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The Emergence of Green Chemistry : Triple-Helix for Environmental Science in United States†

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Green chemistry is a new scientific field which focuses on the design, manufacture, and use of chemical processes that could prevent pollution and at the same time improve yield efficiency. The few who have written on the emergence of green chemistry have not shed light on the political and economic motivations of green chemistry. As a new study of the emergence of green chemistry, this paper focuses on the relationship among the triple helix of academia, industry, and government which has been critical in the emergence of green chemistry. This paper argues that academia, industry and government created a common ground during the emergence of green chemistry under the common goal of sustainable development since its creation in 1991. Green chemists produced the knowledge to improve the synthetic efficiency to prevent pollution, and the chemical industry used green chemistry research to increase the economic profitability of production system. This specific form of alliance was supported and maintained amid a changing national environmental policy toward pollution prevention and a self-regulatory framework.

【 Key terms 】 Green chemistry, Sustainable development, Triple helix

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1. Introduction

The term green chemistry often arouses the curiosity and suspicion as it combines two opposite words which seems oxymoron as it stands. Green chemistry is a new scientific field which focuses on the design, manufacture, and use of chemical processes that could prevent pollution and at the same time improve yield efficiency. What makes it different from previous types of environmental chemistry is that whereas previous approaches focused on managing pollution after it is produced, green chemistry attempts to prevent the creation of pollutants by improving the synthetic procedure of chemical products. The creation of what became known as green chemistry dates from 1991, when the U.S. Environmental Protection Agency (EPA) launched the Alternative Synthetic Pathways for Pollution Prevention research program under the auspices of the Pollution Prevention Act of 1990. The term green chemistry was coined for the program in 1993, and the government began to support it with national research funds and awards thereafter. In particular, the Clinton administration's Reinventing Environmental Regulation Initiative of 1995 and the Technology for Sustainable Environment research grant program co-sponsored by EPA and the National Science Foundation (NSF) were instrumental in catalyzing the rise of green chemistry. And remarkably, the chemical industry also promptly began to participate in promoting green chemistry by applying it in the manufacturing process.

Several scholars of science and technology studies and science and technology policy have studied the birth and development of green chemistry. First, Edward Woodhouse analyzed the goal of green chemistry and concluded it was a social movement that "tries to convince others to make challenges in humanity's policy for chemicals" (Woodhouse & Breyman, 2005: 217). As a political scientist, Woodhouse witnessed the birth and developmental stage of the field and participated in the legislative process of the Green Chemistry Research and Development Act of 2004. Based on his close relationship with green chemistry, he concluded that the goal of green chemistry was not only to add new chemical knowledge to academia, but also to establish a new approach to the way in which chemistry is applied. Scientists' strategies to activate green chemistry were studied by Jody Roberts, who focused on the role of leading green chemists. He concluded that green chemistry was a scientific movement that accompanied such strategies as 1) making an historical narrative of the field; 2) defining the concrete boundaries of the field; and 3) considering the testimony of intellectual leaders regarding the necessity of the field (Roberts, 2006).

Despite the goals and strategies of green chemistry has been studied by pioneering works, there has been a relative lack of empirical research on the political and economic motivations of the field. Step backward from the trials to interpret the meanings of green chemistry, and to analyze the strategy of the field, this research intends to contribute to the empirical studies on the process how various actors from the sectors of academia, industry, and government gradually formed and shaped the field, green chemistry. In other words, this research is to shed light on the different motivations of each sectors, and how the encounters among the motivations reached until it forged the new scientific field as well as new meaning of environmental friendliness. Therefore, the following questions are valid. What specific motivations existed among diverse actors? How were the motivations of these actors interrelated? And what are the implications of environmental friendly characteristic of green chemistry?

This paper focuses on the triple helix – academia, industry, and government which have been prime movers of the green chemistry. Myriads of scholars have shed light on interrelated dynamics of three entities in economic wealth generation or knowledge production (Etzkowits and Leynesdorff, 1997: 191-203; Mowery, Nelson, Sampat, & Ziedonis, 2004). However, environmental science has not been a subject of triple-helix analysis yet, and this research intends to highlight environmental science as a new subject of triple-helix analysis. Since environmental science is one of the most radically emerging scientific field in modern society that interacts with social and political circumstances, triple-helix analysis of the green chemistry would bring empirical evidences how the new scientific fields are formed as well as under which political and social circumstances they were maintained.

This paper argues that academia, industry and government created a common ground not found in the framework of environmental policy before 1990. The rise of new environmental agenda, i.e., sustainable development, enabled the foundation of a 'common ground' capable of satisfying government and industry, both. In addition, chemists who were able to respond to common needs of government and industry by applying their classic research interests played an instrumental role in the creation of the new field, green chemistry. Green chemists produced the knowledge to improve the synthetic efficiency to prevent pollution, and the chemical industry used the results of green chemistry research to increase the economic profitability of the production system. This specific form of alliance was supported and maintained in the context of changing national environmental policy toward a self-regulatory framework, and newly defined the environmental friendliness in accordance with the industrial needs.

2. Governmental Environmental Policy and the Rise of Green Chemistry

For more than a decade after the establishment of the U.S. Environmental Protection Agency (US EPA) in 1970, its main approach to environmental policy remained what has been characterized as "command and control" and "end-of-pipe treatment." The purpose of the initial series of legislative actions and policies was to command the industries to control the emission of toxic waste by managing the pollution after it was produced. Until 1990, when the Pollution Prevention Act was passed, majority of policy agenda or research program was to control and purify the pollution.

The Toxic Substance Control Act of 1976 (TSCA) showcased the "command and control" tactics before the pivotal change in environmental policy. TSCA's primary goal was to regulate the toxic chemicals produced and used in United States. Polychlorinated biphenyl (PCB), asbestos, and lead-based paint were the representative chemicals regulated by this act. However, despite the TSCA's extensive database and scientific approach, it was widely recognized as a failed policy. (Wilson & Schwarzman, 2009) Most notably, although the TSCA clearly stated that "government should have adequate authority to regulate chemical substances that present an unreasonable risk to health or the environment and to take action in imminent hazards," it became too heavy of a burden for EPA to prove the toxicity of every suspected chemical (Nabholz, Clements, & Zeeman, 1997). In 1976, the TSCA managed 62,000 chemicals, but only 1,200 of them could be reviewed in the first 15 years (US EPA, 2003).

The increasing burden for pollution management and pollution control thus led United States government to consider an alternative policy approach. The Pollution Prevention Act of 1990 (PPA) marked the beginning of the shift away from the "command and control" approach to environmental policy (Goehl, 1997: 264-265). The goal of the PPA was not simply to regulate the amount and the kind of pollution emissions, but to manage the entire structure of the industry to reduce the amount of pollution fundamentally. To prevent pollution, the PPA focused on source reduction, defined as the fundamental reduction of the amount of any inputs prior to recycling, treatment, or disposal. The act stated that "source reduction is fundamentally different and more desirable than waste management and pollution control" and "[the] Environmental Protection Agency must establish a source reduction program which collects and disseminates information, provides financial assistance to

States, and implements the other activities."

Soon, "pollution prevention" became a slogan of the national environmental policy. Federal agencies made voluntary goals to reduce their pollution emission by 50% by the end of 1999(US EPA, 1995a: 6). The EPA wrote that "pollution prevention should be the strategy of choice in all that the agency does. […] pollution prevention will be the first strategy considered for all programs at EPA" (US EPA, 1994).

During the Clinton administration, this perspective was amplified. The Clinton administration was interested in a diverse set of environmental issues, including the issue of renewable energy research and development, domestic carbon dioxide emissions, the new Clean Air Act, and the tightening of the toxic waste law (Clinton & Gore, 1992). Most importantly, the Clinton administration believed in abandoning the traditional belief in a trade-off between environmental protection and economic growth. The administration said, "United States economy will depend on developing environmentally clear, energy-efficient technologies" (Vig & Kraft, 2010: 82). The administration established a new Office of Environmental Policy in February 1993 and opened the President's Council on Sustainable Development (PCSD) in June 1993 (Vig & Kraft, 2010: 83).

The administration's philosophy was reflected in President Clinton's announcement of the Reinventing Environmental Regulation Initiative on March 16, 1995. This initiative—the Clinton administration's ambitious new environmental policy to move beyond "command and control"—emphasized that environmental protection and economic, environmental, and social goals should be complementary, not conflicting (Clinton & Gore, 1995: 89-99). The initiative' slogan was "protect more and cost less." To increase efficiency, the initiative promoted pollution prevention. According to the initiative, "pollution is often a sign of economic inefficiency." President Clinton stressed the importance of common sense and active participation of environmental actors to go beyond the prescriptive regulations of the past. The initiative stated that "we have seen both the value and the limitations of command-and-control regulation and end-of-pipe strategies. (…) We have learned that setting 'performance standards' and allowing the regulated community to find the best way to meet them can get results cheaper and quicker than mandating design standards or specific technologies."

The EPA's reaction to the initiative was immediate and clear. It had already agreed that the entire approach to environmental regulation should be changed (US EPA, 1994b), and the policy response for the initiative was a continuous effort to reinvent environmental regulation (US EPA, 1995b: 3). Among the 306 parts of Code of Federal Regulations responsible for the EPA, more than 70% were modified or deleted to respond to the initiative (US EPA, 1995a).

Green chemistry was born in this new policy circumstance related to pollution prevention of the 1990s. The EPA's Office of Pollution Prevention and Toxic (OPPT) founded the Alternative Synthetic Pathways for Pollution Prevention research program in 1991(US Department of Energy, 1993). In 1993, the program was expanded to include other topics, such as greener solvents and safer chemicals; it was renamed Green Chemistry. The role of the OPPT was updated to include a "new mission" to "promote safer designs, wiser use of materials, products, processes, practices and technologies, and disposal methods using pollution prevention as the guiding principle of first choice" (US EPA, 1994c: 91).

To achieve the new principles of the initiative, the administration selected 25 high priority actions to alternate the past environmental policy. Green chemistry was introduced in the initiative under the name of "Design for Environment (DfE)," which was one of the 25 high priority actions. The purpose of this action was to develop the technologies to prevent pollution by "using renewable resources for chemical production, substituting solvents that do not contribute to air pollution and designing new chemicals and chemical process that are more safely made and that are safe for the environment." The government claimed that "design for the environment partnerships with the chemical industry can encourage changes that both promote economic development and benefit the industry by helping find cost effective ways to prevent pollution" (US EPA, 1994c: 93).

The new environmental policy agenda-namely, pollution prevention-changed the details of national environmental policies. Thus, by the early 1990s, the framework of the national environmental policy had changed to give birth to green chemistry. How, then, did academic scientists react to these policies for pollution prevention?

3. Synthetic Chemists as Translators: Inventing Green Chemistry for Pollution Prevention and Efficiency Enhancement

Some chemists had already pointed to the limitations of the "command and control" strategy. For example, several physical chemists said that previous environmental chemistry was limited to an inadequate understanding of natural phenomena with underlying chemical expressions. To overcome this limitation, they insisted that "participation of all chemistry approaches—experimental, theoretical and computational—and of all disciplines of chemistry—organic, inorganic, physical, analytical, and biochemistry—will be required to provide the necessary fundamental understanding" (Dunning & Garrett, 1993). Chemists also claimed that the waste management policy could not solely deal with the huge amount of chemical waste that had been produced from the 1990s despite high social costs (Anastas & Farris, 1994).

At the same time, some environmental chemists also were complaining that academic chemists would not be interested in the field if the "cleaning up is all about it." Although the environmental agenda had changed, environmental chemists faced challenges in maintaining their academic prosperity. First, environmental chemistry thought they were largely discredited as an academic field. Even the highest environmental scientists thought they were discredited because "people working in that field usually were not the ones making contributions to the academic [chemistry] community" (Amato, 1993: 1538-41).

In this transitional state, green chemistry was understood as providing a new approach that differed from the traditional environmental chemistry[1]. Even since before the term green chemistry became popular, some chemists had claimed that they would overcome the "limitation" of traditional environmental chemistry. The new "green chemists" separated themselves from the old environmental chemists. They thought that they were doing fundamentally different research from traditional environmental chemists in a sense that green chemists aspired to solve the environmental problem by using the methodology of "synthetic" chemistry—that is, improving the synthetic procedure of chemicals[2].

One of the principal founders of green chemistry was Paul T. Anastas, who worked in the EPA when the Pollution Prevention Act of 1990 was passed. Anastas earned his doctoral degree in synthetic chemistry and joined the EPA as chief of the Industrial Chemistry Branch. As a director of the green chemistry program, Anastas co-edited one of the first books on green chemistry, *Benign by design*. In this book, he said, "The role of synthetic chemist is crucial toward meeting the goals of both environmental protection and economic growth. (…) While the traditional areas of

1) Green chemistry was introduced to scientists and the general public as a new field compared to traditional environmental science. See Ember, L. (1991), "Strategies for Reducing Pollution at the Source are Gaining Ground" *Chemical Engineering News*, (July 8), pp. 7-16; Illman, D. (1993) "Green technology presents challenge to chemists", *Chemical Engineering News*, (Sept. 6), pp. 26-30; Rotman, D. (1993), " Chemists map greener synthesis pathways" *Chemical Week*, (Sept. 22), Vol. 153, pp. 56-57.

2) Synthetic chemistry is an approach in chemistry that deals with synthetic procedures of target molecules from the reactant materials. Synthetic chemists are interested in the investigation of new synthetic methods of specific molecules and discovering new catalysts to increase the manageability of chemical reactions.

environmental chemistry, such as analytical and atmospheric chemistry, will always play an important role it is crucial that synthetic now be associated with the avoidance of environmental problems. (…) Synthetic chemists are the only ones capable of instituting this fundamental change." In sum, green chemists were "synthetic" chemists who had not been regarded as environmental chemists in the past but who sought to separate themselves from "academically discredited" traditional environmental chemists by using synthetic chemistry as a new tool (Anastas & Farris, 1994: 2).

At the same time, green chemists emphasized that the field is both for industrial-social needs and academic community's needs. Anastas wrote that "this area of research meets both the chemical industry and society's needs in developing the concept of pollution prevention and the academic community's need to focus on basic research. The next generation of synthetic chemists will certainly be focused on how to build new chemical structures but they will also be incorporating all of the impacts, scientific, economic and environmental, into their selection of how to make the chemical product." In detail, Anastas defined the three basis of green chemistry – efficiency, economic viability, and environmentally benign – and assured that green chemistry "should be the option of first choice which is built into the earliest stage of planning to manufacture a chemical product" (Anastas & Farris, 1994: 20).

Whereas the Pollution Prevention Act of 1990 was the initiator of green chemistry, the Clinton administration's Reinventing Environmental Regulation of 1995 was an amplifier of the field. With the initiative, the EPA's Office of Research and Development launched research grant programs in collaboration with the National Science Foundation (NSF), entitled Technology for a Sustainable Environment (TSE), to support green chemistry (US EPA, 1996a). TSE was good chance for many chemists—especially synthetic chemists—to bring new perspectives to environmental issues. In 1995, the EPA and NSF awarded 4.5 million dollars for 19 research projects. With this grant, "green" issues became a matter of interest to chemists from numerous fields who shared an interest in sustainable technology. Among the eight research programs supported by the EPA in 1995, three were in organic chemistry (one each in inorganic, bio, and analytical chemistry) and two were in physical chemistry. Three of the research grants focused on solvent replacement, three were for new chemical processes, and two were for the development of new catalysts.

TSE's impact was not limited to budget allocation. The project's research activities were part of the process that drew the boundary between green chemistry and non-green chemistry as well as sustainable technology and non-sustainable technology, as the name of the funding program indicated. TSE research grant recipients and researchers in green chemistry demonstrated how green chemists stabilized the ground of the field by adapting the idea of sustainable development into chemists' term.

For example, the new concept of "atom economy" was one of the bridges between the concepts of sustainable development and chemistry. Atom economy was first suggested by Barry M. Trost and further developed by his postdoctoral fellow Li-Chao Jun. Before the development of the atom economy, the only factor to evaluate the efficiency of the chemical reaction was the yield of the reaction. According to Trost, atom economy was new criterion to overcome the limitation of the yield concept (Trost, 1991). He insisted that yield was not a rational criterion by which to evaluate the fundamental efficiency of the reaction because it was not affected by the loss incurred by side products. If the reaction produced unnecessary side products, it was not efficient, even if it had an extremely high yield. In the atom economy, the ratio between the used number of atoms and the number of atoms in the useful products was important. In other words, high atom economy was possible only if unnecessary side products were not produced.

Trost's idea to introduce the atom economy was closely related with his life-long research topic, the metathesis reaction. Metathesis reaction is chemical synthetic pathway that produces the target molecules by rearranging the carbon-carbon chemical bonds. As the metathesis reaction only accompanies the reassembling of the reactants, it does not produce the 'side materials' that are generally produced in other kinds of chemical reactions. Atom economy was the concept which could highlight Trost's research interest as well as fit for the general claim of green chemistry.

Jun, follower of Trost, researched metathesis reactions for several years under the TSE program, insisting on the importance of the metathesis reaction for the atom economy. He received TSE funding four times from 1997 to 2003, totaling $860,000 in research funds, and published 84 academic papers and two books. He consistently investigated the formation of the carbon-carbon bond in alternative media (e.g., water) using metathesis reaction. As a postdoctoral fellow in Trost's laboratory from 1992 to 1994, Jun had the chance to get used to the concept of atom economy intensively. Among the several ways of achieving the high atom economy, he had focused on metathesis reaction and began to publish academic papers about carbon-carbon bond formation (Jun, 1993). In his TSE research, his idea was to "use water as solvent for various chemicals and pharmaceutical syntheses to achieve a win-win situation both for the chemical/pharmaceutical industries and the environment" (Jun, 2000). His new solvent system and new synthetic method earned him the Presidential Green Chemistry Challenge Award in 2001. His work led to metathesis reaction becoming a part of green chemistry to bolster the identity of the field, and the problem of atom economy becoming a focal issue of green chemistry. Metathesis chemists such as Yves Chauvin, Richard Schrock, and Robert Grubbs received the Nobel Prize in Chemistry in 2005, which was deemed to be a great step forward for green chemistry.

Not only metathesis researchers, but also many catalyst chemists began to think about the possibility of their participation to green chemistry. Two catalyst chemists, Ryoji Noyori and Karl Barry Sharpless—two of the three winners of the 2001 Nobel Prize in chemistry—worked with green chemistry. Noyori, for example, was a leading chemist in the hydrogenation reactions method. A hydrogenation reaction adds the hydrogen atom into unsaturated chemical bonds, generally producing molecules known as optical isomers, which are twin molecules that have the same chemical formula but have different geometrical shapes, like the relationship between the right hand and the left hand. As a synthetic chemist, Noyori developed catalysts and solvent systems of hydrogenation reaction that can selectively produce the target molecule, thereby helping to increase the efficiency and efficacy of hydrogenation reaction[3]. His recent work mentioned green chemistry as the most important field for future chemistry (Noyori, 2005). Noyori wrote that "chemists need new catalytic systems affecting perfect chemical reaction that give only the desired products, with 100% selectivity and 100% yield without unwanted wastes" (Noyori, 2001: 343). He further declared that, "long before Green Chemistry received proper appreciation, the Noyori research group had already consistently focused on molecular catalysis and, consequently, contributed in many ways to the progress of modern chemistry directed toward this goal" (Noyori, 2003: G37).

Meanwhile, Sharpless, another winner of the 2001 Nobel Prize in chemistry, researched organic oxidation reaction in water using a TSE research grant in 2000. He received a $540,000 research grant from TSE and published 22 research articles as a result of the grant. Sharpless developed a foundation of knowledge that was potentially useful for green chemistry. His articles were published in mainstream academic chemistry journals such as *Angewandte Chemie International Edition, Journal of American Chemical Society, Journal of Organic Chemistry, and Organic Letters*-not in *Green Chemistry* or other journals for environmental studies. In one of his articles published in 2001, he wrote that "it is hard to ignore water as a solvent. Beyond being environmentally benign, its extraordinary physical

3) See http://nobelprize.org/nobel_prizes/chemistry/laureates/2001

properties are widely appreciated" (Sharpless, 2001: 7945). His focus was not the environmentally benign characteristics of water, but its physical properties, such as polarity, catalytic character, and solubility, as a unique solvent.

Anastas' twelve principles of green chemistry, created in 1998 to define the research in the field, demonstrate that efficiency improvement was essential for green chemists in light of what they had done and what they would do. These principles—prevention; atom economy; less hazardous chemical syntheses; safer chemicals, safer solvents, and auxiliaries; design for energy efficiency; use of renewable feed stocks; reduction of derivative; catalysis; design for degradation; real-time analysis for pollution prevention; and inherently safer chemistry for accident prevention—were much more detailed compared to his own three definition of the basis of green chemistry made in 1994 in his book. Consequently, the principles reflected the vision of the research that green chemists wanted to do[4]. Except for the principles on safety, most of the principles (e.g., atom economy, design for energy efficiency, use of renewable feed stocks, reduce derivatives, and catalysis) focused on enhancing efficiency. For example, Trost suggested the concept of atom economy in his article, writing that "a key goal must be synthetic efficiency in transforming readily available starting materials to the final target." To achieve a high atom economy, Trost suggested several types of chemical reactions, such as hydrogenation, metathesis, and cylco-addition. Each reaction was atom economic;

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4) Judy Roberts also determined that the twelve principles of green chemistry were 1) a summary of work that had already been done and 2) a guide for the direction in which green chemistry will go in the future. See Roberts, J. (1996) 86-96.

the products of each reaction could contain most of its raw material and had high yield productivity (Trost, 1991: 1471).

The importance of atom economy in green chemistry was more than one of principles. Anastas wrote that "the foundation of the principles of green chemistry is that of atom economy" (Anastas & Williamson, 1996: 13). In addition, the atom economy provided the foundation for other principles. Principles of green chemistry were often justified in the goal of high efficiency for target chemical reactions as defined by atom economy. For example, the principle of catalyst was rooted in atom economy. Like Jun's TSE research project and Noyori's catalyst research, various kinds of catalyst research—including asymmetric catalysis, solid acid catalysis, bio catalysis, heterogeneous catalysis and phase transfer catalysis—were regarded as part of green chemistry.

In 1999, the journal *Green Chemistry* was created by Royal Society of Chemistry (RCS). The very first paper appearing in the first volume showed that the goal of sustainable development was well intertwined with the mission of green chemistry. The author, James Clark, wrote that the "green chemistry revolution" had "opportunities to discover and apply new chemistry to improve the economics of chemistry manufacturing and to enhance the much-tarnished image of chemistry." And, he noted that the features of the ideal synthesis were changing, so that the goal of synthetic chemistry and green chemistry was not only the "discovery and development of new synthetic pathways using alternative feed stocks or more selective chemistry," but also "a combination of a number of environment, health and society, and economic targets" (Clark, 1999: 2).

4. Chemical Industry and Green Chemistry

The winning of the Noble Prize by researchers like Noyori, Sharpless, and Robert Grubbs in 2001 and 2005 was a sure sign that green chemistry was rapidly gaining recognition as one of the most promising fields of research in chemistry, and the mission of green chemistry was becoming more concrete by using traditional synthetic chemists' research goals—enhancing the efficiency. Moreover, it was the chemical industry who promptly became a user of green chemistry, resulting in numerous concrete industrial applications.

The chemical industry had every reason to welcome the advent of green chemistry. Rachel Carson's *Silent Spring*, whose publication in 1962 is usually credited with launching the modern environmental movement, provided an eloquent indictment of hazardous chemicals (Guha, 2000; Hays, 2000; Walker, 1994; Stoll, 2007). The Pesticide Control Act of 1972 and Toxic Substance Control Act of 1974 were some of the direct outcomes of the fear of deadly chemicals poured into the land. In fact, it is only a slight exaggeration to say that the EPA itself was created in order to deal with the chemical industry. It was important for companies to obey environmental regulations as well as to claim to stand for environmental protection at least apparently.

From the beginning, green chemists considered industry to be their main audience. Green chemists promised a win-win situation to both the chemical industry and the environment. In *Benign by Design*, Kenneth G. Hancock of the National Science Foundation wrote that, "for the United States, the crux of the problem is that economic growth and environmental quality are now both at risk [….] Economic competitiveness and environmental quality are intertwined—they can be mutually addressed in a win-win approach." He added that "we must shift from an atmosphere of regulation and litigation to one of designed minimization of environmental impact" (Anastas & Farris, 1994: 30).

Meanwhile, the government also encouraged the participation of industry in developing concrete applications of green chemistry. In 1995, as a part of the Reinventing Environmental Regulation Initiative, the Clinton administration founded the Project XL (Excellence and Leadership). Project XL bridged green chemistry and industry by encouraging the latter to adopt new environmental technologies. It also promoted the self-regulation of facilities that had previously passively obeyed national environmental requirements. As such, it intended to "provide more flexibility for those 'good actors' and environmental leaders that have developed creative, common sense ways of achieving superior environmental protection at their facilities."[5] In this program, innovative technologies for the environment could be tested by the companies that voluntarily participated to make manufacturing processes "greener".[6] Until 2000, approximately 500 companies, small businesses, and local governments participated in this experimental partnership. The EPA found that, "for five years, these experiments have enabled our society to explore fundamental new approaches to environmental

5) Federal Register, 60 (May 23, 1995), 27282.
6) Federal Register, 63 (June 23, 1998), 34164.

protection […] we have been using pilot projects to test bold new ideas that promise better results for the future" (US EPA, 2000). According to the EPA, "a possible XL project may involve the use of green chemistry that would make a production process cleaner and reduce the regulatory burden that would be required of the production facility."[7)]

Further evidence of the conscious and deliberate alliance formed among the government, chemists, and chemical industry was provided by the Presidential Green Chemistry Challenge Award founded in 1995, which encouraged industries to adapt and develop green chemistry. The purpose of the award was to "promote pollution prevention and sustainable development through a new Design for Environment (green chemistry) partnership with the chemical industry" (US EPA, 1996c). The challenge offered five awards: the Academic Award, Small Business Award, Greener Synthesis Pathways Award, Greener Reaction Condition Award, and Design Greener Chemicals Award (US EPA, 2009). Except for the Academic Award, the awards went to industrial firms.

Most of the chemical companies that received awards gained economic benefit by increasing the productivity of the manufacturing process. For example, the Merck Corporation, one of the world's biggest chemical firms, was nominated for a Greener Synthesis Pathways Award in 2005 and 2006; both achievements stemmed from Merck's new synthetic pathway for the synthesis of drugs. The company developed a new asymmetric hydrogenation catalyst that increased the yield of synthetic process of Sitagliptin by

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7) Federal Register, 63 (June 23, 1998), 34170.

nearly 50%; it further adapted the new process in the synthesis of Emend, eliminating approximately 41,000 gallons of waste for every 1,000 pounds of the drug produced. The other international chemical firms that won the competition were BASF, Dow Chemical Company, DuPont, Pfizer, Bayer, and Monsanto. Bayer won the Greener Reaction Condition Award in 2000 and the Greener Synthetic Pathways Award in 2001 for developing an alternative agent of organic feed stocks to water-based non toxic agent (US EPA, 2001). Pfizer improved its Zoloft production line, doubled product yield, and reduced the use of raw materials by 20-60%, winning the 2002 Greener Synthesis Pathways Award. Monsanto received the first Greener Synthetic Pathways Award in 1996 for increasing the yield of the Disodium iminodiacelate (DSIDA) synthesis process (US EPA, 1996b).

With green chemistry, chemical companies could be certified as sustainable and environmentally friendly. For example, Presidential Green Chemistry Challenge Award winners were presented to Congress as environmentally friendly companies. Imation Corporation, which received the award in 1997, was introduced to Congress by Representative Bill Luther (D-MN) because the company was based in Minnesota. He praised the Imation Corporation, saying that "Minnesota has a long and proud tradition of finding ways to improve our way of life while protecting and nurturing our natural surroundings. I am very pleased to bring their success to the attention of the House and to congratulate them on their achievement."[8] In this case, Imation Corporation became a

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8) Congressional Record—Extensions of Remarks, (1997),

symbol of environmental protection of the Minnesota in the name of green chemistry.

Presidential Green Chemistry Award winners were also used in the legislative process to give companies or chemicals justification for being regarded as environmentally friendly. During the debate on the legislation of Antimicrobial Regulation Technical Correction Act of 1998, the technical problem of deciding the toxicity of the material was important because the act sought to correct the technical problem of the Food Quality Protection Act of 1996 by excluding the antimicrobial chemicals from the category of pesticides.[9] Supporters of the act insisted that the Food Quality Protection Act of 1996 changed the definition of pesticide chemicals, resulting in the regulatory jurisdiction of antimicrobial being moved from the Food and Drug Administration to the EPA. As a result, some antimicrobial chemicals were regulated as pesticides. Supporters thought that the Food Quality Protection Act of 1996 was outdated and required technical correction. According to Representative Eva M. Clayton (D-NC), "since the passage of the Food Quality Protection Act, pending petitions for antimicrobial food additive petitions have been put on hold at the FDA. (…) One such petition that is still waiting for production is a new 'slimicide' for papermaking usage. This item had previously received the President's Green Chemistry Challenge Award. It has been identified as a safer chemical than what is on the market today."[10] The act was signed into law by President Clinton on October 30,

9) Congressional Record—House (1998a),

10) Congressional Record—House (1998b: E2197-E2198).

1998.

In sum, green chemistry was rapidly adopted by the chemical industry, and companies reaped many benefits. First, companies could increase the efficiency of manufacturing process by using catalysts, synthetic pathways, and solvents developed by green chemistry. Furthermore, although enhancing efficiency had been the major interest of the industry, the benefits induced by green chemistry provided additional value in terms of environmental friendliness. Companies that participated in Project XL or received the Presidential Green Chemistry Award were certified as environmentally friendly or sustainable by the government. With the name of green chemistry, companies found a new way to be regarded as 'green' while maximizing their profitability.

For the chemical industry, green chemistry was not only good for increasing efficiency, but also a symbol of its self-regulatory efforts. As an extension of Reinvention Environmental Regulation Initiative of 1995, governmental environmental policy kept a friendly attitude toward the industry; green chemistry provided a buffer between the two. Green chemistry could be used for both the government and industry in their own ways. The Green Chemistry Research and Development Act of 2004, proposed by Representative Phil Gingrey (R-GA) on March 16, 2004, demonstrates the alliance between the regulator and the regulated entities through green chemistry. The goal of the legislation was simple: the formation of an interagency working group to coordinate federal green chemistry research and development activity funded by the NSF, EPA, National Institute of Standards and Technology, and Department of Energy.[11)] Gingrey and other supporters of the act highlighted the advantages of green chemistry, emphasizing national security benefits, workers' safety, and economic growth, among others.

Gingrey said that industry had discovered that environmental and economic advantages could both be achieved by green chemistry. He used Pfizer, Shaw, and Dow—all of which had received the Presidential Green Chemistry Challenge or participated in the Project XL—to emphasize that the state's investment had been economically successful. As a physician who had been trained in chemistry, Gingrey insisted that green chemistry was an alternative to the old "brown chemistry." Representative Eddie Bernice Johnson, another supporter of the act, claimed that green chemistry is an attractive new paradigm of environmental regulation.

> Too often, we romance about the environmental benefit of regulations and other environmentally benign practices without regard to their impact on businesses and the economy. That approach is shortsighted, especially in today's globally competitive environment where even the most minor misguided regulation can drive entire industries overseas. With its potential to provide non-regulatory, economically competitive solutions to some of today's most pressing environmental challenges, green chemistry can be a win-win approach to what is all too often a lose-lose situation.[12]

It is remarkable that the chemical industry supported the act. Dr. Berkeley Cue, vice president of pharmaceutical sciences in Pfizer's

11) Congressional Record, (2004: E369).

12) H.R. 3970, *Green Chemistry Research and Development Act of 2004: Hearing before the committee on science House of Representatives, 108th congress*, (March17, 2004): 18.

global research and development, and Steven Bradfield, vice president of environmental development in Shaw industries, testified in support of the act in 2004. Both companies have previously won the Presidential Green Chemistry Award. Cue insisted that green chemistry is beneficial to the environment and to the economy. After introducing the twelve principles of green chemistry, he said, "the general perception among chemists who are not savvy about green chemistry is that the environmental gain usually comes at an economic cost. We demonstrated that for every principle there is both an environmental and an economic benefit. […] Without a doubt, it has been a win-win proposition for Pfizer." Bradfield raised a similar point, adding that voluntary regulation is effective: "Customer demand and profitability are the most enduring drivers of green chemistry and sustainability. […] The permanence and efficiency of positive change driven by a free market cannot be underestimated. No regulations could have moved our industry so far and so fast in the direction of sustainable development" (H.R. 3970, 2004: 63).

The legislative process illustrated the relationship among government, industry, and green chemists. The linkage between chemical industry and green chemistry was tight enough to let the cadre insist on a non-regulatory environmental policy for sustainable development, and the alliance between the chemical industry and the government was deeply rooted in green chemistry. Green chemistry became a synonym for rational management that could prevent pollution and produce economic benefits; it was no longer separable from the new vision of sustainable development emerging in the industry and the country.

5. Conclusion: Green Chemistry, through or for the Common Ground of Triple Helix

In 2003, the Rand Science and Technology Policy Institute published its report entitled "Next Generation Environmental Technologies (NGETs): Benefits and Barriers" for the White House Office of Science and Technology Policy. At that time, Anastas—the father of green chemistry—was working in the White House Office of Science and Technology Policy as an assistant director for environment. According to the report, NGETs were synonymous with green chemistry: "Next generation environmental technologies for sustainable development focus on the redesign, at the molecular level, of manufacturing process and products so as to reduce or eliminate the use of hazardous materials." Not only was the definition of NGETs similar to the definition of green chemistry, but the report also explicitly focused on the achievements of green chemistry. Most of the report was dedicated to 25 case studies of green chemistry research, and the authors acknowledged the Green Chemistry Institute and American Chemical Society for their help. Although the report mentioned the limitations of green chemistry, it complemented green chemistry with the title of Next Generation Environmental Technologies. Thus, green chemistry became a symbol of sustainable environmental technologies that "play an important role in a new approach to environmental protection" (RAND Science and Technology Policy Institute, 2003: iii).

This article has examined the relationship among governmental environmental policy, industrial participation, and academic activities by green chemists to deliberate on the implications of the emergence of green chemistry. Yet, it has not been able to separate the growth of the field from institutional cooperation in the context of consistent trials for making common ground capable of satisfying three different entities. Academia, the chemical industry, and the government concurrently served as co-developers of green chemistry. In the name of green chemistry, improved efficiency, pollution prevention, and manufacturing process management became a model of sustainable development in the chemical industry. Accordingly, the government promoted the economic benefits of green chemistry to industrialists who hoped to move environmental policy toward a non-regulatory market-based approach incorporating the language of green chemistry. Under the common goal of sustainable development, confrontational entities could find ways to cooperate. Therefore, the making of green chemistry was the making of a common ground.

The emergence of green chemistry has, to a large extent, been due to the fact that academic chemists, chemical companies, and government agencies shared the vision of sustainable development in a business friendly way. As the report of the White House Office of Science and Technology Policy indicated, green chemistry became a prime example of sustainable technology, thanks to the alliance of the academia, industry, and government.

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녹색화학의 출현
: 미국 환경과학의 삼중나선

전 준

녹색 화학은 오염 물질의 배출을 피하면서도 동시에 공정 효율을 향상시키고자 하는 목적 하에 화학 공정의 설계, 운영에 대해 연구하는 새로운 과학 분야이다. 1991년에 처음으로 싹트기 시작한 녹색 화학은 오염물질을 청소하는데 집중했던 기존의 미국 환경 보호청의 정책에서 선회한 행보를 보였다. 이러한 녹색 화학의 형성 과정에 대해 연구한 선행 연구자들은 녹색 화학의 정치, 경제적인 동기에 대해서는 집중하지 않았다. 이 논문은 정부의 환경 정책, 산업계의 참여, 그리고 새로 출현한 녹색 화학자들의 학술 활동 사이의 관계를 보였으며, 이를 통해 녹색 화학의 형성 과정이 보여주는 함의를 알아내고자 하였다. 학계, 산업, 정부는 지속 가능한 발전이라는 폭넓은 정책 목표 아래에서, 녹색 화학을 형성했다. 녹색 화학자는 합성연구의 전통 안에서 합성 효율을 높이는 반응 경로를 연구함으로써 오염물질 배출을 회피할 수 있는 지식을 만들어 내었고, 화학 산업계는 생산 효율성 증가를 통해 경제적인 이득을 얻고자 이것을 적극적으로 도입하였다. 이러한 새로운 형태의 동맹은 오염 회피, 자발적 규제 등의 방향을 선호하였던 미국 정부의 새로운 환경 정책의 흐름 안에서 지원받고, 유지될 수 있었다.

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