replacing solvent-based processes with water-based ones. Nike says it has decreased the amount of hazardous waste generated in making a pair of shoes by more than one-third since 2005.
- BASF in Ludwigshafen, Germany, and Dow Chemical in Midland, Michigan, have developed a process to convert hydrogen peroxide into propylene oxide, a key component in products ranging from domestic appliances and furniture to paint and pharmaceuticals. The companies say that their process reduces waste water by 70–80% and energy use by 35%.
- Codexis in Redwood City, California, has engineered a more efficient enzyme and come up with a low-cost feedstock for making simvastatin, a leading cholesterol-lowering drug. The process cut the number of steps involved in synthesizing the drug and reduced the use of hazardous solvents.
- Geoffrey Coates of Cornell University, Ithaca, New York, developed a family of catalysts to convert carbon monoxide and carbon dioxide efficiently into polymers used in commercial plastics, some of which are biodegradable. Start-up company Novomer in Waltham, Massachusetts, is using the catalysts to produce a polycarbonate coating for use by electronics manufacturers. The production process is expected to use only half the amount of energy typically required to make similar products.
- Genomatica in San Diego, California, has developed a microbe that ferments sugar to synthesize 1,4-butanediol (BDO), a chemical building block for plastics such as spandex. The process is estimated to use 60% less energy and produce 70% less carbon emissions than BDO synthesis from natural gas. **N.S.**

Laura Muollo studied green chemistry in her PhD.

LAUREN PLAVISCH/WARNER BABCOCK INST.

GLOBAL SHIFTS

One study suggests that green chemistry could be a means for US chemical manufacturers to strengthen their global foothold (see go.nature.com/7o8yqy). Plastics production and non-pharmaceutical chemical manufacturing in the United States have seen a drop from about 807,000 workers in each area in 1992 to 626,000 and 504,000 in 2010, respectively. The study's authors, political economists James Heintz and Robert Pollin at the University of Massachusetts, Amherst, argue that focusing on green chemistry could increase jobs across the board, in part by making US products more attractive to environmentally conscious consumers.

Chemical production is growing in China, Singapore and India, partly because of the shift of heavy industry away from the West, says James Clark, head of the Green Chemistry Centre of Excellence at the University of York, UK. China is by far the largest manufacturer of chemicals worldwide, according to the European Chemical Industry Council in Brussels, with US$982 billion in sales in 2011, nearly double those of the United States in second place. Clark has had many students from China who return home after their course to work in the chemical industry. "They find it relatively easy to walk into jobs," he says.

Clark adds that large manufacturers in Europe have not entirely shifted focus to green chemistry, but there are still plenty of jobs for his graduates. Many small companies are developing products that use chemical ingredients derived from biomass rather than from scarcer, carbon-generating petroleum. These firms are mostly start-ups, he says, although some large firms are moving in the same direction — one is DuPont, which is based in Wilmington, Delaware, but has a big European presence.

The Delft University of Technology in the Netherlands provides all its chemistry students with green training to make them more employable, says Isabel Arends, head of the biotechnology department. "All of our students find a job within two months after they graduate," she says. Some have studied industrial ecology and get policy-oriented jobs, whereas others take manufacturing jobs in pharmaceuticals, polymers or food engineering.

PAESMEM PHOTOGRAPHY

"You can't make a career being a green chemist. You do green chemistry in a career."
John Warner

Students who cannot get onto a formal master's or PhD course that includes green chemistry should "take it upon yourself to get that information anyway", says Warner. One way to do that is through programmes aimed at recent graduates, including a week-long summer school run by the ACS in conjunction with its annual conference. Alternatively, meetings with a green-chemistry focus enable networking and an overview of developments in the field. A Gordon Research Conference in Green Chemistry and an associated Gordon Research Seminar will be held in Hong Kong next July, and the University of Nottingham, UK, last month hosted the 6th International Conference on Green and Sustainable Chemistry. Warner Babcock's non-profit education arm, Beyond Benign, also offers resources (www.beyond-benign.org).

Fortunately, green-chemistry courses are becoming more common. Yale University in New Haven, Connecticut, which Muollo turned down in 2005, now has a Center for Green Chemistry and Green Engineering. Founded in 2007 by current director Paul Anastas, who co-wrote the textbook *Green Chemistry* (Oxford University Press, 2000) with Warner, the centre offers courses on green engineering and sustainable design, product life-cycle assessment, water-resources management and how businesses can become greener.

The field, says Muollo, has grown since 2005. Eventually, she says, green will be integral to chemical manufacturing. "I think green chemistry is going to become chemistry." ■

Neil Savage *is a freelance writer based in Lowell, Massachusetts.*

CORRECTION

The Turning Point about Jason Weber (*Nature* **500,** 493; 2013) wrongly identified Senator Dick Durbin as a Republican. He is a Democrat.

COLUMN

Two-body blessing

Romantic partnerships between scientists offer plenty of benefits, argues **J. T. Neal**.

EMPRIZE/SHUTTERSTOCK

I am frequently amazed by how many of my fellow scientists are unwilling to pursue romantic relationships with other scientists. No matter how many times I tell them how great it is that my wife is also in science, too many have heard horror stories from a mentor or colleague about spouses forced to find jobs with carnivals, impact-factor-related divorces or children lost to the liberal arts.

"Don't you just talk about work all the time?" they ask. What? No! Sure, our dinner conversations sometimes cover the advantages of stimulated emission depletion over confocal microscopy, the finer points of TAL-effector-nuclease design, or whether Reviewer 3 would be more appropriately classified as an Old or a New World monkey (I say New World; you would need a prehensile tail to grasp at that many straws!). But we are just as likely to talk about, you know, the weather. Or that movie — the one we are totally going to see next week. Probably. Or that local sports team.

It is true that science can be hard on a relationship. Late-night data-gathering, grant-application deadlines and manuscript revisions can play havoc with domestic bliss. But who is going to understand these challenges better than another researcher? A scientist-partner will accept you stumbling, bleary eyed, into the house in the middle of a week night without accusing you of carousing or philandering (I spilled 70% ethanol on myself, I swear!). A scientist-partner will sympathize when your undergraduate research assistant kinks the light guide on your tissue-culture scope the day before the lab meeting (I'm looking at you, Ben).

A scientist-partner really understands the myriad daily successes and failures that are unique to science, and either too obscure or too unimaginably mundane for the rest of the world to care about. My wife and I drank champagne when her paper was accepted and ate tiny, expensive French food when I got my fellowship. We spent a week in sweatpants when my paper was rejected for the 16th time, and ate fast food and ice cream when she got scooped. I pack leftovers for her to eat when she gets back from her 1 a.m. experiment. She massages my pipetting arm after 12 straight hours in the tissue-culture hood. It's awesome.

And that is not all. Your scientist-partner can act as a 24-hour sounding board for your next great scientific idea. "Hey honey, what do you think about a forward genetic screen in African elephants? No? I guess you're right. That'll never fly in this funding climate."

"But what about the two-body problem?" you ask. "It's hard enough to get one faculty job as it is." Ah, the dreaded two-body problem. It sounds like some kind of development patterning defect. Sure, getting two science jobs in the same time zone can be tricky, but what about all those Egyptologist couples? The two-body problem is far from unique to academia, or to science in particular, because, no matter how you slice it, balancing two careers is hard (see *Nature* **466,** 1144–1145; 2010). We scientists like to imagine that we are exceptional in all things (and we mostly are), but all relationships, scientific or otherwise, require hard work and patience to succeed. Thankfully, scientists have these in spades. (Wine also helps.)

"A scientist-partner really understands the myriad daily successes and failures that are unique to science."

As for my wife and me, I am not sure how it will all shake out when we finish our postdocs and start looking for positions in academia and/or industry. But I know one thing: I wouldn't trade our situation for anything. Not even a full professorship. ■

J. T. Neal *is a postdoctoral fellow in cancer research at the Stanford University School of Medicine in California.*