The Role of Government Policy in Supporting the Adoption of Green/Sustainable Chemistry Innovations

Series on Risk Management
No. 26

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Sustainable chemistry is a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. The concept of Sustainable Development was established at the 1992 UN Conference on Environment and Development in Rio de Janeiro. It has been further elaborated in 2002 at the Johannesburg World Summit on Sustainable Development. Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes. Within the broad framework of sustainable development, government, academia and industry should strive to maximise resource efficiency through activities such as energy and non-renewable resource conservation, risk minimisation, pollution prevention, minimisation of waste at all stages of a product life-cycle and the development of products that are durable and can be reused and recycled.

Sustainable chemistry is also a process that stimulates innovation across all sectors to design and discover new chemicals, production processes, and product stewardship practices that will provide increased performance and increased value while meeting the goals of protecting and enhancing human health and the environment.

The OECD’s work on Sustainable Chemistry was initiated in 1998. The Issue Team on Sustainable Chemistry was established in 1999 and focused largely on developing guidance for “Establishing Research and Development Programmes in Sustainable Chemistry”. In 2006, the Issue Team established a Sustainable Chemistry Network for information exchange, review of new developments and further elaboration of incentives for sustainable chemistry. In 2007, the Issue Team started to develop a Sustainable Chemistry Platform to serve as a networking resource and a place to disseminate information about workshops, training courses, and other capacity building opportunities (see http://www.oecd.org/env_sustainablechemistry_platform/).

This report was initiated by the OECD’s Sustainable Chemistry Issue Team. Previous work within the OECD attempted to use patent data to better understand innovative activity in sustainable chemistry. However, more information and analysis is needed to understand the dynamics of innovation in this area, especially from the industrial perspective. In order to begin the process in a preliminary way, researchers from the Yale Center for Green Chemistry and Green Engineering and the London School of Economics and Political Science collaborated with the OECD to produce this report on the role that government policy has played in supporting the adoption of sustainable chemistry by the private sector. The report is based on responses to a questionnaire issued to individuals in the chemical industry about their own experiences with and perceptions of green/sustainable chemistry.

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THE ROLE OF GOVERNMENT POLICY IN SUPPORTING THE ADOPTION OF GREEN/SUSTAINABLE CHEMISTRY INNOVATIONS

I. INTRODUCTION

The manufacture, use and disposal of chemical products is a major element of modern life. The chemical industry is estimated to interact with 96% of global manufacturing activities.\(^1\) Chemicals are inputs into almost every supply chain, and innovations from the chemical industry have significant impacts on quality of life. Many of these innovations are distinctly positive—there would not be antibiotics or modern medicine or chemical fertilizers without the chemical industry, for example. But the chemical industry is also heavily resource intensive, and many of the innovations that have improved the lives of billions have also resulted in environmental damage and negative impacts on health and well-being. As a result of both its importance and its impact, the chemical industry has become one of the most regulated, with a nearly exponential increase in the cumulative number of environmental and safety regulations.\(^2\)

Green Chemistry is an approach to chemical synthesis that considers life cycle factors like waste, safety, energy use and toxicity in the earliest stages of molecular design and production, in order to mitigate environmental impacts and enhance the safety and efficiency associated with chemical production, use, and disposal. It takes a life-cycle approach to minimize undesirable impacts that can be associated with chemicals and their production. While many of the ideas and technologies behind Green Chemistry have been around for decades, they were first elucidated as a concept by Paul Anastas and John Warner in the early 1990s, as the concept of Pollution Prevention began to receive increased attention. Anastas and Warner stressed that it is important to anticipate and mitigate potential negative impacts of chemicals and their production processes at the earliest stages of research and development, in addition to later in production, use, and disposal phases.

Anastas and Warner codified the 12 Principles of Green Chemistry (Table 1), which provide a roadmap for anticipating, and potentially avoiding, consequences of chemicals and their production process. Anastas and Warner have also stressed for more than fifteen years that green chemistry innovation can be technically equal or superior to existing chemistry, and financially profitable when commercialized. Despite the promise, there are only a limited number of green chemistry solutions that can be brought to market immediately.\(^3\) That leaves considerable underlying science and engineering required for new green product lines to be investigated and made commercially viable. The result of the paucity of existing technologies means that there are many opportunities for industrial R&D that could lead to profitable new product lines.

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\(^3\) For example, John Warner, one of the leading experts on green chemistry, has estimated that only 30-35% of the greener alternatives needed by the chemical industry currently exist Bardelline, Jonathan “John Warner: Building Innovation Through Green Chemistry”. GreenBiz.com, October 18, 2010. http://www.greenbiz.com/blog/2010/10/18/john-warner-building-innovation-green-chemistry?page=0%2C1
Over the past fifteen years, awareness of the concepts of green chemistry has grown. In many countries this has been mainstreamed within more general efforts to ‘green’ the trajectory of the economy. Many firms, ranging from large, established market leaders to small, innovative start-ups, have engaged in the research, development and commercialization of green chemistry products. However, as noted above, much more needs to be done in basic chemical synthesis and production engineering research before the green chemistry vision becomes the norm. At the same time, increased concern about a variety of environmental, health and safety issues, including climate change, carcinogens, natural resource depletion, and chronic exposures to low levels of potentially toxic substances have resulted in a range of public and private initiatives to deal with these concerns. This includes new regulations affecting the chemical industry, private industrial standards, and voluntary certification programs.

The Twelve Principles of Green Chemistry

1. **Prevention**
   
   It is better to prevent waste than to treat or clean up waste after it has been created.

2. **Atom Economy**
   
   Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. **Less Hazardous Chemical Syntheses**
   
   Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. **Designing Safer Chemicals**
   
   Chemical products should be designed to effect their desired function while minimizing their toxicity.

5. **Safer Solvents and Auxiliaries**
   
   The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

6. **Design for Energy Efficiency**
   
   Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

7. **Use of Renewable Feedstocks**
   
   A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. **Reduce Derivatives**
   
   Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. **Catalysis**
   
   Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. **Design for Degradation**
    
    Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. **Real-time analysis for Pollution Prevention**
    
    Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. **Inherently Safer Chemistry for Accident Prevention**
    
    Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

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4 For example, the European Association for Chemical and Molecular Sciences (EuCheMS) recently presented to EU headquarters a few weeks ago and specifically the Roadmap “Developing solution in a changing world” here attached. See http://www.euchems.org/News/EuCheMS_Chemistry_Changing_World.asp.


There are several studies that have tried to illuminate the scientific, policy and economic factors that both drive and hinder green chemistry innovations\textsuperscript{7}. Previous work within the OECD attempted to use patent data to better understand innovative activity in this area. However, more information and analysis is needed to understand the dynamics of green chemistry innovation and commercialization, especially from the industrial perspective.

To begin the process in a preliminary way, researchers from the Yale Center for Green Chemistry and Green Engineering and the London School of Economics and Political Science collaborated to produce this report on the role that government policy has played in supporting adoption of sustainable chemistry by the private sector. The report is based on responses to a questionnaire issued to individuals in the chemical industry about their own experiences with and perceptions of green/sustainable chemistry. Section II of this report details the means of implementation. Results are presented in section III, and finally, implications and conclusions are discussed in section IV.

II. IMPLEMENTATION OF THE QUESTIONNAIRE

Researchers at the Yale Center for Green Chemistry and Engineering, in collaboration with the London School of Economics & Political Science, issued a questionnaire to chemical industry representatives from OECD countries and beyond, in order to get a broad perspective on their view of the current state of green chemistry innovations in industry, future prospects, and the different roles that government policy plays, now and in the future. The Sustainable Chemistry Issues Team, of the Working Party on Chemicals, Pesticides and Biotechnology reviewed the questionnaire.

The objective was to collect the opinions and experiences at the individual, as opposed to the firm or sector level. The survey was conducted electronically, via SurveyMonkey, between January 15 and May 1, 2011. More than 600 chemists received the survey, which included contacts from the Yale Centre’s previous work, members of industry associations and multistakeholder organisations in OECD and emerging economies.\textsuperscript{8} Many of the associations and organisations contacted could be said to have an active


\textsuperscript{8} AIChE Sustainability Institute; American Chemical Society Green Chemistry Institute international chapters; California Green Chemistry Initiative; European Catalyst Manufacturers’ Association; European Chemicals Industry Association; European Fermentation Group; European Renewable Resources and Materials Association; Great Lakes Green Chemistry Network; Green Chemistry Centre of Excellence (University of York); Guangdong Provincial Government Department of Science and Technology; Industrial Green Chemistry World (IGCW); Lille Conference on Greener Chemistry; Michigan Green Chemistry Roundtable; American Chemical Society Green Chemistry Institute Cleaning Products Roundtable.
interest in promoting green chemistry, a point which must be borne in mind. In addition, other groups of firms and individuals interested in green/sustainable technology in the chemical industry were contacted.9

The final sample includes 146 respondents from firms with headquarters in 22 different countries. In principle this indicates a response rate of just under 25%. However, while the majority of the responses originate from invitations that were sent via email to specific contacts, some respondents received the survey link from one of several groups who emailed their membership directly. As such, we do not have an exact figure for the number of chemists who were contacted, and the actual response rate is therefore lower.

Moreover, the survey was completely anonymous, so while the invitation to participate was sent to multiple individuals in some firms, no data is available on whether multiple individuals from any given firm are in the sample. However, the survey was meant to probe the experiences and opinions of individual chemists.10

Given the nature of the questionnaire it is assumed that a majority of the respondents have experience, or at least some knowledge, of green chemistry. As such, we expect that on average, the respondents to this survey are more familiar with green chemistry than a random sample of individuals within the sector. For this very reason, it must be also emphasised that this is not a representative sample of officials within the chemical industry as a whole.

III. RESULTS

Background Data on Respondents

The survey respondents were employees of firms with headquarters in 22 different countries at the time of response. 125 respondents were employed in firms that are headquartered in OECD countries, while the other 20 were from firms based outside of the OECD (see Figure 1).11 There are 24 responses from countries which are members of the European Union. There is significant over-representation of respondents of firms from the United States and this must be borne in mind.

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9 Members whose information was publicly available via industry association websites: Norwegian Bioindustry Association, The Association of Swiss lacquer and paint industry, Turkish Chemical Manufacturers Association (TCMA), Swiss Industrial Biocatalysis Forum, Cefic -European Chemical Industry Council, Polish Chamber of Chemical Industry, The Association of Chemical and Pharmaceutical Industry of the Slovak Republic, Association of the Chemical Industry of the Czech Republic, Hungarian Chemical Industry Association, Brazilian Chemical Industry Association, Israel SOCMA FACS Lifetime Members, European Association for Chemical and Molecular Science.

10 All results are presented in terms of chemists’ responses, and should not be taken as a sample that represents the make-up of the chemical industry as a whole.

11 One respondent did not provide a response.
The respondents were employed in firms that span the range of chemical manufacturing (see Figure 2), including basic chemicals, paints and coatings, fertilizers, and pharmaceuticals. Respondents reported that the companies with which they are associated also varied widely in size (see Figure 3): 27% of the firms had 100 employees or less and 26% reported more than 25,000 employees. Of these firms, 64% produce primarily for the domestic market, and 36% produce products primarily for export. The firms were nearly evenly divided between publicly held and privately held- 51% were employed by firms listed on a stock market, and 49% were employed by firms that are not listed13.

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12 “Where is your company headquartered?” N = 146
13 “Is your firm listed on the stock market?” N=140
Figure 22. Firm Activity by Sector

- Basic
- Feedlots
- Fats
- Fertilizers
- Ferts
- Paints & Coatings
- Soap & Detergents
- Pharmaceutical
- Other

Figure 23. Firm Size

- 1-100
- 101-250
- 251-500
- 501-1000
- 1001-2500
- 2501-5000
- 5001-10000
- Over 10000

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14 “In which of the following sub-sectors is your firm active? Please check all that apply.” N = 138

15 “Approximately how many employees are in your firm?” N=142
Market Context

Individuals from the chemical industry and academia have emphasized that industry will only pursue green chemistry approaches so long as it produces competitive and therefore potentially profitable products. This point was echoed in many of the open-ended responses provided by respondents. But it is less clear how the profitability of those green chemistry products compares to more conventional product lines. Respondents to the questionnaire believe that in the majority of cases, green chemistry products are as profitable (44%), or more profitable (34%) than conventional products (see Figure 4). Only 9% felt that green chemistry products were generally less profitable than other products. However, the responses raise the question of whether there is need for specific government intervention in this field, at least for existing product lines.

Figure 24.  Perceived Relative Profitability of Green/Sustainable Chemistry Related Product Lines

The responses related to firm turnover are also revealing. Respondents were asked to estimate the percentage of their firm’s turnover from green chemistry products over the past three years. The median estimate was 11-15% of turnover, but 12% of respondents reported that 100% of their turnover comes from their green/sustainable products (Figure 5). The data suggest that for most of the firms in this sample, green chemistry product lines may be a small sub-set of their business. But there are also a non-trivial number of firms whose employees believe that the company bases most, if not all, of their products on green chemistry. Only a small number (8%) reported no turnover from green chemistry product lines. This is certainly a reflection of the bias in the sample towards employees of firms with a degree of specialisation in product lines that could be said to be green.

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16 “For your firm, are green/sustainable chemistry-related product lines [less profitable than / about the same as / more profitable than] other product lines?” N = 116
In order to better understand the views of the respondents on the future outlook of green chemistry, opinions were sought on likely change in market share over the course of the next ten to twenty years. 87% of respondents believe that the share of turnover for these products will increase, including 42% who predicted a significant increase (see Figure 6).

17 “Over the past three years, approximately what percentage of your turnover relates to green/sustainable chemistry products?” N = 113
Developing the Next Generation of Products: Research and Development

Do the respondents feel that industrial R&D investments in their firms are targeted at developing green chemistry products? While just over two-thirds (68%) of respondents report that their firms are probably spending less than 50% of their R&D in this area, 23% reported spending above 75% and only 6% reported no R&D investment in this area at all. The median R&D expenditure, as a percent of overall R&D, was in the 11-15% range (Figure 7).

All but two of the 12 respondents reporting that their R&D is entirely focused on green chemistry had less than 500 employees. The majority of respondents from the largest firms (>5,000 employees) reported that their company is devoting less than 30% of its R&D expenditures to green/sustainable chemistry, with only a few spending more than 50%. Since the larger firms are more likely to have a diverse product line, this is not surprising.

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18 “For your firm, how do you foresee the share of green/sustainable chemistry-related products, in terms of total turnover, changing in the next 10-20 years?” N=119
As one would predict, respondents who perceive a greater market potential for green chemistry in the coming years report that, on average, their company is investing significantly more in R&D in this area. Respondents who agreed that the potential market for green chemistry is greater than the chemistry market as a whole reported a median R&D investment level of 21-30%, while respondents that viewed green chemistry as an area with less potential than the chemical industry as a whole reported a median R&D investment of 6-10% (Figure 8).

19 “Approximately what percentage of your research and development expenditures over the last three years relate to green/sustainable chemistry?” N=96
A second important element of understanding R&D for green chemistry innovation is understanding the sorts of issues that green chemistry investments might address. Respondents were asked to rank the potential that different green/sustainable chemistry products have to provide solutions to a range of environmental problems, with 1 being the least potential and 7 being the greatest potential. The respondents ranked “reduction in toxic and hazardous substances” as the area where green chemistry has the most promise (median ranking of 6), followed by “natural resource conservation” and “waste management” (both with a median ranking of 5). “Climate change mitigation”, “air pollution abatement” and “water treatment” had median rankings of four, while “soil reclamation and bioremediation” was ranked the lowest (median of 2).

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20 For all “whisker” style plots, the boxes represent the central two quartiles (the 25-75% range); the dotted lines the range of minimum and maximum values, and the dots or bold lines the median value for each answer.
Assessments of R&D investment is partially based on the market potential for the resulting innovations (or the commercial risk) and partially a calculation of the research risk (or technological risk). The majority of respondents reported that they felt that commercial and research risk for green chemistry products is approximately the same as for other products. A somewhat higher percentage of respondents saw commercial risk as being greater rather than less for chemistry than for other fields (Figures 9-10).

Figure 29. Perceived Relative Commercial Risk for Green/Sustainable Chemistry Products

21 “Relative to other product lines, how would you categorize the commercial risk for green/sustainable chemistry products?” N=94
The respondents also provided their opinions about their perception of the factors that influence their firms’ decisions to invest in green/sustainable chemistry. Not surprisingly, the two most highly rated influences mentioned by respondents were customer demand and exploitation of new markets. This is consistent with the view that green chemistry must be economically viable to be adopted.

**R&D: Funding and Collaborations**

Another important aspect of R&D decisions is what sources of funding are available to firms and whether that funding is harder to access for green chemistry R&D than for other product lines. Survey respondents were requested to indicate the relative importance of different funding sources (from 1 to 4). They reported that retained earnings are the most important source for all R&D, followed by conventional external sources (i.e. banks). In the “other sources” category, respondents mentioned government funding and contractual relationships as important sources. Venture capitalist funding and public offerings were ranked as the least important by respondents (see Figure 11).

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22 “Relative to other product lines, how would you categorize the research risk for green/sustainable chemistry products?” N=95
Figure 31. Respondents’ Perception of the Importance of Funding Sources for R&D

40% of respondents that report investing in green chemistry R&D also reported that they face the same difficulty securing funding for green chemistry R&D as other areas. 20% said that it is easier to secure R&D funding for green chemistry, and 27% reported that it is more difficult (see Figure 12).

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23 “For your firm, what are the most important sources of funding for research and development?” N=92.
Many firms collaborate with other companies and/or organisations in the course of R&D. The largest number of respondents reported that their firm collaborates with universities (73%), followed by suppliers (56%) contract/private research (53%), government agencies and public research institutes (53%), and customers/clients (53%). More than half have collaborated with other firms in their sector (52%), 41% reported collaborations with firms in other sectors, and 38% have collaborated with non-governmental organisations (NGOs). For 86% of the respondents, collaboration on green chemistry R&D does not differ from their collaborators on other, conventional products.25

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24 “How difficult is it to finance research and development for green/sustainable chemistry products relative to other product lines?” N=95

25 “Is this different from your other product lines?” N=95
When a respondent’s firm has collaborated directly with government agencies or public research institutes, the largest share of respondents (35%) reported that they did so through research cooperation projects. Nearly as many respondents (32%) have engaged in information sharing, and 16% have collaborated in cost-sharing partnerships (Figure 14).

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26 “In the development of green/sustainable chemistry products, please indicate with which of the following groups you have collaborated.” N=91
The Public Policy Context

Survey respondents indicated that government policies and programmes are an important factor in decisions to invest in green chemistry. There are several different kinds of policy measures that could have an influence. The first is policy support for R&D through public-private collaboration. As noted previously, when a respondent’s firm has collaborated directly with government agencies or public research institutes, the largest share of respondents (35%) reported that they did so through research cooperation projects. Nearly as many respondents (32%) have engaged in information sharing, and 16% have collaborated in cost-sharing partnerships (Figure 15).

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27 “If you have collaborated with government agencies or public research institutes, please describe the nature of the relationship (Please check all that apply).” N=84
Programs like the US EPA’s Design for the Environment (DfE) were cited in the open-ended responses as examples of policies that have had a positive impact on the development and adoption of green/sustainable chemistry innovations. Other countries, such as China and France, have been expanding the funding budgets for green chemistry innovations in recent years.

The questionnaire asked respondents to assess the transparency and stability of the environmental regulatory framework affecting their firm. Previous work at the OECD (2011) has indicated that flexible and stable policy regimes are key factors in inducing environmental innovations. As such, respondents were requested to indicate whether they felt that regulatory regimes were transparent and stable. In this case (Figure 16) the median response is in the middle of the range of possible responses. This was also the case, when requested to indicate whether respondents felt that the regime provided a degree of flexibility in terms of implementation (Figure 17). However, the distribution of responses is somewhat more to the right, indicating that overall this may be less of a concern than a lack of policy stability and transparency.

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28 “If you have collaborated with government agencies or public research institutes, please describe the nature of the relationship (Please check all that apply).” N=84


Figure 36. Regulatory Context: Perception of Transparency and Clarity of Regulations in Your Main Markets\textsuperscript{31}

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{figure36}
\caption{Regulatory Context: Perception of Transparency and Clarity of Regulations in Your Main Markets\textsuperscript{31}}
\end{figure}

\textsuperscript{31} “How would you describe the environmental regulations which your firm faces in its main markets?” N=93

Figure 37. Regulatory Context: Perceived Flexibility to Comply with Regulation in Main Markets\textsuperscript{32}

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{figure37}
\caption{Regulatory Context: Perceived Flexibility to Comply with Regulation in Main Markets\textsuperscript{32}}
\end{figure}

\textsuperscript{32} “How would you describe the environmental regulations which your firm faces in its main markets?” N=93
Previous work\textsuperscript{33} has also found that policy regimes that are fragmented across different jurisdictions discourage the realisation of economies of scale necessary to recoup innovation efforts. In particular, firms that operate in multiple jurisdictions can face a fragmented regulatory landscape. Figure 18 indicates that the majority of respondents whose firms operated in multiple jurisdictions reported a high degree of regulatory fragmentation. When regulatory requirements differ significantly across jurisdictions, producers may be required to engage in potentially costly customization of products and compliance systems.

\textbf{Figure 38. Regulatory Context: Perceived Regulatory Fragmentation Among Main Markets}\textsuperscript{34}

However, the extent to which firms have difficulty adjusting to a variety of different regulatory frameworks is a function of their degree of exposure. Firms that rely mainly upon export markets are more accustomed to dealing with heterogeneous markets and consumers, therefore a differing regulatory landscape may be a normal part of doing business and not a disruptive or overly burdensome challenge. Conversely, primarily “domestic” companies may be used to dealing with more homogenous markets, so any regulatory variation is more challenging to deal with.

Efficient and effective policy design requires an understanding of which policy incentives are the most effective at stimulating the development and adoption of green chemistry technologies. The respondents provided their perspectives on which policy mechanisms have had impact in the past. Their responses, shown in Figure 19, indicate that respondents felt that traditional regulatory measures and product standards have a greater influence on their firms’ involvement with green chemistry. However, it must be borne in mind that respondents were not requested to indicate their views on the relative efficiency of different policy measures. The three measures which have direct implications for government


\textsuperscript{34} “In the markets in which you are active, would you describe the regulatory frameworks in different countries as being [generally quite similar in nature, allowing us to market products widely / fragmented, requiring us to develop specific products for each market]?” N=92
expenditures (procurement, prizes and grants) were seen as being less influential, perhaps simply because they are felt to be less prevalent.

Figure 39. **Perceived Importance of Specific Policy Measures to the Development of Green/Sustainable Chemistry**

35 “How important have the following types of policy measures been in encouraging you to develop green/sustainable chemistry innovations?” N=89
Intellectual Property Strategies

One area of particular policy interest for green chemistry innovation is how intellectual property policy impacts decisions to invest. To determine a baseline, respondents reported the frequency with which they employ different strategies for protecting their intellectual property. The two most frequently used strategies were patent, trademark or copyright (one response category), and confidentiality agreements (Figure 20). Trade/industry secrets ranked third, and complexity of design was reported as used least frequently. Compared to conventional innovations, very few indicated that intellectual property protection in the form of patent, trademark or copyright are more important for green chemistry innovations. For all three, the largest number of respondents ranked these strategies as equally important for all innovations. However, a quarter of respondents believe that in the case of green chemistry innovations, patenting is more important that for other products.

Figure 40. Reported Use of Different Strategies to Protect Intellectual Property for Green/Sustainable Chemistry Innovations

Recognizing the importance of patent protection as an incentive for firms to invest in innovations, some countries, including South Korea, Japan, the US and the UK, have introduced proposals for “Fast Track” patent approval for green/sustainable technologies. The rationale behind these proposals is that the “Fast Track” advantage would stimulate companies to invest more resources in developing green/sustainable technologies, and also to seek patent protection more often. However, only a small majority of respondents to the questionnaire felt that “Fast Track” policies would lead to an increase in resources spent on R&D (52%). 54% reported that patent protection would increase the number of patents.

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36 “How frequently do you adopt the following strategies in your efforts to protect your green/sustainable chemistry innovations?” N=89

they would file. Once Fast Track programmes have been in place for some years it should be possible to assess their impacts statistically.

**IV. IMPLICATIONS AND CONCLUSIONS**

This project investigated the experiences, perspectives, and future expectations of green chemistry innovations among chemists employed in the chemical industry. The group surveyed is not representative of the chemical industry as a whole, but did span a large number of sectors and geographic jurisdictions.

By virtue of the population to which the survey instrument was directed, the response sample consisted of a large portion of individuals who should be expected to have experience, or at least some knowledge, of green chemistry. Their awareness and familiarity also makes the sample well-placed to respond to questions about which factors drive decisions to invest in R&D of these innovations, and also on the future potential of these technologies, both commercially and environmentally.

The respondents believe that for those green chemistry products that have already entered the market, most are as profitable, or in some cases, more profitable than more conventional products. A majority of respondents indicated that they felt that the share of the market of green chemistry products will increase over the next 10-20 years.

Respondents indicate that there are specific environmental problems for which green chemistry innovation have promise to provide technical solutions. Of the environmental challenges that respondents assessed, they responded that the replacement of toxic and hazardous chemicals is the one where green/sustainable chemistry innovations have the most potential. Natural resource conservation and waste management were also thought to have high potential.

The survey responses also provided insights into several key areas of concern for policy makers. Respondents indicate their companies collaborate with a number of different groups, including government agencies, research laboratories, other firms, and universities. There is obviously a great deal of experience in forming collaborative efforts within the industry. The respondents indicated that in terms of collaboration with government, research cooperation and information sharing were the most common forms of partnership.

As noted, respondents view green chemistry as a growing area and predicted an expansion of production based on these technologies. But achieving increases in turnover requires that firms invest in new technologies and new markets, which can be risky and uncertain. Amongst the different policy specific policy measures, regulatory requirements and product standards were identified in the survey as the most important policy factors in driving investment decisions in green/sustainable chemistry. However, respondents were not requested to assess their perception of the efficiency of the different policy measures.

Another strategy for policy makers that has already been discussed in some countries is “Fast-Track” patent applications for environmentally friendly technologies. Only slightly more than half of respondents replied that this would increase the resources that they devote to R&D in green chemistry, and also would increase the number of patents they would file.

Policy makers should consider what kinds of interventions are likely to have an impact on the development and adoption of green chemistry innovation. This study confirms conclusions stated in previous OECD research on green chemistry patent activity which indicated that government regulation is a driver in decisions to invest in research and development in this area, although respondents felt that purely commercial factors are more important.
While specific incentives, like grants, subsidies, and procurement can have an impact on firm behaviour, the survey also highlighted challenges for policy makers. For example, survey respondents were not able to conclusively identify a clear “winner” among three broad potential technologies for achieving green chemistry innovations. Ensuring a flexible and stable policy regime which allows firms to identify market opportunities over the investment cycle may be the most important policy determinants of investment in green chemistry.
APPENDIX: QUESTIONNAIRE
## Sustainable Chemistry Innovation Efforts

1. **Approximately how many employees are in your firm?**
   - [ ] 1-100
   - [ ] 101-250
   - [ ] 251-500
   - [ ] 501-1000
   - [ ] 1001-2500
   - [ ] 2501-5000
   - [ ] 5001-10000
   - [ ] 10000-25000
   - [ ] More than 25000

*2. **In what country are you located?**

*3. **In what country is your firm headquartered?**

4. **What is the primary market for your firm’s goods and services (Please choose only one)**
   - [ ] For the national market
   - [ ] For the export market

5. **Is your firm listed on the stock market?**
   - [ ] Yes
   - [ ] No
Sustainable Chemistry Innovation Efforts

6. In which of the following sub-sectors is your firm active (Please check all that apply)

- Basic chemicals (ISIC 2011)
- Fertilizers and nitrogen compounds (ISIC 2012)
- Plastic and synthetic rubber in primary forms (ISIC 2013)
- Paints and other paint chemical products (ISIC 2014)
- Paints, varnishes and similar coatings, printing ink and pastes (ISIC 2022)
- Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations (ISIC 2003)
- Pharmaceutical, medicinal chemical and botanical products (ISIC 2003)
- Other chemical products (please specify)

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Sustainable Chemistry Innovation Efforts

1. How do you foresee market potential for 'green chemistry' products over the next 10-20 years? (please check one)
   - Less than for the chemicals sector as a whole.
   - About the same as for the chemicals sector as a whole.
   - Greater than for the chemicals sector as a whole.

2. Over the past three years, approximately what percentage of your turnover relates to green/sustainable chemistry products?
   - 0%
   - 1-5%
   - 6-10%
   - 11-15%
   - 16-20%
   - 21-25%
   - 26-50%
   - 51-75%
   - 76-99%
   - 100%

3. For your firm, are green/sustainable chemistry-related product lines
   - Less profitable than other product lines?
   - About the same as for other product lines?
   - More profitable than other product lines?
   - We do not have any green/sustainable chemistry-related product lines.
Sustainable Chemistry Innovation Efforts

4. For your firm, how do you foresee the share of green/sustainable chemistry-related products, in terms of total turnover, changing in the next 10-20 years?

- Decreasing significantly
- Decreasing somewhat
- Staying the same
- Increasing somewhat
- Increasing significantly
### Sustainable Chemistry Innovation Efforts

1. **For the following environmental challenges, how much potential do you think green/sustainable chemistry products have to provide solutions? Please rank the challenges from 1 to 7, where 1 = least potential and 7 = most potential. Please use each number only once.**

<table>
<thead>
<tr>
<th>Challenge</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change mitigation (e.g. renewable energy, carbon capture and storage)</td>
<td></td>
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<td></td>
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<tr>
<td>Waste management, reduction and prevention</td>
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<tr>
<td>Soil reclamation and bioremediation</td>
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<tr>
<td>Water and wastewater treatment</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Air pollution abatement</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in toxic/hazardous substances</td>
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<tr>
<td>Natural resource conservation (e.g. energy, water efficiency)</td>
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</tr>
</tbody>
</table>

2. **Are there any other environmental problems for which you think green/sustainable chemistry has significant potential?**

3. **In which of the following fields is your firm active? (Please check all that apply)**

- [ ] Industrial biotechnology
- [ ] Materials technology
- [ ] Reaction and process design
- [ ] Other (please specify)

4. **Which of the following fields do you see as being the most commercially promising? Please rank the fields from 1 to 3, with 1 = the most promising and 3 = the least promising. Please use each number only once.**

<table>
<thead>
<tr>
<th>Field</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial biotechnology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials science/technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction and process design</td>
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</tbody>
</table>
### Sustainable Chemistry Innovation Efforts

5. Which of the following fields do you see as being the most environmentally promising? Please rank the fields from 1 to 3, with 1 = the most promising and 3 = the least promising. Please use each number only once.

<table>
<thead>
<tr>
<th>Field</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial biotechnology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction and process design</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Sustainable Chemistry Innovation Efforts

1. For your firm, what are the most important sources of funding for research and development? Please rank the funding sources from 1 to 4, with 1 = the most important and 4 = the least important. Please use each number only once.

<table>
<thead>
<tr>
<th>Source</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retained earnings</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Conventional external sources (e.g. banks)</td>
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<tr>
<td>Venture capital</td>
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<tr>
<td>Public offerings</td>
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<tr>
<td>Other</td>
<td></td>
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</tr>
</tbody>
</table>

If other, please specify ________

2. Approximately what percentage of your research and development expenditures over the last three years relate to green/sustainable chemistry?

- 0%
- 1-5%
- 6-10%
- 11-25%
- 16-20%
- 21-30%
- 31-50%
- 51-75%
- 76-99%
- 100%

3. How difficult is it to finance research and development for green/sustainable chemistry products relative to other product lines?

- More difficult
- Same
- Less difficult
- n/a
### Sustainable Chemistry Innovation Efforts

4. Relative to other product lines, how would you categorize the risk for green/sustainable chemistry products?

<table>
<thead>
<tr>
<th></th>
<th>More risky</th>
<th>Same</th>
<th>Less risky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Sustainable Chemistry Innovation Efforts

1. On a scale of 1 to 7, please rate how important the following factors are in your firm's decision to develop green/sustainable chemistry innovations? Please rate the factors from 1 to 7 with 1 = the least important and 7 = the most important.

<table>
<thead>
<tr>
<th>Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most government regulations</td>
<td></td>
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<tr>
<td>Market our firm brand on the basis of environmental essentials</td>
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<tr>
<td>Respond to demands of our customers and clients</td>
<td></td>
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<tr>
<td>Exploiting new market opportunities</td>
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<tr>
<td>Other</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>If other, please specify</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

2. On a scale of 1 to 7, how would you describe the environmental regulations which your firm faces in its main markets? (1 = confusing and frequently changing, 7 = transparent and stable)

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
</table>

3. On a scale of 1 to 7, how would you describe the environmental regulations which your firm faces in its main markets? (1 = offer no options for achieving compliance, 7 = are flexible and offer many options for achieving compliance)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
Sustainable Chemistry Innovation Efforts

1. Please give an example of a policy or regulation which has had positive effects on your innovation efforts in the area of green/sustainable chemistry.

2. Please give an example of a policy or regulation which has had negative effects on your innovation efforts in the area of green/sustainable chemistry.

3. In the markets in which you are active, would you describe the regulatory frameworks in different countries as being (please tick one)
   - Generally quite similar in nature, allowing us to market products widely
   - Fragmented, requiring us to develop specific products for each market
   - n/a
Sustainable Chemistry Innovation Efforts

1. In the development of green/sustainable chemistry products, please indicate with which of the following groups you have collaborated.
   - [ ] Other firms in the sector
   - [ ] Firms in other sectors
   - [ ] Universities or other higher education institutions
   - [ ] Consultants, commercial laboratories, or private research centers
   - [ ] Government agencies or public research institutes
   - [ ] Clients or customers
   - [ ] Suppliers
   - [ ] Non-governmental organizations
   - [ ] Other (please specify)

2. Is this different from your other product lines?
   - [ ] Yes
   - [ ] No

   If yes, please state why:
   
   [ ]

3. If you have collaborated with government agencies or public research institutes, please describe the nature of the relationship (Please check all that apply).
   - [ ] Research cooperation
   - [ ] Information sharing
   - [ ] Cost sharing
   - [ ] N/A
   - [ ] Other (please specify)
   
   [ ]
# Sustainable Chemistry Innovation Efforts

1. How important have the following types of policy measures been in encouraging you to develop green/sustainable chemistry innovations? Please rate the policies from 1 to 7, with 1 = not at all important, and 7 = very important.

<table>
<thead>
<tr>
<th>Policy Description</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government procurement</td>
<td></td>
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<tr>
<td>Awards or prizes</td>
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<td></td>
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<tr>
<td>Labelling and public information campaigns</td>
<td></td>
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<tr>
<td>Mandatory testing and information provision</td>
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<td>Ozone-depleting substances for product development</td>
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<tr>
<td>Product standards</td>
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<tr>
<td>Regulatory measures</td>
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</tr>
</tbody>
</table>

Are there any other types of policies that have been important in encouraging you to develop green/sustainable chemistry innovations?

2. How frequently do you adopt the following strategies in your efforts to protect your green/sustainable chemistry innovations? Please rate the strategies from 1 to 7 with 1 = never and 7 = always.

<table>
<thead>
<tr>
<th>Strategy Description</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apply for a patent, trademark, or copyright</td>
<td></td>
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<tr>
<td>Confidentiality agreements</td>
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<tr>
<td>Industry secrecy</td>
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<tr>
<td>Complexity of design</td>
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<tr>
<td>Other</td>
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</tr>
</tbody>
</table>

If other, please specify
### Sustainable Chemistry Innovation Efforts

1. Relative to other innovations, how important are intellectual property rights (patents, trademarks and copyrights) in your strategy to protect green/sustainable chemistry innovations?

<table>
<thead>
<tr>
<th></th>
<th>More Important</th>
<th>Same</th>
<th>Less Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trademarks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copyrights</td>
<td></td>
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</tr>
</tbody>
</table>

2. Intellectual property offices in a number of countries (Korea, Japan, US, UK) have introduced "Fast track" proposals for patent applications for green technologies, in order to reduce processing times. Do you think that such measures will...

- Encourage you to devote more resources toward developing green/sustainable chemistry innovations?  
- Encourage you to seek patent protection more often for such inventions relative to other strategies?  

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>Encourage...</td>
<td></td>
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</tbody>
</table>
Sustainable Chemistry Innovation Efforts

1. Is there anything else that we should know about green/sustainable chemistry innovations, based on your firm's experiences?

2. If you would like to receive a summary of the results of this survey, please enter your email address below.

Thank you for participating in our survey. We very much appreciate your time and your thoughtful response. If you have any questions or concerns, please feel free to send an email to greenchemistry@ysle.edu.