Research between Science, Society and Politics

The History and Scientific Development of Green Chemistry

by

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Chapter 1: Introduction: the Emergence of Green Chemistry

1.1 Chemistry and the Environment

During large parts of its history chemistry was seen as a science of progress, admired by many. Since a few decades though, public debates on chemistry have been quite critical, mainly for environmental reasons. Often "chemistry" and "the environment" are seen as opposing concepts. Seen in that light is it interesting to note that in the course of the 1990s a new field of chemistry emerged, which has been called "Green Chemistry". The birth, evolution and scientific meaning of that new field are the subject of this book.

The first decades after World War II were a period of strong focus on economic growth; but societies paid a negative price too. Rachel Carson's famous book *Silent Spring* documented the serious consequences of chemicals such as pesticides with respect to ecological damage and public health.[1] Societies faced environmental catastrophes with chemical factories, e.g., the Givaudan-La Roche plant at Seveso (1976), and the Union Carbide plant at Bhopal (1984).[2] They had also to cope with growing amounts of chemical waste. As a result, chemical industries were seriously criticized by the public in many Western countries.

The public environmental concerns received international political recognition at the 1972 United Nations Conference on the Human Environment in Stockholm.[3] Chemicals also caught headlines due to the negative impact of chlorofluorocarbons (CFCs) on the ozone layer, as well as emissions of sulfur dioxide to the atmosphere that caused transboundary air pollution and acid rain.[4] As a consequence, new environmental policies and measures were introduced in modern democracies that were often based on geopolitical agreements, e.g., the phasing out of CFCs (1987), the policy goal of sustainable development (1987) and the agreement on the reduction of greenhouse gas emissions (1992).[5]

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[1] Rachel Carson, *Silent Spring* (New York, NY: Houghton Mifflin Company, 1962).
[2] The journal *Ambix* devoted a special issue to this topic in March 2002.
[3] United Nations, "Declaration of the United Nations Conference on the Human Environment," in *Report of the United Nations Conference on the Human Environment* (Stockholm: United Nations, *1972*), 3-5.
[4] Anthony N. Penna, *The Human Footprint: A Global Environmental History* (Chichester: Wiley-Blackwell, 2010).
[5] The years of the geopolitical agreements are between brackets. United Nations, *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal: United Nations, 1987); United Nations World Commission on Environment and Development, *Our Common Future* (Oxford: Oxford University

As a result, the public meaning attached to chemistry and to the chemical industry became ambiguous. Countries experienced major economic benefits from chemical industries in terms of employment and contributions to their national income. Chemical industries, and as a result, also societies, relied on robust knowledge of the chemical science, which significantly shaped our material culture. But people were also worried about environmental issues, which led to a growing demand for chemical knowledge concerning the environment.[6] These developments also strongly influenced the organizational structure of professional and learned bodies such as chemical societies. In most industrial countries, divisions, working groups and committees on so-called "environmental chemistry" were established within those societies during the early 1970s. Environmental chemistry emerged as a subfield that contributed to the analysis and solving of environmental problems.[7] During those years also new journals in that field were launched, such as *Toxicological & Environmental Chemistry Reviews* in 1972.[8]

In this thesis I investigate the emergence and further development of scientific subfields of the chemical sciences devoted to environmental and ecological issues: first environmental chemistry, and then the rather different field of green, or sustainable, chemistry. I do this by focusing on three highly developed industrial countries – the USA, the UK, and the Netherlands – and within those countries I look in particular to the developments within the national chemical societies, and how these differed, or did not differ, from one country to the other. This historical study of environmental and green chemistry aims to improve our understanding of the responses by chemists and chemical societies to public environmental concerns, and of changing knowledge demands in modern democracies.

The paths along which environmental and green chemistry emerged in the USA, the UK and the Netherlands are analyzed in this thesis through the lens of the history of the chemical societies studied: the American Chemical Society (ACS), the Royal Society of Chemistry (RSC) and the Royal Netherlands Chemical Society [Koninklijke Nederlandse

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Press, 1987); United Nations, *United Nations Framework Convention on Climate Change* (Rio de Janeiro: United Nations, 1992).

[6] Hannah Gay, "Before and After *Silent Spring*: from Chemical Pesticides to Biological Control and Integrated Pest Management-Britain, 1945-1980," *Ambix* 59 (2012): 88-108.

[7] Throughout this thesis I follow a commonly used terminology by historians of science: discipline (e.g., chemistry and physics), subfield (e.g., organic chemistry) and scientific specialty (e.g., bio-organic photochemistry). For further reading see: Eduard Jan Rinia, "Measurement and Evaluation of Interdisciplinary Research and Knowledge Transfer," (PhD diss., Leiden University, 2007), 20. In Leiden University Repository; available from https://openaccess.leidenuniv.nl/handle/1887/9923, accessed May 22, 2022.

[8] This journal is currently titled *Toxicological & Environmental Chemistry*.

Chemische Vereniging] (KNCV). These routes will be explained in a context of changing public environmental values and of differences in political cultures and styles of policy making concerning science and the environment. These changes in environmental values and policies influenced the three chemical societies in different ways. A comparative analysis of the ACS, the RSC and the KNCV helps to better understand the construction and communication of chemical knowledge with respect to environmental problems in those three nations, leading to three different trajectories in the emergence of "green chemistry".

The story of environmental and green chemistry presented in this book can also illustrate the changing societal context of the chemical sciences in the late 1980s. During those years people were increasingly worried about the quality of the environment. This increase of public environmental concerns ran parallel to the worldwide attention paid to the goal of sustainable development. At the same time, new demands were formulated for chemical knowledge in order to prevent pollution at the source. But, as I will argue in this book, chemical societies and other actors in the USA, the UK and the Netherlands also shaped their own science and environmental policies in that context. They did that in different ways. I will demonstrate how culturally conditioned differences influenced the emergence and further development of a new movement and scientific field that holds, even today, great promises for society: green chemistry.

Green chemistry emerged during the early 1990s at the cutting-edge of chemical science and society, and has since then witnessed a huge growth in both academic and industrial circles. At the same time government policies concerning science and the environment became increasingly democratized.[9] In order to understand the origins of green chemistry I also take that factor into account.

From the earliest publications on green chemistry in scientific journals there has been much discussion about its precise (scientific) meaning. Walter Leitner, for instance, argued in 1999 that clean chemistry, sustainable chemistry and green chemistry essentially do have the same meaning.[10] But members of the Working Party on Green and Sustainable Chemistry (European Association for Chemical and Molecular Sciences) argued in 2008 that there was still 'no consensus in the scientific community' on the prefixes "green" and "sustainable".[11]

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[9] See for example: Esther Turnhout et al., "New Roles of Science in Society: Different Repertoires of Knowledge Brokering," *Science and Public Policy* 40 (2013): 354-365.
[10] Walter Leitner, "Toward Benign Ends," *Science* 284 (1999): 1780-1781.
[11] P. Tundo, "Report of the 1st meeting of the Working party on Green and Sustainable Chemistry" (European Association for Chemical and Molecular Sciences, Rome, February 28, 2008). See also in: Johan A. Linthorst, "An Overview: Origins and Development of Green Chemistry," *Foundations of*

More recently, (former) editors of *Green Chemistry* commented on the growth and identity of green chemistry, and in particular on the question which green chemistry labeled research rightly counted as green chemistry proper, and which did not.[12] The identity and status of green chemistry thus appears to be a matter of dispute, and as a result its promises and meaning for society are a bit obscure too. Against that background this thesis aims to clarify these disputes and analyze the evolving meaning and importance of green chemistry for science and society by tracing its scientific development. It will address in particular its origins in the USA, the UK and the Netherlands, both from an internal scientific and from a socio-cultural point of view. My analysis in this book therefore aims to be of interest to historians of science, policy makers, and chemists as well.

Societies have provided infrastructures and funding for chemical research. Major policy activities and lobbying have been undertaken in the 1990s by the ACS, the RSC and the KNCV in order to secure the legitimacy of the chemical sciences, in view of the deteriorating public image of chemistry.[13] ACS President S. Allen Heininger argued in the early 1990s that 'improving the public's perception of chemistry' was a key aim of the ACS, because the 'American public is highly interested in environmental issues, and a common misconception is that chemists, chemistry, chemicals, and the chemical industry are all detriments to the environment'.[14] So, the negative public image of chemistry should certainly be taken into account to understand the emergence and recognition of green chemistry.

Chemistry 12 (2010): 55-68. See also: "Who is EuChemS," The European Chemical Society, accessed May 22, 2022, EuChemS Who is EuChemS – EuChemS.

[12] James H. Clark et al., "15 Years of Green Chemistry," *Green Chemistry* 16 (2014): 18-23. See also: Carlos A. Marques and Adélio A.S.C. Machado, "Environmental Sustainability: Implications and Limitations to Green Chemistry," *Foundations of Chemistry* 16 (2014): 125-147.

[13] Johan A. Linthorst, "The Image of Chemistry and Curriculum Changes," *Educacion Quimica* 23 (2012): 240-242; Ernst Homburg and Elisabeth Vaupel, "Conclusion," in *Hazardous Chemicals: Agents of Risk and Change, 1800-2000*, ed. Ernst Homburg and Elisabeth Vaupel (New York: Berghahn Books, 2019), 382-386. See for chemical societies for instance: ACS, *American Chemical Society Annual Report 1996* (Washington, DC: ACS, 1997), 14; RSC, *The Royal Society of Chemistry: Annual Review 1995* (London: RSC, 1996), 15; KNCV, "KNCV Jaarverslag 1990," *Chemisch Weekblad* 87 (1991): 196. See also: Michelle Francl, "How to Counteract Chemophobia," *Nature Chemistry* 5 (2013): 439-440; Carla Morais, "Storytelling with Chemistry and Related Hands-on activities: Informal Learning Experiences to Prevent "Chemophobia" and Promote Young Children's Scientific Literacy," *Journal of Chemical Education* 92 (2015): 58-65; Pierre Laszlo, "On the Self-image of Chemists, 1950-2000," *Hyle* 12 (2006): 99-130; Peter H. Spitz, "The Chemical Industry and the Environment: Meeting the Challenge," in *The Chemical Industry at the Millennium: Maturity, Restructuring, and Globalization*, ed. Peter H. Spitz (Philadelphia, PA: Chemical Heritage Press, 2003), 206-246.

[14] S. Allen Heininger, "President's Statement," in ACS, *American Chemical Society Annual Report 1991* (Washington, DC: ACS, 1992), 3.

1.2 Studies on the Development of Environmental and Green Chemistry

Only a limited number of studies have been conducted that systematically examined the history of environmental chemistry and green chemistry. The major studies that do exist will be discussed below.

The history of environmental chemistry

There are many histories of chemistry, but most of these do not take the debates on chemistry and the environment on board. William Brock and Trevor Levere are exceptions. They emphasize the important impacts on the discipline by accidents in the chemical industry and instances of worldwide pollution, by for instance pesticides.[15] Moreover, specific historical studies on the emergence of environmental chemistry as a subfield of chemistry are scarce, and they were often written by environmental chemists themselves.

Environmental chemistry emerged in the early 1970s. The KNCV Division Environmental Chemistry [Sectie Milieuchemie] was established in 1970, and the ACS Division of Environmental Chemistry (DEC) in 1973.[16] In the UK, the Environment Group was founded in 1972 within the Industrial Division of the Chemical Society (CS), one of the predecessors of the RSC.[17] In the same period research and educational programs on environmental chemistry were launched at universities in the USA, the UK and the Netherlands.[18] In 1974, the environmental chemist G. Fred Lee argued in a special issue on

[15] William H. Brock, *The Fontana History of Chemistry* (London: Fontana Press, 1992), 656-662; Trevor H. Levere, *Transforming Matter: a History of Chemistry from Alchemy to the Buckyball* (Baltimore, MD: The Johns Hopkins University Press, 2001), 192-200.
[16] Stuurgroep Sectie Milieuchemie, *Koninklijke Nederlandse Chemische Vereniging: Sectie Milieuchemie*, August 4, 1970; KNCV, "Jaarverslag van de Koninklijke Nederlandse Chemische Vereniging over 1970," *Chemisch Weekblad* July 23/30 (1971): 28; DEC, "Division of Water, Air, and Waste Chemistry," April 10, 1973.
[17] Geoff Dickes, "A Brief History of the Environmental Chemistry Group," *Environmental Chemistry Group Newsletter* 1 (1995): 4-5; David H. Whiffen and Donald H. Hey, *The Royal Society of Chemistry: The First 150 Years* (London: RSC, 1991), 206-209.
[18] See for the USA: Glen E. Gordon, "The Role of Chemistry Departments in the Environmental Education of Chemists," *Journal of Chemical Education* 51 (1974): 769; George L.B. Pratt, "Educational Needs of Chemists in Pollution Control and Abatement," *Journal of Chemical Education* 51 (1974): 770-771; G. Fred Lee, "Graduate Education in Environmental Chemistry," *Journal of Chemical Education* 51 (1974): 772-774; D.D. Davis, "An Operational Graduate Program in Environmental Chemistry," *Journal of Chemical Education* 51 (1974): 775-776. See for the UK: Brendan Keely, "Environmental Chemistry at the University of York," *Environmental Chemistry Group Newsletter* 5 (1997): 3-4. See for the Netherlands: Werkgroep Aspekten van

environmental chemistry education of the *Journal of Chemical Education*, that this emergence in the USA was supported by 'substantial research funds'.[19] Environmental chemists who later reflected on their own subfield, identified the early 1970s as the period when environmental chemistry took off.[20] But the limits of the field were a matter of dispute. Donald Crosby, for instance, argued that the identity of environmental chemistry as a scientific subfield was hard to characterize due to the fact that the creation of knowledge in environmental chemistry is subject to a wide range of 'things, conditions or influences'.[21] The Dutch environmental chemist Jan Willem Copius Peereboom agreed with that, but emphasized that environmental chemistry was not only a subfield of chemistry, but also a 'specialism' within the interdisciplinary environmental sciences, which were based on both the social and the natural sciences.[22] He associated this chemical subfield thus also with social concerns. The environmental historian Christopher Hamlin positions environmental chemistry pretty close to actions of the people as well in his definition of the 'perilously vague term' environmental chemistry:[23]

> (…) a field of study: inquiry into the chemical systems of the environment, a concern with the effects of the environment on human health and the effects of human activities on environmental systems, (…)

The environmental historian Henk van Zon does the same, but also points to the impact of natural effects on environmental systems.[24]

Milieuproblematiek in de Chemische Opleiding, *De Milieuchemie in het Wetenschappelijk Onderwijs* (Den Haag: KNCV, 1976).

[19] Lee, "Graduate Education in Environmental Chemistry," 772. This special issue was USA oriented. See for the increases in research funding also: Laszlo, "On the Self-image of Chemists, 1950-2000," 114; Gay, "Before and After *Silent Spring*," 97-100.

[20] Dickes, "A Brief History," 4; Donald G. Crosby, "Review: Environmental Chemistry: an Overview," *Environmental Toxicology and Chemistry* 1 (1982): 1; J.W. Copius Peereboom and K. Bouwer, "Environmental Science 'Milieukunde' in the Netherlands: a Review," *The Science of the Total Environment* 129 (1993): 161.

[21] Crosby, "Review: Environmental Chemistry," 8.

[22] J.W. Copius Peereboom, *Chemie, Mens en Milieu: Schadelijke Stoffen in Milieu en Voeding, een Studie over Chemische Milieuverontreiniging* (Assen: Van Gorcum, 1976), VIII; Werkgroep Aspekten van Milieuproblematiek in de Chemische Opleiding, *De Milieuchemie in het Wetenschappelijk Onderwijs*, 4; Copius Peereboom and Bouwer, "Environmental Science 'Milieukunde' in the Netherlands," 157-158.

[23] Christopher Hamlin, "Between Knowledge and Action: Themes in the History of Environmental Chemistry," in *Chemical Sciences in the Modern World* , ed. Seymour H. Mauskopf (Philadelphia, PA: University of Pennsylvania Press, 1993), 295.

[24] Henk van Zon, "Geschiedenis van Milieuproblemen in Vogelvlucht," in *Milieuchemie. I. Onderzoeksmethoden in de Milieuchemie*, ed. M.A.M. Meester (Heerlen: Open Universiteit, 2000),

Despite these ambiguities, expectations were high: Crosby even predicted that environmental chemistry would become 'the chemistry of the 21st century'.[25] But despite those expectations, the emergence and growth of environmental chemistry from the early 1970s onwards has not specifically been studied by professional historians of chemistry.

I conclude that a comprehensive historical analysis of environmental chemistry is still lacking. Despite that, I also conclude that several authors recognized major influences by public environmental concerns on the identity of environmental chemistry. Crosby and Hamlin signaled difficulties in assessing the scientific character of environmental chemistry. In order to better understand the identity of this chemical subfield I will analyze in the next three chapters its emergence and development by studying in more depth the histories of the relevant divisions, or sections, of the three national chemical societies.

Studies on green chemistry and its history

Contrary to the history of environmental chemistry, the history of "green chemistry" has been studied in some depth by a number of authors. The term "green chemistry" entered the chemical sciences in the early 1990s, but by the turn of the century the use of this new term in chemical journals increased suddenly. That phenomenon became therefore subject of scholarly interest in the field of Science and Technology Studies (STS), which gained momentum in the mid-2000s and was often spurred by the laudable promise of green chemistry for society: sustainability. In order to understand the emergence and growth of green chemistry this scholarly interest led to different characterizations of green chemistry, which I have grouped in four different categories: (1) green chemistry as a scientific movement; (2) green chemistry as a social movement; (3) green chemistry as mere rhetoric; and (4) green chemistry as a (meta-)specialization within the chemical sciences.

Green chemistry as a scientific movement

One of the first STS-scholars who studied green chemistry thoroughly was Jody Roberts (Chemical Heritage Foundation), who in 2005 wrote a dissertation on the emergence of green

31-32 and 46-47. The following environmental chemists put forward similar characterizations: Dickes, "A Brief History," 4; Crosby, "Review: Environmental Chemistry," 1; Copius Peereboom and Bouwer, "Environmental Science 'Milieukunde' in the Netherlands," 161.
[25] Crosby, "Review: Environmental Chemistry," 6.

chemistry in the USA in the years 1990 to 2005.[26] He argues that the nature of environmental legislation changed in the USA with the passage of the Pollution Prevention Act (PPA) of 1990. Since then the focus on pollution prevention increased, with positive effects on both the environment and the economy.[27] The PPA also led to the formation of a green chemistry program within the US Environmental Protection Agency (EPA). According to Roberts, PPA was therefore a major turning point for the emergence of green chemistry. The roots of green chemistry in the USA are thus within the EPA, and chemists within that organization developed a program that received major political support in 1995, when the Presidential Green Chemistry Challenge Awards program was launched. One of its aims was to show society the benefits of the chemical sciences and chemical industry. The Awards also stimulated the further development of green chemistry.[28]

Roberts, who interviewed several early key-figures within the field of green chemistry, argues that these proponents were strategically creating a green chemistry movement.[29] In order to persuade other chemists to join the green chemistry community they created a historical narrative of chemistry, the environment and the economy.[30] In order to solve USA's environmental and economic problems, the logical outcome of that story was a unique selling-point for the chemical sciences: "green chemistry". In 1998, this 'alternative form of chemistry' was intellectually shaped through the establishment of the so-called "twelve principles" by two leading promoters of green chemistry: Paul Anastas and John Warner (both from the USA).[31]

These principles play a fundamental role in Roberts' characterization of green chemistry as a "scientific movement". He uses in his analysis the general theory of Scott Frickel and Neil Gross on the social dynamics and conditions of scientific movements, in which they included insights of various scholars within STS. These "scientific movements" are 'collective efforts to pursue research programs or projects for thought in the face of

[26] Jody A. Roberts, "Creating Green Chemistry: Discursive Strategies of a Scientific Movement," (PhD diss., Virginia Polytechnic Institute and State University, 2005), abstract. In VirginiaTechWorks; available from https://vtechworks.lib.vt.edu/handle/10919/27529, accessed May 22, 2022. The current name of the Chemical Heritage Foundation is Science History Institute (Philadelphia, PA).
[27] Ibid., 10-13.
[28] Ibid., 64-67 and 130.
[29] Roberts also attended green chemistry conferences.
[30] Roberts, "Creating Green Chemistry," 38-67.
[31] Ibid., abstract and 69-96. In 1998, Warner and Anastas published these principles in their handbook: Paul T. Anastas and John C. Warner, *Green Chemistry: Theory and Practice* (New York, NY: Oxford University Press, 1998), 29-55.

resistance from others in the scientific or intellectual community' and 'involve dramatic breaks with past practices'.[32] Roberts concludes:[33]

> I argue that we have little choice but to call it a scientific movement. (…) Additionally, I think that perhaps the problem lies not so much in calling this a movement, but in calling it scientific.

Roberts doubts in this characterization is mainly based on his views on the nature of the twelve principles of green chemistry and on its institutional origins. With respect to the latter, he argues that green chemistry initially emerged 'not out of any academic unit, let alone a prestigious one. And the leaders of the movement hail from a variety of institutions, but none from a particular place of prominence'.[34] This lack of intellectual leadership could thus be a reason for not calling green chemistry a scientific movement, according to Roberts. But, similar to dominant advocates of green chemistry in the USA, he also states:[35]

> The establishment of the definition and the [twelve] principles, I argue, constitutes an important move in constituting the field as a very specific interdisciplinary group with a forged identity and the beginnings of a system for determining what properly 'counts' as green chemistry.

Roberts acknowledges the work of his STS-colleagues Edward Woodhouse and Steve Breyman (see below) 'to address and overcome the social and political obstacles' in the recognition of green chemistry, but he also emphasizes the pivotal role of the twelve principles in giving green chemistry a *scientific* identity.[36] For that reasons Roberts characterizes green chemistry as a scientific movement, which aims at transforming chemistry

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[32] Scott Frickel and Neil Gross, "A General Theory of Scientific/Intellectual Movements," *American Sociological Review* 70 (2005): 206-207.
[33] Roberts, "Creating Green Chemistry," 149.
[34] Ibid., 150.
[35] Ibid., abstract. See for instance the advocates of green chemistry: Paul T. Anastas and Mary M. Kirchhoff, "Origins, Current Status, and Future Challenges of Green Chemistry," *Accounts of Chemical Research* 35 (2002): 686-687.
[36] Roberts, "Creating Green Chemistry," 95. See also: Laura Maxim, "More than a Scientific Movement: Socio-political Influences on Green Chemistry Research in the United States and France," *Science & Technology Studies* 31 (2018): 24-46. Maxim also characterizes green chemistry as a scientific movement on the basis of Frickel and Gross.