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LEM
Working Paper Series

Environmental Technologies in the European Chemical Industry

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2001/09 **May 2001**

ISSN (online) 2284-0400

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May 2001

* We would like to thank Davide Fratini, Alfonso Gambardella and the participants in seminars at University Pompeu Fabra (Barcelona), University Carlos III (Madrid) and University of Stuttgart for helpful comments and useful suggestions on earlier drafts of this report. The research received the financial support of the Commission of the European Communities, TSER Project “From Science to Product”. The usual disclaimer applies.

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Introduction

(R. Arduini and F. Cesaroni)

The ecological question has today assumed great general importance, while the chemical industry has often been accused of being highly responsible for pollution. As a matter of facts, processes of production, distribution and use of chemical products can be very dangerous and some relevant accidents (e.g. Seveso, Bhopal) have contributed to generate a diffuse suspicion against chemicals. For this reason chemical firms, before others, have been highly committed to solve environmental problems.

Since the 1970s, norms of environmental protection have determined a progressive increase of control measures on environment, thus creating greater ties for enterprises. Legislative instruments, particularly "command and control" laws, have become an important constraint for manufacturers.

Another important factor is represented by the market, because consumers are more attentive to the environmental impact of products and production processes. This aspect is becoming more and more important. In the chemical sector this fact has both a direct and an indirect influence, through the "supply relationships". As a matter of fact, the chemical industry supplies many intermediate products that are parts of end products from other industries. And the environmental performance of end products depends on the environmental performance of the entire production line.

In a broad sense, pollution in chemicals is generated from raw materials that are not incorporated in the end product, so that very often "green" products or processes are also more efficient solutions. The prevention of pollution often determines an increase in process efficiency and, in the same way, it can be argued that solutions dictated from economic estimation often generate some positive effects for the environment. These factors have pushed the chemical industry to find new ways to reduce their own environmental impact.

This work aims to pursue two main analysis:

1) how the European chemical industry contributes to the development and the diffusion of environmental technologies;
2) the competitive position of the European chemical industry in environmental technologies, compared with the U.S. and Japanese industries, and the differences amongst European countries.

This analysis will be performed through:

- Bibliographic research;
- Patent analysis (European, and US patent databases);
- Case studies (bibliographical research, business surveying);
- Internet analyses (site exploration, questionnaire).

In the first part (Chapters 1 and 2), we report a survey of the existing literature, with the objective of providing a general exploration of the environmental issue within the chemical sector. In chapter 1, a definition of environmental technologies is provided, by stressing the differences between end-of-pipe, recycling, and clean technologies. This distinction is important both from a technical and a political point of view. On the one side, the three technologies face the environmental problem by following different approaches – i.e., the former aims to *reduce* pollution, while the latter aims to *prevent* pollution. On the other hand, they require different policy interventions. By using this definition, we have analysed the factors that pushed the chemical companies to develop and adopt environmental innovations. In this respect, the roles of market pressures, public opinion, and environmental policies is considered, and the main legislative tools are analysed.

Chapter 2 shows the main features of the models of environmental policy promoted by the US, Germany, UK and Japan. Furthermore, it analyses in depth the specific instruments used in Europe and the US, to purse the development and diffusion of environmental technologies, especially in the chemical industry.

The second part of the report consists of three different analyses, aimed at a better understanding of the processes of development and diffusion of environmental technologies. By using patent information we have investigated the innovative rate of the chemical industry in the environmental field. By using case studies we have examined the reasons that would push or dampen the development and the diffusion of environmental technologies. Finally, by means of an Internet analysis we have analysed the environmental industry, i.e., the sector specialised in the supply of environmental products, services and technologies.

Chapter 3 discusses the results of the patent analysis. We have used two different patent databases, i.e. the US and European databases. This opportunity has allowed us, firstly, to cover the international arena in a more extended and complete way. Secondly, and perhaps even more important, to make some cross comparison between the patenting behaviour of the companies in their origin and foreign countries. Indeed, the innovative behaviour of companies is related to their technological competencies, but the decision to patent in a foreign country depends also on the competitive importance of that country. Hence, this approach allowed us to evaluate the technological strength as well as the technological dimension of different countries.

We have developed the patent analysis following three steps. Firstly, we have considered the situation of the environmental sector as a whole. Secondly, we have analysed the patenting behaviour in this field by the largest chemical and petrochemical companies. And, finally, we have observed the characteristics of the firms that are mostly responsible for environmental innovations.

In chapter 4, we have reported the results of five case studies. The objective of this analysis was to define the forces that drive chemical companies to pursue R&D and innovations in clean technologies and green products. We have looked at the more relevant R&D projects of the five companies, and addressed the following questions: how does (public) financial support influence company innovative behaviour in this sector? How does policy regulation matter? Is public opinion pressure relevant in company decisions? Do companies consider research collaborations, both with research institutes, universities, and engineering firms, useful in innovation development processes? Do companies consider patents and/or licenses a useful tool for innovation diffusion?

In chapter 5, we have analysed the "environmental industry", by collecting relevant information from the Internet. We have firstly looked for specialised Web-sites that were promoted to create a linkage between the environmental industry and other sectors. Then, we have analysed in depth some of the firms listed in those Web-sites, by implementing a specific questionnaire. A special attention has been paid to engineering firms, because of their important catalytic role in fostering the technological change. The objective of the questionnaire was to understand whether the engineering firms offer end-of-pipe technologies, or whether they enlarged their supply portfolio, by including also clean technologies. We have then looked at the characteristics of such firms, in terms of size and diversification, and at the characteristics of the technologies supplied, in terms of degree of standardisation and diffusion. Furthermore, we have aimed to understand the role of chemical companies within the environmental industry.

Chapter 6 concludes the report, and provides some considerations of environmental policy.

Chapter 1
Introduction to environmental technologies

(R. Arduini and F. Cesaroni)

1.1 Definition of environmental technologies

The concept of *environmental technologies* includes a very large range of technologies, and indicates all technological means and interventions whose aim is to reduce or eliminate pollution and environmental degradation. Such category includes both purification and treatment plants, and pollution preventing technologies (Gerelli, 1994). Technologies of the first class do not modify the production techniques, are placed at the end of production processes, and their aim is to transform wastes in less polluting or not injurious products. According to different studies, these technologies are defined “ex-post”, “downstream”, “add-on”, “end-of-pipe”, “au bout de chane” technologies. Even if susceptible of improvements through efficiency enhancing innovations, this group of technologies is very delimited. In the rest of this work, we will refer to them as **end-of-pipe** technologies.

While *end-of-pipe* technologies represent a first level of environmental technologies, a second level is represented by **recycling technologies**, aiming at transforming wastes so that it is possible to re-use them. Recycling process can be pursued either within the chemical process or by other means.

A third class of technologies regards **clean technologies**. These are technologies aiming to prevent the formation of pollution through an *ex-ante* intervention. Prevention is today considered the best method to solve environmental problems. As a matter of fact, both US and European environmental policies underline the importance of the orientation to prevention rather than to purification and reclamation. In general terms, technologies aiming at preventing waste and pollution production, at reducing resource input and the use of energy, and at using recycled material are considered clean technologies. While end-of-pipe technologies are inserted at the end of the production process, clean technologies demand a partial or radical modification of the process, so that the pollution is avoided to the source or it is reduced, thanks to the recovery and the valorisation of wastes.

In addition to clean technologies, **green products** are those products realised with recycled or less harmful input, or products avoiding the formation of pollution or generating less pollution during their life. Examples of green products are fuel without lead, detergents with low content of phosphorus, and biodegradable plastics. However, it has to be emphasised that the term "clean" or "green" has a relative and not an absolute meaning. Clean technologies and products are not absolutely clean, but cleaner than those already existing.

Notice that the boundaries between the various type of technologies are not always strongly delineated, even if, in general terms, clean technologies are more effective and efficient than end-of-pipe, or recycling technologies. There are, for example, new purification plants which apply advanced type of purification processes, which have the advantage of giving marketable under-products. As well as, there are recycling technologies that for some aspects can be defined as clean technologies. In particular, as far as recycling technologies are concerned, it may be difficult to clearly distinguish them from the end-of-pipe or clean technologies. In this study, according to the requirements, such technologies will be either considered as a separate category, or subsumed either to additive or to clean technologies. Each time it will be specified the classification used. When recycling technologies are collected into an independent category it will be presented a reference to all the technologies recovering and re-using wastes without carrying out any distinction. On the contrary, when recycling technologies are not collected into an independent category, it will be made a distinction according to the type of recycle carried out. We will distinguish the case in which the recycle happens inside the process that has generated the wastes, or outside it. For instance, a recycling technology which is added to the production process makes it possible for a part of the emissions generated in the process to be used directly as manufacturing supplies. We subsume such a hybrid form of recycling technology under the class of clean or production-integrated technologies. The remaining class of recycling technologies (where recycling occurs separately from the production process) does not close the production cycle. We regard those technologies as additive technologies.

To sum up, the box below reports a more schematic definition of end-of-pipe technologies, recycling technologies, clean products and technologies, so that the existing difference between the various types of technologies can be made clearer.

1) End-of-the-pipe technologies or additive technologies:
This class includes all the technologies added downstream to the processes and which do not alter the production process. They only modify the gross emissions in that way that they become less environmentally harmful or can be better stored. Hence they are considered as transformation technologies since emissions are not avoided or reduced.
Within this class we can distinguish:
- purification plants;
- waste disposal technologies;
- re-mediation technologies.

2.a) Clean technologies or production-integrated technologies:
We define as clean technologies or production-integrated technologies all technologies aiming at the prevention of pollution **during the production process**. These technologies include:
- technologies reducing emissions and generating smaller wastes;
- technologies reducing resource inputs (including energy);
- technologies using recycled materials or less harmful inputs.

With respect to the chemical industry these technologies aim to reduce, prevent and utilise residues. The term "residues" denotes all components that take part in the chemical reaction and do not give the desired end product (Wiesner, J; Christ, C. et al., 1995). Because joint production is an important characteristic of a chemical production process, the existence of residues is very common.

2.b) Green products or product-integrated technologies:
These are products that:
- are realised with recycled, less harmful (e.g. other product components), or a smaller amount of inputs;
- avoid pollution or generate less pollution during their life (design, production and use), and at the end of their life (disposal).

3) Recycling technologies
In this category are included all technologies that recover and re-use wastes.

According to a conceptual point of view, such technologies represent a particular category. However, according to a practical point of view, it is often difficult to distinguish them from end-of-pipe or clean technologies. As a matter of fact, with reference to the necessities of the various parts of this study, we will consider recycling technologies alternatively as one single category, or as a category pertaining to the other two (end-of-pipe or clean technologies), by specifying each time the type of classification used.

1.2 Environmental technologies in the chemical sector

The development of cleaner technologies is becoming a key element of the industrial strategies, and in the case of the chemical industry it represents a relevant issue of the innovative activity. The rationale of this changing situation will be better explored in the following section. However, since now it is important to notice that chemical products are inputs of many downstream manufacturing processes, so that cleaner chemical products also means a reduction of pollution of downstream sectors (Federchimica, 1992).

Transformations of industrial processes in order to satisfy environmental requirements vary according to the chemical sector. In the case of basic chemicals, the size of plants, the reduced technical flexibility, the presence of established technological know-how, the need of complementary investments, and the rigidities in terms of raw materials and intermediates to be used, make those transformations more complex. By contrast, these factors play a marginal role in the case of speciality chemicals, where problems concern the use of toxic reagents and the purification of final products.

In general terms, it is possible to identify the main trends in the development of clean technologies in the chemical industry. First, as far as plant technologies are concerned, continuous reactors – which make use of smaller amount of reagents –, low-temperature separation processes, continuous fluid bed processes, and technologies characterised by greater safety standards – e.g., control procedures automatically activated in the case of emergence – are usually preferred. Second, as far as processing chemicals is concerned, high-selectivity reactions which reduce the amount of by-products and residuals, reactions producing recycling by-products, more selective catalyst or catalysts working at lower temperature and/or pressure, and biological processes as an alternative to chemical processes are usually preferred. Finally, as far as chemical products are concerned, interesting examples can be found in water-based inks and varnishes, bio-degradable deterging intermediates, substitutes for CFCs, bio-degradable plastics and fibres, and substitutes for asbestos.[1]

A further remark concerns the use of chemical products in downstream processes, to which chemical firms tend to offer products that can be better recycled and more easily disposed. In many chemical sectors, further incentives in the development of cleaner technologies arose by the fact that many firms became supplier both of chemical products and chemical processes related to those products. In turn, this required the development of competencies in downstream technologies, in services related to products' uses, and in some cases also in the recycling and disposal processes. An example in this sense is the activity of recover of plastic materials, whose exploitation requires in many cases the setting-up of a network between users and producers. The network has to promote an integrated design of materials, in order to satisfy the environmental impact and to ease the subsequent recover.

[1] For greater details see Federchimica (1992) and Wiesner *et al.* (1995).

1.3 Factors influencing the development and diffusion of environmental technologies

Firms' environmental behaviour is influenced by two main factors, namely the *public opinion* – including consumers' behaviour – and the *public authority*. Furthermore, in recent years environmental issues have become one important component of firms' competitive capability (Frey, 1993). Firm's environmental behaviour is strictly linked with processes of innovation development and diffusion, since the ecological dimension simulated a growing necessity of inventing and introducing new technologies aiming at the reduction of pollution. Hence, product and process innovations have become a relevant component of firms' answer to the growing pressures of governments and public opinion. The search for environmental efficiency has also increased the competitiveness of those companies with strong R&D capabilities, that were able to anticipate stricter regulation standards (Skea, 1994).

The following sections focus on those aspects. Section 1.3.1 analyses government pressures. Section 1.3.2 deals with public opinion and customers pressure. Section 1.3.3 concerns with the problem of firms' competitiveness and the influence played by environmental technologies.

1.3.1 Government environmental policy

Government intervention is mainly based on two instruments: i) the "command and control" approach, based on direct regulation; ii) the use of economic instruments and voluntary programmes. The first solution is characterised by a reduced flexibility, because it consists of measures aimed at directly influencing the environmental behaviour of social actors. Indeed, it determines limits, restrictions and rules related to specific product and processes. On the contrary, the second solution is comparatively more flexible, because it consists of instruments such as taxes, tradable quotas, subsidies, covenants and so on.[2]

Direct regulation

This instrument consists of commands and bans. Commands seek to reduce certain environmental impacts, whereas bans stop certain activities. Compliance with these provisions is checked by the government, and failure to comply is penalized.

Mainly, the direct regulation is based on the definition of emission standards that firms have to satisfy. However, if those standards are based on available technologies, their utility is reduced, because they do not stimulate technology development but only the diffusion of existing technologies. In order to foster innovation, technology-forcing standards may be used (Kemp, 1997), i.e. standards that cannot be satisfied by using existing technologies. These standards, however, may strongly increase firms' costs, and require enough time in order to allow firms to develop the new technologies.

[2] Concerning the different instruments for environmental regulation, see Hemmelskamp (1997), Kemp (1997), Croci (1993), Croci (1994b), Sassoon and Rapisarda Sassoon (1993), Commissione delle Comunità Europee, (1993).

One example in this direction comes from *innovation waiver*. This tool gives firms a temporary standards exemption, in order to leave them enough time to pursue innovation development. A different solution consists in defining long-term standards. In this way, the firms have time to satisfy stricter standards, and have enough incentives for adopting new prevention solutions.

Economic instruments

Economic instruments are based on an incentive-based approach. They aim at modifying agents' behaviour by acting on market prices. Many different instruments belong to this category, of which the most relevant are discussed in the following.

The **effluent fees** (taxes) define prices for environment exploitation. They provide revenues to governments and, at the same time, represent an incentive for firms to reduce pollution. In terms of total economy, effluent fees represent an efficient allocation. Each firm looks at its marginal costs and decides the amount of taxes that is willing to pay. In turn, only those firms whose marginal costs in technology development are lower than the effluent fees will invest in new environmental technologies.

Tradable quotas (permits) are issued by a government authority and may be traded among companies. Each permit consists of an emission entitlement limited in terms of quantity and period of validity, allowing the owner to emit pollutants into specified environmental media. The sum of the issued emission entitlements is equivalent to the total volume of emission the government wants.

By using **subsidies**, the processes of innovation and diffusion can be oriented towards environmentally-safe directions. If the objective of the measure is to foster innovation, subsidies are oriented to R&D investments. If the objective is to foster diffusion of existing technologies, subsidies are oriented towards investments in machinery acquisition.

Economists usually consider these economic instruments the most efficient tools in order to spur innovation in pollution control. As a matter of fact, taxes and tradable quotas allow each firm to decide whether it is more convenient to pay the tax or to introduce less polluting technologies. In this way it is possible to reach an efficient allocation of resources at the level of total economy. Furthermore, economic instruments represent an engine for technology innovation, especially in the case of clean technologies. To be sure, economic instruments have some disadvantages as well, which reduce their effectiveness.

As happened in countries in which they have been used, abatement costs and tax payments are likely to be high, which reduces their political attractiveness. In turn, they may induce the regulator to set a low (and ineffective) tax (Kemp, 1997). In other words, the tax has to be set at a very high value in order to effectively induce firms to develop clean technologies.

At the same time, subsidies may represent a useful incentive in order to promote innovative solutions, even if policy makers have to take into consideration existing risks. In the first place, subsidies may be given to firms that would have developed the innovation in any case, so that the subsidy becomes a windfall gain. In the second, policy makers have to pose attention in avoiding to finance second-rate technologies (Kemp, 1997). Hence, subsidies should be used for those cases that present particular problems, such as either technologies for which a market do not yet exist, or technologies with long development times, or technologies for which it is difficult to capture benefits (Kemp, 1997).

Voluntary programmes (covenants, agreements)

Voluntary programmes aim at enhancing the speeches between government and the industrial sector. They can be classified according to their nature (Croci, 1994b), which can be either private, public or negotiated. The programme has a *private nature* when it comes from the action of a private company or a group of firms. One of the most interesting example is represented by the programme “Responsible Care”, promoted by the world-wide chemical industry in order to increase industry’s attention to the issues of environment, safeness and health.[3]

On the contrary, the programme has a *negotiated nature* when it comes from an agreement between private and public actors. In this sense, the agreement can represent either a binding obligation, or a declaration of intentions.

Finally, the programme has a *public nature* when it comes from a public agent, and firms spontaneously whether agree or not. Firms expressing their interests to the programme have to respect the limits and obligations specified in the programme, so that they can benefit of a specific certification, or other benefits. These programmes may be introduced with a specific law (e.g., the case of **Ecolabel** or **EMAS**),[4] or may be the result of an administrative action (e.g., the case of programmes **33/50** and **Green Lights**, promoted by the Environmental Protection Agency).

In general terms, voluntary agreements are positively accepted by firms, because they permit enough freedom with regard to the time and methods by which each company has to respect the limits. A survey on this issue studied the impact of EPA’s voluntary 33/50 programme on toxic releases and economic performance by US chemical firms (Kanna and Damon, 1999). The survey showed that the programme allowed a reduction of pollution emissions. Firms’ participation to the programme has been mainly due to the expected benefits. First, a benefit from technical assistance offered by EPA. Second, public recognition. Third, a reduction of environmental liabilities in the future, and a reduction of high-cost compliance with mandatory regulation. This latter theme suggests that, by imposing a penalty in the form of liabilities and compliance costs, the environmental regulation created an incentive for firms to spontaneously agree to the programme.

One of the main disadvantages in the use of covenants and voluntary agreements is the danger of strategic exploitation of the agreements by industrial firms who may engage in free-rider behaviour, by claiming it is impossible to meet the targets through compliance technology that meets important user requirements. Voluntary agreements also mean that there is little incentive for third-party suppliers to develop compliance technologies as the market for the new technologies is sufficiently secured. Hence, if covenants have to be used in the future, they should be more oriented towards innovations. One way of doing this is through "technology compacts" between public authorities and private firms, in order to implement long-term technological change (Banks and Heaton, 1995).

[3] See Section 1.3.2.
[4] See Section 2.3.

Information diffusion

Auditing systems and environmental management, demonstration projects and information campaigns can be useful to ensure that firms make better use of the possibilities available for emission reduction, especially cost-reducing measures. Information disclosure requirements, that force firms to diffuse environment-related information, product information and "green" labels are also believed to be useful. They increase pressures on firms to enhance the environmental awareness of firms, and create a transparent market for green products. They are useful as complementary instruments, not as substitutes for environmental regulations or taxes.

Networks

Networks among technology suppliers, users, and research institutes are another way of encouraging technological innovation. Such a policy requires special competence on the part of policy makers. They must have a technological understanding of the production processes, the associated environmental problems and possible solutions if they have to identify the relevant participants for the development projects. They must also be careful to make sure that more radical solutions with potentially larger environmental benefits are developed and used. One interesting and successful example is the *Danish clean technology development programme*. This programme not only provided firms with economic incentives for developing and implementing clean technologies, but provided them with informative incentives and necessary contacts for finding efficient technological solutions to specific environmental problems (George et al., 1992). Furthermore, often solutions are found through cooperation among the polluters, their customer, their suppliers and consultants.

Table 2.1 describes the characteristics of different political tools, the purpose for which they may be used (to stimulate technological innovation or diffusion), and the context in which they may be applied, based on the experiences with environmental policies and studies of environmentally benign technical change (Kemp, 1997).

(Table 2.1 about here)

1.3.2 Public opinion

Public opinion's attention to environmental issues plays a key role in the solution of ecological problems. People more sensitive to the quality of economic development will orient their consumption towards cleaner products, in turn stimulating firms both to develop new environmentally-safe products and processes, and to create a status of firm which poses attention to environmental issues.

Consumers' attention to pollution prevention is largely growing, broadly in different sectors. However, differences can be observed among countries. A study focussing on the United States (Ottman, 1993) has shown that US consumers are strongly reluctant to buy products that are believed as dangerous for the environment. For most of the products that have been considered in the survey, firms had to find substitutes within two or three years. A similar survey promoted during a two years period (1990-1991) showed that most of the consumers decide whether or not to buy a product on the basis of its environmental impact (Gerelli, 1994).

As far as European consumers are concerned, differences arises among countries. Two examples can clarify the situation. Public pressure in **Germany** for “cleaner” products has become very strong in recent years. The number of people describing themselves as “environmentally aware” has grown from 35% in 1982 to 62% in 1989. In 1991, 57% of the population in Germany declared the preservation of the environment was more important to them than economic growth (Marketing, 1991).

In **Italy**, the environmental responsiveness of people stands at a lower level compared to Germany and the US. A survey promoted in 1993 (Censis – Istituto per l’Ambiente, 1993) has shown that Italians’ attention to cleaner production processes is not largely diffused. In some sectors the demand for cleaner products and processes is higher (this is the case, for instance, of home cleaning and food), but those sectors are quite small and mainly related to personal well-being. The same survey has also shown that Italian consumers are willing to pay higher prices (up to 5 to 10%) for cleaner products. Similar values have been obtained in different countries, where consumers are willing to pay higher prices in order to buy environmentally-safe products (Sasson, Rapisarda Sasson, 1993).

The role of the public opinion has certainly been more effective in the case of the chemical industry. Public pressures have strongly influenced the behaviour of chemical companies, which consumers considered not paying enough attention to environmental matters. Hence, in Europe, since several years the same companies have promoted specific actions of “green marketing” in order to diffuse an environmentally-safe image[5].

Chemical producers have recognised the importance of public perception in policy decisions affecting them. This was the main rationale for the promotion of voluntary industry initiatives. Among those, **Responsible Care** started in 1985 in Canada as a response to the combination of major incidents and changing public attitudes over the last decades. It suddenly has spread to many industrial countries (the US and many European countries). Responsible Care embodies a public commitment to continuous improvement of health, environmental, and safety performance, and to responding to public concerns about chemical products. Two out of three major chemical companies operated environmental managerial systems by 1996, up from only a few companies in 1993. Most member companies have already implemented some of the codes of Responsible Care (i.e. pollution-prevention, health-and-safety, and chemicals-transport codes), and, especially in the US, have also become increasingly open about their environmental, health, and safety performance.

In the United States, an important improvement towards the public diffusion of information related to potential troubles to the health and environment caused by dangerous chemical compounds has been the approval of the *Emergency Planning Community Right to Know Act*

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[5] Some examples concerning the Italian chemical producers help clarify this situation. The advertisements promoted by **BASF** usually reveal that safe production, resources protection, processes of waste disposal are a priority for the company. In the same way, **Hoechst** points out how to protect the environment by obtaining raw materials and energy from wastes. **Procter&Gamble** promises “to respect the environment: an objective, a commitment”. **Henkel** (with the line of products *Atlas*) claims to have promoted environmentally-safe productions since 1970. **Ciba Geigy** has built its advertising on environmental topics, so as **Dow Italy** and **Bayer** (Sasson, Rapisarda Sasson, 1993).

by the Congress in 1986 (Croci, 1993), whose definition was certainly influenced by the Bhopal tragedy. By this Act, chemical producers are asked to communicate the amount of chemical compounds in stock, the amount of emissions in the air, water and ground, and the release by accident of chemical substances.

All these information disclosed by chemical producers are used by different subjects in order to rank the companies and sectors on the basis of the amount of annual emissions. The rankings receive great attention among customers, and have a direct impact on firms' behaviour. Some of them (e.g. DuPont, Monsanto and Mobil) have tried to anticipate the reactions of customers, so they implemented long-term plans to reduce emissions by 50% to 90%.

Indeed, the disclosure of information on emissions promoted by the EPA has proved to be the most effective instrument of pressure on polluters, and surely more effective than monetary fines, which have a small impact on budgets of large companies (Croci, 1993). At the same time the public itself, both by national based organisations and spontaneous groups of interest, induces EPA to intervene and face conditions of particular risk and injury.

1.3.3 Firms' competitive capacity

The growing pressures on environmental issues put by governments and the public opinion have directly influenced the competitive capacity of firms (Frey, 1993), which have tried to transform this threats in new technological opportunities (Golinelli, 1988). Indeed, with prevention, the reduction of the environmental impact involves a reduced use of raw materials, and results in lower costs and greater productive efficiency. As a matter of fact, many innovations that have been introduced for economic purposes (decreased energy consumption, cost reduction and productivity increase) implicitly brought to greater environment protection. Most of the innovations introduced in the last decades have, in fact, been adopted with the objective of improving the use of resources and processes. However, an "environmental objective" has explicitly been pursued only later, in the presence of specific public policies or stronger pressures from customers asking for greater respect of the environment (Malaman, 1994).

It is possible to find many examples showing that "pollution is equal to inefficiency", which can be reduced by introducing specific innovations. Indeed, many chemical companies have tried to reduce the environmental impact by increasing at the same time the efficiency of their productions.

One of the most important examples is given by **3M**. In 1975, 3M introduced the so-called **3P** program (*Pollution Prevention Pays*), composed by more than 3,000 specific projects. These projects allowed for more than a million pounds in reduction of polluting emissions, and more than $500 million in cost savings. Despite those encouraging results, the company understood that its competitive position was strictly influenced by the environmental concerns. Hence, the new **3P Plus** program was launched, and new objectives and activities were defined. Even if not explicitly required by any specific policy standard, the new program decided a 90% reduction of any kind of emissions by 2000, and a 70% reduction of the emissions in the air by 1993 (Schmidheiny, 1992).

Other chemical producers show similar examples. Since 1960, **Dow Chemical** has reduced the production of dangerous wastes of about one thousand times (Ehrenfeld, 1990). In 1979, the average efficiency of the production processes of **Ciba-Geigy** was about 30% (70% were wastes). In 1988 the overall efficiency had grown by 62%, and by the end of the decade it had grown by 75% (Hirshhorn and Oldenberg,1991). At **Du Pont**, the production of Nylon was generating a stock of 3,600 tons of un-used by-products. Only some years later it was clear that those “wastes” could have been used as raw materials in the production processes of other sectors (e.g. pharmaceuticals). In 1989, the demand become greater than the supply and Du Pont started producing that “by-product” intentionally. In Germany, **BASF** declares of producing about 71.5% of the steam it needs either by using the heat generated in the chemical processes, or by burning the residuals of those processes (Environmental Business, 1991). A recent survey (Jost and Muller-Furstenberg, 1996) considered 33 products whose production processes were substituted with new processes using an *integrated environmental protection* approach, during the period 1960-1990. At least 40% of those processes recorded an improvement of their profitability.

These examples show that the objective of environment safeguard realised by developing and introducing clean product or process technologies is often integrated with the objective of saving costs and increasing the overall productivity. From the economic viewpoint, this approach represents the main difference between clean technologies and end-of-pipe technologies. As a matter of facts, the latter always involve a cost increase which becomes an increase of prices for consumers. However, the strong relationship between pollution reduction and productivity increase might not be an adequate incentive for developing and diffusing environmentally-safe products and technologies, as the introduction of those technologies entails many technical and economic problems.

It is possible to identify three main classes of **obstacles to the diffusion of clean technologies** (OECD, 1987):

a) *Structural Obstacles*: this class of obstacles is probably the most important. It is possible to define different sources of structural obstacles:
   - The first refers to the need of amortizing the existing end-of-pipe plants, which have often been introduced to respond to the government intervention;
   - Second, the clean technologies are more risky than end-of-pipe technologies. While the latter are sufficiently known in terms of functioning and expected results, the efficiency of clean technologies has to be empirically assessed. Furthermore, the depuration systems can be easily introduced at the end of production processes, while the adoption of new clean technologies involves a radical change;
   - Third, the introduction of clean technologies is a strategic decision for the company, which requires the presence of R&D facilities, a positive financial situation and the capability of absorbing the external technical information;
   - Forth, there are obstacles deriving from the public administration. The government intervention often imposes the introduction of the “best available technology”, which pushes the companies to adopt traditional end-of-pipe technologies.

b) *Financial and Conjunctural Obstacles*: these obstacles are linked with the degree of competition existing on the market, with the financial internal situation and the capability that companies show of accessing the financial market. Indeed, the adoption of clean technologies involves greater financial investments, and this makes clean technologies less favourable than end-of-pipe’s (OECD, 1987).

c) *Commercial Obstacles*: new ecological processes and products face greater marketing troubles. On the one side, firms prefer to sell more standardised and easily recognisable products. On the other, they prefer to avoid the adoption of processes requiring to be adapted to the different local contexts. As the OECD survey pointed out, companies operating in this sector are reluctant to substitute traditional and standardised with innovative products. When they do operate the substitution, the price difference between the two products is so relevant to be a disincentive to diffusion (OECD, 1987).

The **rate of innovation** is usually influenced in the environmental field by the same factors influencing innovation in others sectors. These factors refer to the existence of technological opportunities, to the presence of a market demand, to the appropriability conditions, to the market structure and to firms size.[6]

When we consider the environmental innovative process it is possible to distinguish between two possible paths. In the first, the innovation is developed by specialised firms (e.g. an engineering firm specialised in the environmental sector). In the second, the innovation is directly developed by the user. The latter is usually less common than the former, as only the more knowledge-intensive firms (as the chemical companies) have the capabilities to develop cleaner production processes. In the case in which the environmental innovation is introduced by a specialised firm, the same company has the economic incentive to market the technology, so that the diffusion process is potentially faster. On the contrary, when the innovation is introduced by the users, the technology is usually designed in order to respond to specific needs (and to increase the internal productivity) and the rate of diffusion is potentially slower. The “mission” of these companies rarely includes the marketing of process innovations, and they rarely have the managerial and commercialisation capabilities for this purpose. The chemical sector faces similar problems in the diffusion of environmental innovations. However, chemical companies show a greater propensity to codify and modularise the technologies, as the aptitude to patenting seems to demonstrate (Arora et al., 1999). Indeed, licensing-out represents one of the main incentives for chemical companies to codify and standardise their technologies.

At the same time, the propensity to innovate is strictly influenced by the **demand size**. It is possible to distinguish two different cases. As far as cleaner *products* are concerned, the propensity to innovate is directly influenced by customers, in terms of their aptitude to purchase goods with better environmental features. On the contrary, the diffusion of cleaner *processes* is influenced by the propensity the companies show to introduce waste-saving production processes.

Despite the presence of stricter environmental regulation, firms offering clean products (technologies) face uncertain sales, as the demand of clean products is still weak (Cramer-Schot, 1990). In turn, a weak demand represents an obstacle in the development of clean technologies. With regard to this, the environmental policy plays a critical role. The need to respect strict environmental standards in the short run has encouraged the adoption of end-of-pipe technologies. On the contrary, the development of clean technologies requires a general planning in which environmental goals are clearly defined in advance and firms can adapt progressively (Malaman, 1994).

[6] On this topic, see Kemp, 1997; Malaman, 1994; Kaimen and Schwartz, 1982; Dasgupta and Stiglitz, 1980; Antonelli, 1982; Cohen and Levin, 1989; Gerelli, 1994.

Finally, the development of clean technologies faces a further obstacle. The objective of a “clean production” stands at a lower level than the objective of “profits”. In the phase of introduction, clean technologies frequently show higher prices and lower quality, because of the lower scale of production and the employment of raw materials with poorer characteristics (not in terms of environmental impact, of course). Furthermore, the introduction of clean technologies requires to adopt organisational changes that reduces even more their diffusion (Malaman, 1994).

Table 2.1 – A summary of policy instruments

Policy Instrument	General characteristics	Final purposes	Context in which they may be applied
technology-based environmental standards	• effective in most cases (it is when they are adequately enforced) • uniform standards give rise to inefficiencies in case of heterogeneous polluters	technological diffusion and incremental innovation	when differences in the marginal costs of pollution abatement are small and economically feasible solutions to environmental problems are available
technology-forcing standards	• effective (in focussing industry's minds on environmental problem) • danger of forcing industry to invest in overly expensive and sub-optimal technologies • problem of credibility	technological innovation	when technological opportunities are available that can be developed at low enough costs
innovation waivers	same as technology-forcing standards	technological innovation	when technological opportunities are available and when there is uncertainty about best solution
taxes	• efficient • uncertainty about industry response • danger that they provide a too weak and indirect stimulus • total environmental costs for industry are likely to be high • limited political attractiveness	technological diffusion and incremental innovation	in case of heterogeneous polluters that respond to price signals when there are many different technologies for achieving environmental benefits
tradable permits	• effective • cost effective (which means that environmental benefits are achieved at lowest cost)	technological innovation and diffusion	same as taxes costs of monitoring and transaction should not be prohibitively high
covenants and technology compacts	• uncertainty about whether industry will meet agreements; should be supplemented with penalty for non-compliance • low administrative costs	technological diffusion	in case of many polluters and many technological solutions when monitoring environmental performance is expensive
R&D subsidies	• danger of funding second-rate projects • danger of providing windfall gains to recipients	technological innovation	when markets for environmental technology do not yet exist and when there is uncertainty about future policies when there are problems of appropriating the benefits from innovation
investment subsidies	• in conflict with polluter-pays principle • danger of windfall gains	technological diffusion	when industry suffers a competitive disadvantage due to less strict regulations in other countries
communication	helps to focus the attention of firms and consumers on environmental problems and available solutions to these problems	technological diffusion	when there is a lack of environmental consciousness when there are information failures
government as a match maker	• solutions may be tailored to specific needs • requires technological understanding of processes and products	technological diffusion and innovation	when there are information failures

Source: Kemp, 1997

Chapter 2

The environmental policy in Us and Europe

(R. Arduini)

2.1 A general vision

This chapter intends to give a general overview of the environmental policy developed during the last years in US and Europe. In particular, we try to underline the existing differences and the instruments used by these countries to stimulate the innovation and diffusion of environmental technologies. This first paragraph will analyse the main characteristics of the environmental policies of some countries, while the following paragraphs will present the political tools used in Europe and the US.

In the analysis of environmental policies it is possible to observe three main elements (Esteghmat, 1998). The first refers to the kind of regulation adopted. The regulation can be flexible or rigid, it can use command and control or self-regulation, the standards can be very strict or more mild. The second element is the relationship between government and industry, which can be adversarial or co-operative. The third element is the involvement of public in the regulatory process, as an involved public can change decisions of regulatory-policy. The environmental policies realised by the different European and American countries combine in different ways the above mentioned elements.

A recent study underlines the different kind of environmental policy used by United Kingdom, Germany, United States and Japan (Esteghamat, 1998).

United Kingdom

The environmental policy of United Kingdom has been more flexible then the other three countries. It has made a wide use of industrial self-regulation and it has adopted standards which are less complex. The penalties for non compliance have been relatively mild and the laws have imposed fewer administrative and legal costs on firms.

The relationship between governments and industry has been co-operative and environmental regulation are made through discussion among industry experts and government civil servants. On the contrary, the participation of public in the environmental decision has been very closed and the access to regulatory information has been very limited. Recently, this closing to public and environmental organisations has diminished.

Germany

Germany's approach is more rigid and it has adopted the strictest European standards. An important example is given by the recycling laws. The strictness of this regulation has been considered an obstacle by many exporters. However, in the chemical industry these laws have stimulated investments to develop new recycling processes. Furthermore, governments of Germany and of some European countries have provided assistance to industry to develop pollution control technologies. For example, chemical firms can receive subsidised loans in order to invest in pollution control, and small and medium firms can obtain grants to bear one-half of the environmental consultant costs.

The relationship between industry and government has been relatively co-operative and even the public involvement in the regulatory process has been wide. Since late 1970s the Green party has been present in the German parliament and the public pressure for environmental problems is strong.

United States

The U.S. has adopted a very rigid approach in the environmental policy. The standards have been very strict and often they were not achievable by available technologies. U.S have a very wide and severe regulation for hazardous wastes, the system of liabilities is the strictest of all countries and there are strong penalties for non compliance. Recently the environmental policy has been more flexible and the government has adopted voluntary programs for industry.

The relationship between industry and government was not co-operative and experts of industry are little involved, so that environmental decisions have generally been made by government officials and courts. The US pattern has been characterised by open participation and citizens have had access to information.

Japan

Japanese pattern is characterised by strict standards but with more flexibility than US and Germany. The relationship between government and industry has been relatively co-operative and the governments have provided assistance to industry. Low-interest loans are sponsored by governments and environmental expenditures of small chemical firms are assisted by *The Japan Finance Corporation*. The public involvement in the regulatory process has been limited.

2.2 US environmental policy

The US pattern has been characterised by **command and control** style. In the 1970s EPA (Environmental Protection Agency) was founded. Its primary function was to establish environmental regulation on the basis of laws passed by the Congress. The EPA's activity has had a great influence on firms’ environmental behaviour. It is interesting to note that the deregulation promoted by President Reagan has had a negative effects for the environment. This shows that the weakness of prescription, control and penalties causes lower environmental attention by firms. (Croci, 1993).

In recent years numerous flexible instruments have been adopted. The environmental regulation with strict standard has not been eliminated but new instruments support the oldest instruments to achieve better environmental results. We will firstly analyse these instruments from a generic viewpoint, then we indicate some interesting programs that have been implemented to stimulate R&D in pollution prevention for the chemical industry.

The economic instrument which received more application is the **compensation for environmental damages**, which generated several contentious. In some cases, transferable permissions have been adopted, while there is still a large suspicion from the government and the public opinion towards taxes. In general, the economic instruments have been scarcely used while a lot of importance has been given to other instruments such as stimulus to innovation, voluntary agreements, and information. (Croci, 1993).

Stimulus to innovation and to technology diffusion.
In 1991 EPA created a specific "Committee for technology innovation and economy", as an under-committee of NACEPT (National Advisory Council for Environmental Policy and Technology) at the Administration Office, with the task of stimulating the innovation and technology diffusion (Croci, 1993). In the last years EPA is promoting some programmes of technology experimentation in collaboration with some firms, as well as some programmes of technology diffusion through a better circulation of information. For this reason, a range of collaborations with external subjects such as firms, public agencies, providers of information services, research laboratories, universities, associations of professional categories is necessary.

Voluntary programmes of "Pollution prevention".
EPA has launched two voluntary programmes of pollution prevention based on the 1990 Pollution Prevention Act. The first programme is called *Green Lights* and concerns the adoption of more energy efficient lighting systems. EPA provides the technical help to participants, and gives information about the possibilities of financing the required investments. EPA organises also information campaigns to the producers of lighting equipment, to electric energy producers and to electric gates managers, with the aim of inviting them to collaborate to the initiative as supporters.

The second programme launched by EPA in 1991 to reduce the emissions of 17 chemicals substances which cause great environmental problems is called *33/50*. EPA develops an intensive work of information and support to the potential participants through a wide variety of instruments such as phone hot-lines, seminars, courses, conferences, publications, videos and computer services (Croci, 1993).

Environmental Auditing.
EPA promotes the adoption of voluntary environmental auditing programmes from regulated bodies (Croci, 1993). These are private firms and public bodies subject to environmental laws.

Information to the public.
The involvement, first of all informing to the public opinion, is crucial for the success of environmental policies. However, it must be mentioned that the increasing interest from the public opinion produced also some negative aspects. EPA itself noticed that its own priorities very often followed the ideas of the public opinion rather than the intervention in the real situations of more environmental risk (Croci, 1993).

To sum up, the most recent management programmes of US environmental policy share the same elements which allow to individuate a range of features common to the new establishment criteria of the relationship between environmental regulator and regulated subjects. They are:

- the emphasis on prevention,
- the stimulus to technological innovation,
- the importance given to the process of information diffusion,
- the voluntariness of the participation to the programmes,
- the use of economic stimulation systems,
- the flexibility in pursuing the objectives,
- the need of co-operation among different typologies of subjects,
- the transparency towards the public.

We analyse now the more significant US initiatives to stimulate the innovation of cleaner technologies in the chemical sector (Blasco, 1997).

The "Pollution Prevention Act" in 1990 determines the instrument of **prevention** as a primary objective of the national policy. This law foresees the institution of the OPPT (Office of Pollution Prevention and Toxics), inside the EPA, with the task of bring about the instructions of the law, and develop and realise a strategy for the promotion of the reduction of polluting sources. After this law had been approved, the OPPT started to explore the idea of developing new chemical products and processes with the aim of making them less dangerous for human health and the environment. In 1992 the same body launched a programme of encouragement to the research in the field of sustainable chemistry called "Ways of alternative synthesis for the prevention of pollution". From here it started the consolidation of the Green Chemistry. The Green Chemistry foresees the development of safe chemical products and processes, through methods reducing or eliminating the use and/or the production of toxic or noxious substances for man and the environment.

With the aim of developing and consolidating the green chemistry it has been realised a voluntary programme of collaboration called "The Presidential Green Chemistry Challenge Program". It foresees the establishment of a collaboration among chemical companies, university and research institutes, federal agencies and some other organisations (American Industry Association -AIA-, American Chemical Society -ACS-, EPA, Council for Chemical Research –CCR-, Green Chemistry Institute -GCI-). It is opened also to individuals, groups and organisations which in some way are involved in planning and/or production and/or using of chemical compounds. The collaboration should mainly involve the development of innovative science and technology which are the base of the Green Chemistry. Other interesting instruments for the development of the green chemistry in US are:

- *The collaboration EPA-NSF (National Science Foundation)*: in 1992 EPA and NSF signed the agreement "Memorandum of Understanding", with the aim of making a co-ordinate work to sustain basic research of the Green Chemistry.
- *Collaboration among Industry-University-Government*: the OPPT supports several pools established on the participation and the collaboration of industry, university and government.
- *Diffusion of research results*: the OPPT Project foresees the participation to important scientific meetings, e.g. the American Chemical Society National Meetings, the Gordon Research Conferences and the North American Chemical Congress, promoting and reporting results and contents of such meeting on scientific journals and publications, as well as spreading computer and database instruments.
- *The development of the Curriculum on Green Chemistry*: an element which can speed up

the assimilation of culture and the development of professional competence concerning the education on prevention is the codification of the philosophy of pollution prevention in the curriculum of classical chemistry. With this aim OPPT sustains a wide range of initiatives for the cultural and professional training, distributing information equipment and courses addressed to the training of professional research chemists in the industry and the training of students in the university.

- *Presidential Green Chemistry Challenge Awards Program*: this instrument gives an official award to those methodologies and/or technologies which share the principles of the Green Chemistry in the planning, production and use of chemical compounds. The winners of the prizes receive a national public award.

2.3 European environmental policy

At the very beginning of the European Community the environmental policy was not foreseen and the activity of the community was based only on general items included in the preamble to the institutional treaties (e.g. the objective of "improving the human quality of life"). Later, with the introduction of the European Unique Act and with the treaty of Maastricht, the environmental preservation began to have a fundamental role in the European policies. Some action programmes on environment were drawn up and some objectives and guide lines were introduced such as the principle of prevention, the principle of correction, especially at the source, of the damages caused to the environment, the principle of 'who pollutes must pay', the principle of integration between the environmental policy and the other community policies, the subsidiary principle, the principle of precaution.[7]

Until today five action programmes have been drawn up and in general a conversion is occurred from a prohibition to a prevention trend. In the first programme the orientation to prevention concerned the policies, while the command and control continued to dominate in the law. The true innovation was represented by the fifth programme (1993-2000) which modified the relationship among firms, policy, law and controls (Sasson and Rapisarda Sassoon, 1993).

A first element of innovation introduced by the fifth action programme is the fact that the environmental matter is considered as a whole and not as a solution of single problems. Before the implementation of this new approach, all the measures adopted by the European Community were not sufficient to break down the pollution levels (Commission of European Community, 1993). The idea of facing the problem from a global prospective comes also from the cares of safeguarding the internal competition of the European Market (i.e., to avoid the unequal standards in the different member states) as well as from the need to support the Unique European Market. Indeed, the management of natural resources and energy sources has to adopt a global perspective (Sasson and Rapisarda Sassoon, 1993).

The objective of the fifth action programme is to realise a new pattern of economic and social development through a greater investment of responsibilities from the interested parties. The strategy of the programme is based on the dialogue among the economic and social actors (consumers, managers, public administrators, non-governmental organisations). According to the articles 3b and 130 of the Maastricht Treaty, by which the environmental policy should get closer as much as possible to the needs of the individual and to the local needs, this is a

[7] For deeper information, see Caravita, 1994.

bottom-up strategy (Gerelli, 1994).

This new policy trend highlight the need of enlarging the range of political instruments for environmental purposes. In order to support the traditional “command and control” instrument some economic and voluntary tools have been adopted. Indeed, the fifth programme recommends also to promote: (i) R&D investments of more clean technologies; (ii) the extension of education, training and awakening to favour the comprehension of environmental problems; (iii) the reinforcement of knowledge and monitoring of the state of environment.

Among others, the more interesting instruments that have been adopted by the European Community are *Life*, *EMAS*, and *Ecolabel*. In the following, we will firstly review these instruments, and later analyse the specific policy concerning the development of less polluting technologies.

2.3.1 Life

Life’s objective is “to contribute to develop and apply the legislation and the community policy to the environmental sector” (The European Community Council, 1992). While the large part of the European financial instrument presents an element which – directly or not – regards environmental issues, Life is the only specific instrument supporting the elaboration and the application of the environmental community policy. Life The first phase of Life concerned the years 1992-1995, the second phase considers the years 1996-1999. In this second phase, the programme is composed of three different sectors of intervention: Environment, Nature, Third Countries. In the Environment sector there are interesting research points for the Green Chemistry.

Life-Environment supports feasibility actions, demonstrative actions and of technical assistance, and actions of support or incentive aimed: (i) to promote the sustainable development and integration of the environmental topics into the industrial activities; (ii) to help local authorities to integrate the environmental topics into the regional economic interventions; (iii) to strengthen the complementary linkages between the environmental law and the structural fund assistance.

Despite these objectives, the resources assigned to Life are modest if compared to those assigned to the development of other sectors (400 MECU in the first phase and 450 MECU in the second one). For this reason, financial support is given only to the best proposals, having the sufficient size, well-grounded from the technical and financial points of view, having an innovative character and a great visibility (Blasco, 1997).

According to the special report of the European Court of Auditors, written after a survey made in 6 UE countries, it emerges that the volume of the community financial spending regarding the environment results to be hardly computable, because of the disjointedness of the programmes with environmental impact. Moreover, these programmes are often far from the orientation of the community environmental policy because of a great lack of national and community co-ordination in this matter, and also of a great lack of assessment of the final results of the financed projects.

However, with its inspiration to the new community philosophy criteria in this sector, Life represents the first real possibility of realisation of the objectives of a new community environmental policy trend (Gerelli, 1994).

2.3.2 EMAS and Ecolabel

EMAS and *Ecolabel* are both voluntary instruments creating a system for **ecological certification**. According to the fifth Framework Programme, their aim is to promote an action of different actors to develop a more active and responsible participation of the firms towards environmental compatibility.

Ecolabel is formed by an eco-label or a quality mark which is assigned to those products resulting in conformity with the criteria previously established and regarding the whole life cycle of the product. These criteria pretend a high environmental compatibility and the mark is released to those products presenting a lower environmental impact, if compared to those already on the market (European Community Council, 1992). This community measure follows the German experience. In 1977 in Germany it has been introduced the first environmental quality mark (the *blue angel*) which, at the end of 1990, has been assigned to some 4,000 products (Frey,1993).

The aim of the EEC measure about the mark assignment is “to promote the conception, the production, the commercialisation and the use of products with lower environmental impact during the whole life cycle of the product”, as well as “to provide to consumers a better information on the environmental impact of products”.

This instrument represents also a marketing opportunity, especially regarding the new consumer needs. It represents for them a warranty as regards the possible uncertainties about the truth of certain statements on the environmental characteristics of the products. It can be easily understood how such instrument promotes the firms to adopt more eco-compatible behaviours by acting on the demand-side. Indeed, Ecolabel should attain to better sensitise the consumers regards the environmental problems, by inducing them to prefer cleaner products which can easily be recognised by the mark. In this way the firms adopting the certification system should receive an economic return.

With difference to Ecolabel which refers to products, **EMAS** is referred to production plants. A “check up” of the environmental state of a firm is called *environmental audit*. This check-up allows to evaluate and test the ecological performance of a firm through an objective and systematic method testing the constant and direct appliance of operational systems and of proceedings respecting the environment. Due to these advantages and to the positive experience of many European companies using eco-audits, the European Council adopted an eco-audit regulation (Council of the European Communities, 1993). The regulation aims to stimulate a global involvement of the firm on the environmental management, following a clear logic of “Total Environmental Quality” (Sasson and Rapisarda Sassoon, 1993). In fact, the community regulation aims at the generation of a true environmental management system.

A company intending to participate to the European EMAS should then proceed and adopt an internal system of environmental protection, should make a periodic evaluation of the operation of the protection system to lower its environmental impact, and should complete an environmental declaration each year. The purpose of such a process is then the certification of the audit and of the environmental declarations. This certification should be released by independent experts and recognised by special bodies in the different member states.

EMAS represents an opportunity for the firms to demonstrate a greater ecological responsibility, which is a necessary element for rising in quality in the field of environmental preservation as well as to start a sustainable development. It is also an acknowledgement permitting to acquire a competitive advantage. Actually, it is an expensive instrument and many people maintain that it determines a less strong impact on consumers if compared to Ecolabel. The acknowledgement in fact does not concern the whole firm but just the single establishments which received the certification. Moreover it exists the prohibition to use the logo on single products. Considering also the necessary costs of actuation, it can be noticed how the promoting feature of this instrument is limited. It is then necessary to support it by other elements which, looking at the operator interests, push them to its adoption. It is agreed that the more effective instruments concern the possibility of obtaining economic advantages for the subjects adopting EMAS, e.g. the possibility of receiving fiscal incentives or the priority in supplying orders from the government or from public administrations (Frey, 1994).

In order to assess the European environmental policy, a study of the Warwick Business School (Wong, Turner and Stoneman, 1996) underlined that 65% of the contacted companies considered the legislation as an important source of pressure for supplying green technologies, while only 30% of companies were reported to have responded to this pressure. A more detailed analysis has been realised on the UK chemical companies (Zhuang and Synodinos, 1997). This research was aimed to analyse the legislation-behaviour incongruity in the chemical industry. The results put in evidence that much of the legislation has not been as effective as it could have been in reducing pollution-inducing activities. The causes can be resumed as follows: (i) lack of effective communication at EU level; (ii) lack of consultation during the development of legislation; (iii) too frequent legislation changes, (iv) absence of incentive as well as enforcement mechanism, and (v) resource constraints.

2.3.3 The R&ST in Europe

A fundamental role inside the community policy on science and technology is covered by the Community Framework Programmes (FP). The fifth programme, which is operating at the present moment, is divided into four Thematic Programmes and three Horizontal programmes (plus a separate Specific Programme on Nuclear Energy). One of the four thematic programmes focuses on environmental problems (“Energy, environment and sustainable development”). The objectives of this thematic programme is to contribute to sustainable development and it is composed of two sub-programmes.[8]

While the second sub-programme aims at developing sustainable energy systems and services, the first of these sub-programmes aims:

- to promote environmental science and technology,
- to improve the quality of life,
- to boost growth, competitiveness and employment, while meeting the protection of the environment and of resources.

Effective implementation of all activities will direct attention on two main items:

[8] For general information, see http://www.cordis.lu

- to direct complex societal-driven issues though integrated multidisciplinary and multi-sectoral actions involving wherever possible the principal private and public partnerships, and end-user from business, industrial and policy-making sectors.
- to direct the attention on finding solutions to strategic problems, and sustaining only proposal which are of regional, European and global importance.

Apart from the Framework Programmes, there are other government-funded R&D activities which focus on environment. According to a recent studies, the magnitude of direct government support for basic research and engineering development in Europe is generally comparable to U.S. efforts. The study has analysed some R&D programmes of federal and corporate organisations in Europe, and has put in evidence a strong emphasis on investment that improve the knowledge base for clean technologies. There is also an emphasis on technology transfer and especially industrial improvement regarding the competitiveness and the environment. Many collaborative efforts include companies, institutes, universities and government.

Across the European countries which have been analysed by the study, six topics were found to have significant critical mass:

- plastics and polymer recycling presenting materials with greater environmentally friendly properties;
- expansion of the potential for using renewable chemicals and materials in products and processes;
- recycle of a steadily wider dimension of chemicals, materials, or products through targeted Research and Development;
- replacement of diverse chlorofluorocarbon (CFC) and process improvement;
- utilisation of carbon dioxide;
- reduced chemical use preferring natural approaches.

2.4 Summary

In this first part of the report we analysed the existing literature with the objective of providing a general overview of the environmental issue. We analysed as well some interventions promoted by specific Countries, in particular to encourage the development and the diffusion of environmental technologies. Furthermore, we tried to support some examples concerning this chemical industry.

At the firm-level, it can be observed the ever growing importance that the environmental issues assume in the decision-making process, especially regarding the increasing pressure coming from the public opinion and authority. Such pressures vary among different countries, even if a growing convergence can be noticed, which pushes to bring near the different realities. In particular, it can be noticed that:

- there is a concentration of efforts and interventions towards prevention, rather than end-of-pipe intervention. Indeed, prevention is generally considered more efficient than end-of-pipe;
- there is a convergence in the levels established by the standards of the different countries;
- the instrument of “command and control” is ever more supported by economic

instruments grounded on an incentive-based approach. Previous experiences demonstrated that the only direct regulation is not able to obtain sufficient outcomes. Nevertheless, it is not possible to easily individuate the most efficient instruments to realise a satisfactory environmental policy.

In the following chapters we will analyse in deep the process of development and diffusion of environmental technologies in the chemical sector through three different empirical analyses. Then we will try to offer some lines of environmental-economic policy as a sum of the outputs of such analyses and the information collected in these first two chapters.

Chapter 3

Empirical Analysis. The distribution of patents in environmental technologies: What is the role of the chemical industry?

(R. Arduini and F. Cesaroni)

3.1 Patents as a pointer of innovation behaviour

In this section we describe the results obtained through the patent analysis aimed at inquiring the relative innovative position of Europe, the US and Japan in the environmental sector. The choice to use patents for such analysis lies on two conditions: a) patents are a good pointer of the innovative rate; b) the chemical sector faces a high propensity to patent.

As far as the first condition is concerned, the possibility to use patents and patent statistics to recover information on the innovative activity of firms or countries, we can consider the following. Data on patents are easily available, they are directly linked with the inventive activity and they are based on what appears to be an objective and only slowly changing standard (Griliches, 1990). Moreover patent statistics may also be used in comparisons across industries and nations (Basberg, 1987). However, there are also various problems connected to the use of patents that can reduce the significance of the analysis. When, like in our case, various countries are confronted, there is a question whether the patent institutions can be compared. If patent legislation and the practice of patenting vary significantly, this will of course affect the validity and usefulness of any comparisons. In order to obviate to such a problem, we considered patent statistics of two different data-sets (USA and Europe), both showing a high degree of international openness.[9] Within the same database, we will consider the quota of "foreign" patents on domestic patents and, subsequently, the relative percentages will be compared.

The analysis of "foreign" patents gives also a greater information on the quality of the same patents. So, "foreign patents are used as technology indicators because, on average, they are expected to be of higher quality than domestic patents. It is reasonable to assume that only inventions with significant profit expectations in a larger market will be patented abroad because of time and costs involved in such processes" (Gilfillan, 1964, p. 42).

The problem of patents' quality is connected to the fact that the importance and value of patents change remarkably, and therefore the simple patent count can give distorted result. "An idea that has often been suggested is to use patent citations as an index of the importance or value of patents (…), i.e., to count the number of time that each patent has been cited in subsequent patents and use the number to compute weighted patent counts" (Trajtenberg, 1990). Hence, in this report we will also perform some analyses on citations in order to improve the understanding of the results.

3.2 Methodology[10]

[9] Foreign patents in the US database are about 55% and foreign patents in the European database are about 58%.
[10] The methodology is widely exposed in Appendix 1.

Patent search in the field of recycling and end-of-pipe technologies has been realised using a key-words approach. All patents having in the title or in the abstract certain key-words connected to the classes of predefined technologies have been considered. In particular, the field "end-of-pipe technologies" consists of six classes of technologies: (1) purification of liquids, (2) purification of gases, (3) decontamination of soil, (4) decontamination of ground water, (5) treatment of solid wastes, (6) treatment of hazardous wastes. On the contrary, "recycling technologies" only consisted of one class, for it was not possible to find more specific key-words to be used in the search.

The final classification of end-of-pipe and recycling technologies is the following:

A) End-of-pipe technologies

A.1) *Purification*. This class has been distinguished in:

- A.1.1) *purification of gases;*
- A.1.2) *purification of liquids*.

A.2) *Decontamination*. This class has been distinguished in:

- A.2.1) *decontamination of soil*;
- A.2.2) *decontamination of ground water*.

A.3) *Treatment of wastes*. This class has been distinguished in:

- A.3.1) *treatment of solid wastes*;
- A.3.2) *treatment of hazardous wastes.*

B) Recycling technologies

For each class we looked at:

1) the number of patents realised by the US, Europe and Japan;
2) the number of patents realised by the greater chemical firms in Europe, US and Japan;
3) for a stratified random sample, we explicitly looked at the assignee of the patents. This analysis allowed us to verify who realises the environmental innovations (e.g., industrial groups, independent firms, other institutions);
4) finally, in the American database we further developed the analyses, in order to assess the patent "quality". All the patents realised by the greatest chemical firms were considered, and we carried out counts of patent citations.

We considered a five-years period (1993-1997). Notice, however, that the key-words approach that we used to identify environmental patents did not allowed us to draw the totality of patents concerning this sector. Many key-words, though presenting interesting patents, have been eliminated because they included too many "irrelevant" patents. The key-words that eventually we used represent a compromise between extension of the analysis and probability of error.[11]

The analysis of the US, European and Japanese innovative ability in end-of-pipe and recycling technologies has been carried out considering the patent applications presented to the US Patent Office, to the European Patent Office and to the World International Patent

[11] As far as we know, the only other study that used patents to analyse environmental issues has been carried out by Lanjouw and Mody (1995). Their approach to define a patent as environmentally related was much more selective. Instead of using keywords, they referred to specific classes of the International Patent Classification (IPC). The patent sample that they obtained had obviously a smaller probability of errors, but was composed of a smaller amount of patents as well.

Office. The US database includes all the US patents, while the European database includes patents presented both to the European Patent Office (EPO), and to the International Patent Office (WIPO). A difference exists between the two databases. However, we preferred to follow this methodology because of the problems faced in considering any individual European Patent Office.[12]

The possibility to use three different sources of patents allowed us to increase the value of the analyses. If it appears obvious that agents (are they firms, institutions of research, government agencies or single inventors) prefer to patent in the domestic Patent Office, on the other hand, the number of agents addressing to foreign Patent Offices represents a not negligible event. At the same time, this last behaviour can be represented like "a qualitative" index of the inventions incorporated in the patents. It can reasonably be supposed that an agent will demand the extension of the intellectual property right beyond the national borders only if thinking of a possible development in the foreign market for that invention. In this way the comparison between US patents in Europe, European patents in the US and Japanese patents in the US and in Europe allows to characterise technological and competitive forces of these three regions.

Before exposing the result of the analysis, however, it is necessary to specify that the two databases (European and American) can be compared only in relative terms. It is not possible to compare absolute values (i.e., the total number of patents in each technological class) because the databases are organised in a different way, and because the we had to use different key-words in the two databases.

3.3 Results

3.3.1 The general situation

The innovative rates of United States, Japan and Europe in the environmental technologies are not so different from those found for other technological sectors. In particular, observing the distribution of the total of patents introduced to the US Patent Office from 1993 to 1997 (tab. 3.1), it can be noticed that the United States are responsible of approximately 45% of patents in all the technological classes, while the European countries of approximately 13% and Japan of approximately 20%. When we consider only the environmental patents, we find the almost identical shares, with a small increase in the US and a decrease in Japan, increasing in such a way the position of other countries not considered here.

In the case of the European database (tab. 3.2) analogous results are obtained as well. The European innovators are responsible for approximately 42% of the total patent applications introduced in the period 1993-97, while the US are responsible for approximately of 35% and Japan for 14%. Moving from the total patents to environmental technologies the shares remain quite similar, even if it is necessary to evidence an increase of European patents (49%) and a decrease of the others two regions (32% for USA and 9% for Japan).

Table 3.1 - Environmental patents, US database, years 1993-1997

	Environmental Patents	Total Patents

[12] See Appendix 1 for further details.

	Val.	%	Val.	%
USA	2705	48%	261514	45%
Japan	608	11%	116152	20%
Europe	797	14%	77847	13%
Other*	1558	27%	128089	22%
Total	5668	100%	583602	100%

* It comprises patents from other countries and from single inventors.

Table 3.2 - Environmental patents, European database, years 1993-1997

	Environmental Patents		**Total Patents**	
	Val.	%	Val.	%
USA	1886	32%	169515	35%
Japan	520	9%	65512	14%
Tot. Europe	2862	49%	203465	43%
Other*	564	10%	39462	8%
Total	5832	100%	477954	100%

* It comprises patents from other countries and from single inventors.

It is also possible to observe that the US are more present in Europe than Europe in the US. And this is true both in environmental and in total patents. If one stops at the aggregates data, however, it is not possible to add further considerations. Therefore, it turns out opportune to come down in the detail of environmental technologies, both in the distinction between end-of-pipe and recycling technologies, and by dividing of end-of-pipe technologies into the six sub-sectors already characterised (purification of liquids, purification of gases, decontamination of soil, decontamination of ground water, treatment of solid wastes, treatment of hazardous wastes).

Firstly, in table 3.3 we will analyse **end-of-pipe technologies**, with regards to the US database. In all classes it can be observed a clear prevalence of US patents, with only the sector of gas purification presenting the prevalence of Japanese patents. The prevalence of American patents is obviously due to the fact that we are now considering the US database. However, if we consider the same data related to the European database (tab. 3.4), we can observe that only in three areas (purification of liquids, purification of gases and treatment of solid wastes) the European percentages are higher than the US.

As far as Japan is concerned, the shares relative to the two databases are very similar. The values are rather low, with a relative advantage represented by the purification of gases, where Japan appears as the greatest innovator in the US database, and at the second place in the European one. Notice, however, that Japanese patents are always realised abroad (the Japanese database has not been considered) and our analysis considered only a share of the patents realised from this country in the environmental sector.

In conclusion, it seems that the United States have a position of technological advantage in the field of decontamination of soil and ground water as well as in the field of the treatment of hazardous wastes, for they show the greater innovative rate both in the US and European databases. Japan, on the other hand, seems to evidence a leadership in the field of purification of gases, where Europe seems to posses some good technological competencies as well. Finally, in the fields of purification of liquids and the treatment of the solid wastes, even if the United States seem to show a relative advantage, when observing the European database

Europe shows a quite high percentage. This pattern evidences in these fields the presence of a certain innovative capability for Europe.

Table 3.3 - End-of-pipe technologies, US database, years 1993-1997.

	Purification		**Decontamination**		**Wastes treatment**	
	Liquids	**Gases**	**Soil**	**Ground Water**	**Solid**	**Hazardous**
USA	575 (47%)	70 (14%)	224 (68%)	52 (53%)	89 (51%)	101 (66%)
Japan	88 (7%)	280 (54%)	5 (2%)	0 (0%)	5 (3%)	0 (0%)
Europe	172 (14%)	103 (20%)	17 (5%)	8 (8%)	12 (7%)	1 (1%)
Other*	401 (32%)	61 (12%)	82 (25%)	39 (39%)	69 (39%)	51 (33%)
Total	1236	514	328	99	175	153

* It comprises patents from other countries and from single inventors.

Table 3.4 - End-of-pipe Patents, European database, years 1993-1997.

	Purification		**Decontamination**		**Wastes Treatment**	
	Liquids	**Gases**	**Soil**	**Ground Water**	**Solid**	**Hazardous**
USA	381 (28%)	73 (9%)	118 (49%)	37 (62%)	47 (37%)	52 (61%)
Japan	98 (7%)	215 (27%)	10 (4%)	0 (0%)	4 (3%)	0 (0%)
Europe	726 (53%)	441 (56%)	94 (39%)	21 (35%)	59 (47%)	27 (32%)
Other*	169 (12%)	61 (8%)	19 (8%)	2 (3%)	16 (13%)	6 (7%)
Total	1374	790	241	60	126	85

* It comprises patents from other countries and from single inventors.

Now we analyse in the detail the different European countries (Tables 3.5 and 3.6). Initially, it can be observed a similar situation in the two databases. Apart from Germany, the most part of countries presents an innovative rate very low or equal to zero in end-of-pipe technologies. As it was reasonable to suppose, Germany represents the country realising the higher number of patents, underlining once again its leadership position if compared to the rest of European Union. However, the "distance" between Germany and the other countries denotes a German thematic specialisation in the field of end-of-pipe technologies that goes beyond its economic or technological superiority.

We can now consider **recycling** technologies (tab. 3.7). In both databases, domestic patents represent approximately half of all patents.[13] However, while United States are present in the European database as 37%, in the US database Europe just owns 14% of the patents. This is a situation similar to the purification of liquids, that is the percentage of domestic patents is higher than the percentage of foreign patents, but United States do patent in Europe more than

[13] We defined "domestic patents" all US patents in the US database, and all European patents in the European database. On the contrary, we defined "foreign patents" all US patents in the European database, and all European patents in the US database.

Europe in the United States.

Table 3.5 - End-of-pipe patents, US database, years 1993-1997.

	Purification		Decontamination		Wastes treatment	
	Liquids	Gases	Soil	Ground Water	Solid	Hazardous
Belgium	1%	0%	0%	0%	0%	0%
Denmark	7%	3%	0%	12%	8%	0%
United Kingdom	9%	7%	17%	0%	17%	0%
Finland	2%	6%	6%	0%	8%	0%
France	10%	1%	6%	0%	0%	0%
Germany	46%	72%	47%	88%	17%	0%
Greece	0%	0%	0%	0%	0%	0%
Ireland	0%	0%	0%	0%	0%	0%
Italy	1%	0%	0%	0%	25%	0%
Portugal	0%	0%	0%	0%	0%	0%
Spain	1%	0%	6%	0%	0%	0%
Holland	6%	5%	12%	0%	17%	0%
Austria	1%	0%	0%	0%	0%	0%
Sweden	8%	4%	0%	0%	8%	100%
Switzerland	7%	2%	6%	0%	0%	0%
Norway	1%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%

Table 3.6 - End-of-pipe patents, European database, years 1993-1997.

	Purification		Decontamination		Wastes Treatment	
	Liquids	Gases	Soil	Ground Water	Solid	Hazardous
Belgium	1%	1%	0%	0%	2%	0%
Denmark	6%	1%	1%	0%	3%	0%
United Kingdom	10%	7%	19%	19%	8%	41%
Finland	2%	4%	2%	5%	5%	4%
France	6%	5%	6%	5%	13%	15%
Germany	50%	62%	51%	42%	22%	11%
Greece	0%	0%	0%	0%	0%	0%
Ireland	0%	0%	0%	0%	0%	0%
Italy	4%	2%	0%	0%	27%	0%
Portugal	0%	0%	0%	0%	0%	0%
Spain	1%	0%	0%	0%	7%	0%
Holland	4%	2%	16%	14%	3%	7%
Austria	4%	5%	1%	0%	2%	15%
Sweden	7%	8%	2%	5%	3%	7%
Switzerland	3%	3%	2%	10%	5%	0%
Norway	2%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%

In order to better understand the data concerning "foreign patenting" it is useful to compare the relationship between foreign and domestic patents, both for end-of-pipe and for recycling technologies. In the US database, in the field recycling technologies, the relationship between foreign patents (European) and domestic patents (US) is about 0.3 (484/1594), while in the field of end-of-pipe it is equal to 0.28 (313/1111). In the European database, in the field of recycling, the relationship between foreign patents (US) and domestic patents (European) is about 0.79 (1178/1494), while in the field end-of-pipe it is 0.52. As previously observed, these data confirm the US higher innovative rate in both sectors. This result is evidenced either in relation to the higher American percentages in the US database or to foreign patenting. However, in the field of recycling technologies, the difference is more emphasised than in the field of end-of-pipe.

Table 3.7 - Recycling patents, years 1993-1997

	US database		European database	
USA	1594	50%	1178	37%
Japan	230	7%	193	6%
Europe	484	15%	1494	48%
Other	855	27%	291	9%
Total	3163	100%	3156	100%
European countries				
Belgium	11	2%	36	2%
Denmark	7	1%	28	2%
United Kingdom	43	9%	178	12%
Finland	15	3%	58	4%
France	115	24%	245	16%
Germany	172	36%	619	41%
Greece	1	0%	13	1%
Ireland	2	0%	2	0%
Italy	30	6%	76	5%
Portugal	0	0%	0	0%
Spain	7	1%	20	1%
Holland	18	4%	27	2%
Austria	7	1%	35	2%
Sweden	13	3%	69	5%
Switzerland	42	9%	79	5%
Norway	1	0%	9	1%

Observing the situation of European countries (tab.3.4) we can see that Germany, as in the case of end-of-pipe technologies, presents the highest innovative rate. Contrarily to the previous case, the distance between the innovative behaviour of Germany and those of other Countries appears less relevant. Countries like France and UK present percentages higher than 10% as well. Finally, Japan also in the field of recycling presents similar percentages in the two databases and, generally, it possesses higher percentages in end-of-pipe technologies rather than in recycling.

Summarising the results, some main elements can be evidenced:

1. the United States generally patent in the environmental technologies more than Europe;
2. Germany patents more than all the European countries;
3. by analysing the different sub-sectors, the situation appears more fragmented.

The analyses performed above can be synthesised using a different statistical instrument, which has been developed in studies on international trade by Balassa (1965), and applied to patenting (Soete, 1987), or to countries' technological specialisation (Archibugi and Pianta, 1992). It consists of an index – *Normalised Revealed Technology Advantages (RTA)* –, which measures the countries' specialisation in patenting activity. This index has the property of being equal to 0 if the country holds the same share of patents in a given technology as in the total of the country's patents, and of being below (above) 0 if there is a relative weakness (strength) in that field.[14] Notice that a value of the index greater than 0 denotes a *relative* advantage, and should not be confused with an absolute advantage. So, it may be possible that a country has a relative advantage in a certain sector, but an absolute number of patents lower than other countries showing smaller values of RTAs in the same technological sector.

Tables 3.8 and 3.9 show the values of the index in our study.

Tab. 3.8 - Normalised RTA, US database

	Recycling	End-of-pipe
USA	0.03	-0.04
Japan	-0.19	0.17
Europe	0.04	-0.06
Other	0	0.01

Tab. 3.9 - Normalised RTA, European database

	Recycling	End-of-pipe
USA	0.07	-0.10
Japan	-0.19	0.16
Europe	-0.02	0.02
Other	-0.02	0.03

These data evidence that high specialisation of a country in the two classes cannot be observed. However, the United States are more oriented than Europe towards the field of prevention (recycling). As we have already expressed, this is the field in which efforts should be oriented to solve the environmental problems, considering the biggest efficiency and effectiveness of the prevention methods with regards to purification. As we can also observe, Europe is more oriented to recycling in the US database. Two possible explanations can be identified. On the one hand, this may depend on the fact that recycling technologies are more efficient and affective than end-of-pipe, and so they are the technologies that firms sell in foreign markets. On the other hand, as we have observed, the United States invest largely in recycling inside their market. So that European firms "have to adapt" to the mainly demanded type of technologies in the US, if they want to enter in that market.

3.3.2 The situation of the chemical industry

To better understand the contribution of the chemical industry to the development of environmental technologies, we have analysed patents that the major European, Japanese and US chemical firms have realised among those that we have found with the keywords method. Table 3.10 shows the results obtained using the American database, and table 3.11 refers to the European database.

[14] The RTA index has been originally defined as: $RTA_{ij} = (n_{ij}/ \sum_i n_{ij})/(\sum_j n_{ij}/\sum_i \sum_j n_{ij})$, where n_{ij} is the number of the patents of the country i in the technological class j registered in a specific patent office. However, this formulation of the index suffers of the disadvantage of taking values between zero and infinity with a average of 1. So it has a lack of normality. To solve this problem, a different measure has been defined by Dalum, Laursen and Villumsen (1998). It can be identified as a "Normalised" RTA index, and can be expressed as: Normalised RTA = (RTA-1)/(RTA+1). This method has the advantage of attributing changes below unity (zero in this case) the same weight as changes above unity.

Major chemical firms have been selected referring to their 1997 turnover.[15] The study has been carried out for the top ten enterprises belonging to the chemical and petrochemical sub-sectors. To obtain patents, firms' names have been used as keywords. In this respect, for every company the number of patents contains also all patents realised by all subsidiaries whose names is composed at least by the mother company's name.[16]

Table 3.10 - Environmental patents, US database, Large chemical firms

	End-of-pipe		Recycling		Total
	Val.	%*	Val.	%*	Val.
USA					
Dow Chemical	6	21%	22	79%	28
Du Pont	6	16%	31	84%	37
Exxon	14	27%	37	73%	51
Mobil	14	24%	45	76%	59
Texaco	6	20%	24	80%	30
Chevron	3	33%	6	67%	9
Amoco	3	43%	4	57%	7
Total	52	24%	169	76%	221
Average value	7.4		24.1		31.6
Europe					
Akzo Nobel	3	19%	13	81%	16
Basf	10	26%	28	74%	38
Bayer	7	29%	17	71%	24
Hoechst	6	15%	34	85%	40
ICI	2	18%	9	82%	11
Rhone Poulenc	0	0%	3	100%	3
Eni	1	8%	11	92%	12
Ciba-Geigy	4	44%	5	56%	9
Shell	13	50%	13	50%	26
British Petroleum	0	0%	9	100%	9
Elf Aquitaine	1	100%	0	0%	1
Total	47	25%	142	75%	189
Average value	4.3		12.9		17.2

* Calculated with reference to the total number of environmental patents.

It is useful to remember that, in this case, patent nationality corresponds with the parent company nationality. To make an example, all patents realised from firms of the BASF group have been considered as European patents, even if they belong to US associates. So, there is a difference with previous analyses where a different method has been used. In the US database, patent nationality corresponds with the nationality of the patent's owner, while in the European database, nationality depends on the country in which the patent application has been firstly submitted. Different methodologies have been used because of different organisation of the two databases. The special method used in this part of the research is due to the fact that we focused on chemical groups, and patent nationality has to be considered as the mother company nationality. We could use such methodology because of the restricted number of patents that we could check one by one.

[15] We used the Global Fortune 500 rank for 1997.
[16] We tried to extend the analysis to all first-level subsidiaries, but differences were unappreciable.

Now we can examine the results of our analyses. The case of Japan has been here omitted for it refers only to one company (Mitsubishi), with a very small number of patents.
If the number of environmental patents is compared with the total number of patents that each firm has realised during the reference period, we can observe very low values. However, in the chemical sector the ratio between environmental patents and total patents is higher than other sectors. In fact, chemical firms show average values of 1% or 2%, while other industries show smaller values or, at least, halved. For instance, in the US database, recycling patents realised by inventors of different industries represent the 0.6% of the total number of patents (1594/261514), while end-of-pipe patents only 0.4% (1111/261514). The case of the European database is quite similar. Such data reflect a greater attention to environmental innovations by the chemical industry, if compared with other industries. In fact, public pressure and government attention were higher for chemical firms, because of their higher potential polluting power.

Table 3.11 - Environmental patents, European database, Large chemical firms

	End-of-pipe		**Recycling**		**Total**
	Val.	%*	Val.	%*	Val.
USA					
Dow Chemical	6	13%	40	87%	46
Du Pont	4	9%	41	91%	45
Exxon	8	19%	35	81%	43
Mobil	3	7%	42	93%	45
Texaco	6	25%	18	75%	24
Chevron	2	33%	4	67%	6
Amoco	0	0%	5	100%	5
Total	29	14%	185	86%	214
Average value	4.1		26.4		30.6
Europe					
Akzo Nobel	8	36%	14	64%	22
BASF	23	29%	55	71%	78
Bayer	9	18%	41	82%	50
Hoechst	14	33%	29	67%	43
ICI	4	16%	21	84%	25
Rhone Poulenc	3	20%	12	80%	15
Eni	0	0%	11	100%	11
Ciba-Geigy	3	8%	33	92%	36
Shell	0	0%	25	100%	25
British Petroleum	0	0%	11	100%	11
Elf Aquitaine	3	50%	3	50%	6
Total	67	21%	255	79%	322
Average value	6.1		23.2		29.3

* Calculated with reference to the total number of environmental patents.

Another interesting result regards the type of innovation realised. Both in the US and European databases, average values of recycling technologies are clearly higher than values related to end-of-pipe. So, there is an evidence of a greater effort in the field of prevention rather than ex-post intervention and cure.

Previously, we have seen that US agents (not only chemical firms) spend more attention to the recycling sector, while Europeans patent more in end-of-pipe technologies, at least in the European database. When data relative to the chemical sector are observed, some differences arise. Firstly, US chemical companies follow the domestic trend and patent more in recycling technologies, but with higher percentages. Secondly, European chemical companies follow a reverse trend and patent more in Europe in recycling technologies as well. This result suggests that the European chemical industry is following the US pattern, and spends more attention to the recycling sector rather than other sectors. However, we have only taken into consideration large firms, which have an international dimension. So, both the European and US companies are used to work under similar conditions.

Another result of our analyses refers to the greater propensity of US firms than European's to patent in the recycling sector. As tables 3.10 and 3.11 show, the average value of recycling patents made by US firms is always higher than average value made by European firms, even in the European database. US chemical firms have big advantages in patenting recycling technologies in Europe, and so the existence of an European market of such technologies appears.

Furthermore, while US corporate patents are always due to mother companies or to their US subsidiaries, patents of European chemical companies are sometimes made by US associates. For example, in the US database all patents realised by Shell and Ciba-Geigy and some patents by Hoechst, BASF and Akzo belong to US subsidiaries. In this respect, data suggest once again the main role of American agents in patenting. In turn, this result may reflect the greater pressure of legislation and public opinion in the US, rather than in Europe. These pressures were able to stimulate the creation of both a market for environmental technologies (especially recycling), and research competencies in this field. As a result, the existence of positive externalities makes convenient for European firms to locate environmental research in the US.

A different kind of analysis focuses on **patent quality**. In section 3.2.1 we have seen that in order to evaluate patents' quality it is possible to consider the number of times in which that patent has been cited in other patents. The more the number of citations, the more is its importance. We performed this analysis only in the US database (we do not have such data for European patents), and only for patents of major chemical companies. Table 3.12 shows results relative to the end-of-pipe and recycling sectors, respectively. Patents realised by US companies are (on average) more cited than European's, in the case of recycling technologies. However, an opposite situation emerges in the case of end-of-pipe technologies. It can be observed that Shell has the higher average value of citations in end-of-pipe technologies, and this situation enhances the European average value. But all patents realized by Shell have been realised by US subsidiaries.

So we can conclude that, on average, patents realised by US firms are of greater quality than patents realised by European firms also in the end-of-pipe sector. Furthermore, cause we're looking at the US database, we should consider that European patents can be considered as "the best" patents realised by European companies.[17] Even if Shell's patents are omitted, we can observe that US patents are most cited in the recycling sector. This is the sector where innovations are more efficient, because more focused on prevention.

Tab 3.12 - Patent citations, Recycling sector, US Database, years 1993-1997

[17] Following the hypothesis that only innovations of high quality are patented abroad.

Company	Average value of Citation - End-of-pipe -	Average value of Citation - Recycling -
USA		
Du Pont	1.8	1.3
Dow	0.3	1
Texaco	1.7	2.3
Mobil	0.9	1.5
Exxon	1.3	0.5
Chevron	2.3	0.3
Amoco	0.0	2.0
Total	1.2	1.3
EUROPE		
Bayer	0.0	0.5
BASF	3.2	0.8
Akzo	0.3	1.0
Hoechst	0.3	1.0
Ciba	0.5	0.6
Rhone -Poulenc	-	0.3
Shell	5.3	1.4
Eni	0.0	0.9
British Petroleum	-	0.8
Elf Aquitaine	-	-
ICI	0.3	1.6
Total	2.3	0.9

We can now summarise the most relevant results of this section:

1. In the environmental sector, the chemical industry innovates more than other industries. This pattern is similar both for large US and European companies;
2. Both European and US firms make more innovations in recycling rather than the end-of-pipe technologies;
3. The average value of recycling patents made by US firms is always higher than the average value made by European firms (even in the European database). Moreover US firms show higher quality patents than European firms in recycling technologies. So they “export” in Europe patents with higher average quality;
4. Some European chemical corporations produce environmental innovations in the US. Two causes are defined:
   - The existence of greater pressures from public opinion and legislation;
   - The presence of stronger research competencies on environmental issues.

3.3.3 Analysis of patenting agents

Previous analyses have shown that only a small share of environmental patents belongs to large chemical companies. Which agents are then responsible for the remaining amount of environmental patents?

To answer this question we considered a random and stratified sample of environmental patents and controlled for their assignees.[18] When we found patents with more than one assignee we considered them separately (excluding those not belonging to firms). In this respect, the total number of patents is different from the total number of assignees. Referring to this situation, we observed that the number of patents with multiple assignee is higher for Japan than for Europe and the US. In the latter, such patents are about 1,5% of the total number of patents, while in the former they are about 12%. In Japan, therefore, the collaboration between different agents is more likely.

Different assignees have been classified in six classes:
- Firms belonging to chemical groups;
- Firms belonging to other groups;
- Independent firms, i.e. firms which do not belong to any group;
- Government agencies;
- Universities (or other research institutes);
- Single inventors.

The first two groups have been then subdivided between mother companies and subsidiaries. In order to distinguish firms' typology and sector, the "Who Owns Whom" 1997 directory (WOW, Dun & Bradstreet) has been used. Table 3.13 shows results related to the US database (end-of-pipe and recycling sectors, respectively), while table 3.15 shows results related to the European database.

US database

The US show a high prevalence of independent firms, especially in the end-of-pipe sector. In Japan, most patents are carried out by not chemical groups, and the main role is played by the automobile industry, in the end-of-pipe sector. Most of the European patents are carried out by not chemical group in the recycling sector, and by independent firms in the end-of-pipe. It is important to observe that, in this case, European chemical groups show higher percentages with respect to the US and Japan. And this pattern highlights the relevant role played by the chemical industry in Europe.

As in the case of countries' analysis, we tried to compare the relative specialisation of different agents by using the RTA indexes. So, table 3.14 shows that industrial groups are most active in the recycling sector, while the independent firms are active in the end-of-pipe's. This pattern emerges both for Europe and the US, although the specialisation values are quite low. On the contrary, all Japanese agents specialise in the end-of-pipe sector.

Table 3.13 - The innovating agents, US database, years 1993-1997

	End-of-pipe			**Recycling**		
	Europe	**USA**	**Japan**	**Europe**	**USA**	**Japan**
Chemical sector						
Mother Company	10%	8%	9%	19%	17%	11%
Subsidiaries	19%	6%	9%	11%	9%	11%
Total	29%	14%	18%	30%	26%	22%

[18] The 10% of environmental patents were included in the sample. They were proportionally subdivided among countries, and between recycling and end-of-pipe sectors.

Other Sectors						
Mother Company	13%	10%	40%	23%	15%	48%
Subsidiaries	19%	6%	21%	23%	14%	15%
Total	32%	16%	61%	46%	29%	63%
Not in WOW	36%	50%	19%	19%	38%	15%
Government Agencies	3%	8%	0%	0%	3%	0.0%
Universities	0.0%	9%	0%	5%	3%	0.0%
Single Inventors	0.0%	3%	2%	0%	1%	0.0%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3.14 – Normalised RTA indexes, US database

	End-of-pipe			**Recycling**		
	Europe	**USA**	**Japan**	**Europe**	**USA**	**Japan**
Chemical sector	-0.08	-0.24	0.11	0.056	0.14	-0.12
Other Sectors	-0.19	-0.21	0.16	0.11	0.13	-0.19
Not in WOW	0.09	0.04	0.20	-0.09	-0.04	-0.28
Government Agencies	0.37	0.17	-	-1	-0.20	-
Universities	-1	0.19	-	0.29	-0.24	-
Single Inventors	-	0.19	0.37	-	-0.24	-1

Table 3.15 - Innovating agents, European database, years 1993-1997

	End-of-pipe			**Recycling**		
	Europe	**USA**	**Japan**	**Europe**	**USA**	**Japan**
Chemical sector						
Mother Company	9.5%	6%	6%	18%	24%	10%
Subsidiaries	9.5%	10%	11%	19%	15%	14%
Total	19%	16%	17%	37%	39%	24%
Other Sectors						
Mother Company	14%	6%	22%	8%	13%	47%
Subsidiaries	18%	15%	50%	13%	9%	5%
Total	32%	21%	72%	22%	21%	52%
Not in WOW	28%	45%	6%	31%	24%	14%
Government Agencies	0%	0%	0.0%	1%	0%	0.0%
Universities	0%	6%	0.0%	1%	2%	0.0%
Single Inventors	21%	12%	6%	9%	14%	10%
TOTAL	100%	100%	100%	100%	100%	100%

European database

In the case of the European database, while Japanese agents behave similarly to the US database, European and US agents show some differences. In both regions, the chemical groups are mainly active in the recycling sector, while in the end-of-pipe differences emerge in the two cases. So, independent firms in the US, and industrial groups from other sectors are the main patenting agents.[19]

[19] A surprising result of this analysis refers to single inventors. While in the US they account for about 3% of total patents, in Europe this percentage raises to 21% as maximum.

In terms of RTA indexes (Tab. 3.16), previous results seem to be confirmed, and US industrial groups are most specialised in recycling, while US independent firms patent more in the end-of-pipe technologies. In Europe, only the chemical sector shows a specialisation in recycling. And in Japan, all agents show a specialisation in the end-of-pipe sector.

Table 3.16 – Normalised RTA indexes, European database

	End-of-pipe			Recycling		
	Europe	**USA**	**Japan**	**Europe**	**USA**	**Japan**
Chemical sector	-0.18	-0.39	0.09	0.11	0.19	-0.09
Other Sectors	0.11	-0.11	0.21	-0.12	0.07	-0.29
Not in WOW	-0.02	0.08	-0.06	0.016	-0.08	0.047
Government Agencies	-1	-	-	0.29	-	-
Universities	-1	0.19	-	0.29	-0.24	-
Single Inventors	0.19	-0.12	0.048	-0.25	0.08	-0.04

In sum, the most relevant results emerging from the previous analyses are the following:

1. The US independent firms show a technological specialisation in the end-of-pipe sector, for they have high percentages of both domestic and foreign patents. The same can be said by referring to European independent firms, but only when we consider the US database (i.e., foreign patents). On the contrary, none specialisation emerges by considering domestic patents. However, it is not possible for us to check the industrial sectors in which those firms usually operate. It is our concern that most of them are active in the sector of "environmental industry". As a consequence of the introduction of environmental regulation, many firms specialised in the supply of end-of-pipe technologies which were able to satisfy the legislative standards. In chapter 5 we will try to better explore this issue, with the objective of analysing in greater details the industrial organisation and working of this new sector.
2. Chemical groups are more oriented towards recycling technologies, and seem more interested in patenting preventive solutions, which are characterised by a greater technological effectiveness and a higher economic efficiency. This result emerges by observing both the US and European databases. In general terms, however, chemical groups are active in the whole environmental sector.
3. The greater attention paid by US agents to recycling emerges also when considering industrial groups which are not active in the chemical sector. In the case of Europe, only the foreign patenting activity of industrial groups is oriented towards recycling, while domestic patents are more focused on end-of-pipe.
4. The Japanese interest on environmental issues is limited to the end-of-pipe sector. Most of patents are realised by not-chemical groups. Among those, an important role is played by the automobile sector.
5. Universities, research institutes and government agencies show very low percentages of patents in the environmental sector. Highest values are shown by the US in the end-of-pipe technologies.

3.4 Conclusions

This report aims at analysing the way in which European chemical industry contributes to the development and diffusion of environmental technologies. Two analyses have been carried out: (1) a general patent overview, and (2) a specific case study analysis. The former gives information related to end-of-pipe and recycling technologies, and the latter to clean technologies. We have now realised the general overview using the US and European patent databases. Main results can be so summarised.

First, innovative rates of the US, Japan and Europe in environmental technologies are similar to innovative rates in other types of technologies. The US have shown a greater innovative rate in recycling, whose technologies are more effective and efficient than end-of-pipe technologies, both from an economic and ecological viewpoint. Among European countries, Germany shows the greatest innovative rate, both in the end-of-pipe and recycling sectors.

These results could bring to the consideration that rigid environmental standard and strong public pressure have a positive influence on the environmental innovative rate. As a matter of facts, the United States have faced environmental problems through very strict standards, and Germany has adopted the most rigid standards of Europe (see chapter 1). This could evidence the great influence that this type of regulation has on environmental innovation. However, we must specify that both United States and Germany (compared to other European countries) are the more innovative countries, not only in the environmental sector, but also in general terms. This result shows that the environmental sector broadly follows the trend relative to innovation.

The influence of regulation on the innovative rate could be demonstrated from the clear US prevalence in the class of hazardous wastes. Neither Europe nor Japan patent in the United States in this sector, and in Europe the United States possess the 61% of patents. This result can be interpreted by considering that in the United States there is a wide regulation about hazardous wastes and an equally wide system of responsibilities do not exist neither in Japan nor in Europe (Esteghmat, 1998).

Another result of our study refers to the prevailing type of innovations. While the US realise most innovations in recycling, Europe seems more oriented towards end-of-pipe technologies. So, the US show a greater attention to prevention, because recycling technologies are more effective than end-of-pipe in solving environmental problems. On the contrary, in the past years European policy spent greater attention to the end-of-pipe sector, even if at a theoretical level, prevention has been considered as mostly important.

Second, to better understand the innovative pattern of the chemical industry, patents realised by major chemical companies have been analysed. So the chemical industry patents more than other industries in the environmental sector. Among environmental technologies, then, greater attention has been paid to the recycling sector, both for European and US companies. But American firms show a higher average number of domestic and foreign patents than European firms.

This result suggests the existence of an European delay in the development of environmental technologies, and US supremacy is confirmed in two other ways. Firstly, US patents have an average quality grater than European patents. Secondly, in some cases, European firms realise environmental patents in the United States. So, a greater market for environmental technologies exists in the US, and technological and research competencies are there concentrated.

Third, the analysis of a random sample of environmental patents allowed us to study innovating agents. Differences arose among countries. In the US most innovations are realised by independent firms, especially in the end-of-pipe sector. Japan is ever specialised in the end-of-pipe sector, where a high percentage of patents is realised by not chemical groups. Chemical European and US groups realise high percentages of patents, and play an important role mainly in recycling, where they account for about 30-40% of total patents. Finally, universities, research institutes, and government agencies show very low percentages of patents. Interesting results appear only for American agents. Referring to multiple assignee patents, in Europe and the US they are almost rare, but in Japan they are not. So in Japan collaborative patterns in innovative activity are more likely.

Chapter 4

Analysis of clean technologies and green products: Case Studies

(R. Arduini)

4.1 Introduction

Clean technologies represent the main building block for a sustainable development as they are more effective and efficient then end-of-pipe technologies. Moreover, as we already discussed in Chapter 1, they play a critical role in defining the competitiveness of firms which have to deal with growing legislative awareness and increasing public opinion pressures.

As a matter of fact, the chemical industry had to consider human health and environmental impact of new chemical compounds and manufacturing processes. It developed new chemical low-toxicity products, and new processes and syntheses removing or limiting the use of toxic reagents, producing minimal waste, and requiring minimal energy. All these factors gave rise to the so called **green chemistry**.

Clean technologies cannot be analysed by using patent-based statistics, especially when using a key-words approach as we did for end-of-pipe and recycling technologies. On the contrary, we preferred to conduct a set of five case studies of chemical companies that were active in developing some successful clean technologies. To be true, the economic literature reports many examples underlining the effort in R&D that the chemical industry promoted for developing more eco-compatible solutions (among others, see Federchimica, 1992; Sassoon and Rapisarda Sassoon, 1993; Gerelli, 1994; Wiesner *et al.*, 1995; Consorzio Interuniversitario Nazionale, 1999). However, the existing studies do not take into consideration some relevant factors. For example, they do not give enough emphasis to the forces that induce firms to undertake the development of more eco-compatible innovations, such as the role of financial incentives, of legislation, and of public opinion. At the same way, they do not pay enough attention to other relevant questions: is the innovative activity conducted through collaboration agreements? Are specialised engineering firms and research institutes (universities) important actors in the innovative process? Do firms patent their innovations? Do they license their technologies? Are clean technologies transferred to other firms and industries? How is the pattern of diffusion and adoption shaped?

In order to answer these questions, we analysed five Italian chemical manufacturers belonging to large European chemical groups. We chose those companies that agreed to the "Responsible Care" and EMAS voluntary programmes (see chapter 2), which introduced a policy of continuous improvement of the activities related to health, safeness and the environment. In addition, we assessed the impact of such initiatives on the innovative behaviour of the firms.

While the first three cases are examples of clean technologies, the last two concern green products. This distinction is important because, behind the two, companies have to face different strategic choices, incentives, and obstacles. Indeed, in most cases the final users of green products are the consumers, while the users of clean technologies are other firms. Moreover, apart from environmental benefits, clean technologies generate additional economic benefits, while the success of a green product is determined by the consumer's availability to buy more eco-compatible products which usually present higher prices compared to other products of the same category.

4.2 Enichem

Enichem is the largest company of our survey, and employs some 16,000 people. It belongs to the ENI Group and is located all over the world with 25 productive sites, most of which are in Europe and especially in Italy. Enichem is exclusively active in the chemical sector, while other companies of the ENI group operate in the sectors of hydrocarbon research and production, oil products refinement and distribution, natural gas extraction and distribution, and environmental engineering and services. In terms of production, the production activity of Enichem contemplates a wide range of chemical and petrochemical products used in different applicative sectors (packaging, pneumatics, transportation, building, electronics, electric household appliance, lubricating, furnishings).

Apart from other products, in the following, we will focus on the most relevant clean technologies and products developed by Enichem. The first case refers both to a product and process innovation, while the other two examples refer to a process innovation.

4.2.1 DMC Project

The Dimethylcarbonate (DMC) is an organic compound characterised by its low toxicity. It is proposed:
- as a non dangerous solvent;
- in the chemical synthesis, as an intermediate for reactions trough clean processes in substitution to toxic and polluting reagents (phosgene, dimethyl phosphate, methyl chloride);
- in the production of polyurethane foams, in substitution to freon;
- it has also been considered as a possible compound of oxygenated reformulated gasoline and of gas oils able to reduce the polluting emissions of engines.

It is therefore considered a versatile chemical product with low environmental impact. The commercial success of such a product is not directly influenced by the consumers' buying behaviour, since the actual users are other firms. Thus, its success depends mainly from its technical characteristics and from the attention that the customer (other firms) pays to the environmental image and to the promotion of an environmental policy. In this case, Enichem's decision is part of the general tendency shown by the chemical industry to substitute highly reagent intermediates, to employ less toxic substances and to reduce refluents production. The early realisation of these elements allowed Enichem to reach a competitive advantage when the latter began to be largely diffuses and acknowledged. Indeed, thanks to its experience, Enichem presented itself as market and technology leader of this sector.

The introduction of a new compound means also the creation of a market for it. From this viewpoint, Enichem developed a series of new processes, products and applications based on its employment.[20] These processes are characterised by the use of a non dangerous reagent, by the absence of solvents and of polluting wastes.

Very often the development of a new compound with better environmental characteristics needs also a new process, therefore product and process innovations are strictly connected in chemicals. Concerning the DMC production, it has been necessary to develop a new technology – applied to the DMC production at the Ravenna plant – in order to avoid the use of phosgene as well as the co-production chlorides. The only co-product is water. The new technology allows also to obtain DMC at a lower cost in high capacity systems. The new technology has been awarded the Philip Morris prize in 1990.

This technology is covered by several patents, registered from 1979 to 1995, and is currently sold to the market through licenses. Furthermore, the technology has been developed inside the ENI group R&D structures, and is therefore a technology which benefited of the experience and of the competencies of all the group. The DMC project obtained funding within the Applied Research Funds, the Eni Fund for Research and the InterSociety Eni Fund.

4.2.2 Cumene Project

Cumene is an important intermediate of the petrochemical industry. The technology developed by Enichem consists in a new industrial process for its production through a new catalyst. The technology is applied to the cumene production at the Porto Torres Enichem plant. Through this technology the traditional toxic catalyst, requiring special dumps for its disposal, is eliminated. The cost of such disposal is extremely variable and may become extremely high once the plant has not or has exhausted the internal dumps. On the contrary, the new process uses a regenerating catalyst which can be utilised in several reaction/regeneration cycles, and at the end of its life does not requires any special dumps.

At the same time, the new technology allows to obtain cumene having a higher degree of pureness, reducing as well the reagent specific consumption (benzene and propylene), and increases considerably the process outputs. Moreover, a significant reduction of the industrial system maintenance costs has been obtained thanks to the absence of the corrosion problems previously caused by the traditional catalyst. The absence of these problems produced also a sensible increasing of the general security levels in the system management.

The reasons which pushed Enichem to undertake a research activity in this project lie in the need to increase the existing system skills, as well as in the competitiveness increase through the reduction of variable costs, in the improvement of the system efficiency – through the reduction of the system stops and of the maintenance interventions –, and in the reduction of environmental problems linked to the use of the traditional catalyst. The first phase of the research project (analysis and research of materials having to substitute the traditional catalyst) has been financed by the Intersociety Fund for the Research of the ENI Group.

In order to develop the technology, Enichem collaborated with another society of the same group, named EniTecnologie. The technology is protected by several patents (the first one has been issued in 1989), and has not yet been licensed. However, the license is available in some

[20] For example high purity dimethyl carbonate (H-DMC) used in the printed circuits and in the lithium batteries; diphenylcarbonate (DFC) intermediates for polycarbonates and agrochemicals.

selected areas.

4.2.3 Cicloesanone ammoximation project.

In order to produce caprolactam, Enichem developed a new process based on the new cyclohexanone ammoximation technology. This technology takes part of an innovative clean oxidation technology family which Enichem is developing, based on the employment of oxygenated water and the catalyst TS-1, which has been refined inside the group. The previous existing technology (*Raschig*) uses as reagent some toxic and highly polluting gases, and from the reaction it creates a great quantity of ammonium sulphate, whose recover and fertilising use is less and less suitable and more and more problematic. With the new technology, oxygenated water is used, hence producing water after the reaction. In such a way, the emission of NO_x and SO_2 (very toxic gases) are eliminated and the co-production of ammonium sulfate is reduced.[21]

Furthermore, the new technology allows a cost reduction because it uses a simplified process – with elimination of the hydroxilamine sulfate synthesis. This generates a generalised cost reduction, which involves both investment, management and maintenance costs. Moreover, it also reduces the co-production of ammonium salts, whose selling price does not allow a complete recover of costs for raw materials. With the new technology, it is also possible to obtain an efficiency increase, because of the increased outputs of ammonia.

The new technology development has been motivated by the need of improving the competitiveness attaining a technology leadership. Moreover, the influence of the ammonium salts market trends on the caprolactam selling prices – becoming ever more problematic and characterised by strong depressive cycles – was expected to be reduced. For this research, Enichem invested funds of the ENI Intersociety Fund and of the Technology Innovation Fund of the Ministry of Industry. The technology has been protected by several patents. Until today no license has been allowed but licenses are available for selected areas.

4.2.3 What we have learnt from the Enichem case

From the analysis of the previous cases it is possible to drawn the following conclusions. As a general rule, the innovative activity is mainly promoted by the need of increasing one's competitiveness. There are however two different elements playing a role in the development of an environmental innovation.

In a first case, the innovation is linked to internal elements, mainly of economic nature. For example, the innovation introduces, apart from a greater eco-compatibility, an output increase, a cost reduction – both operating, investment, and maintenance costs –, the production of more pure products, the reduction of not favourable co-productions. In all these cases, the environmental concern is only one of the different variable being considered within the innovative activity, and its importance can strongly depend on the legislation – e.g., in the case of cumene, environmental problems are linked to the need of disposing the catalyst in

[21] The ammonium sulfate co-production is completely eliminated in the first phase of process (cyclohexanone ammoximation), while it is still present in the second phase (caprolactam production). The ammonium sulfate production is then reduced. Studies in advanced phase of development are in progress to eliminate also in this phase the ammonium sulfate co-production.

special dumps.

In a second case, the environmental variable represents the main strategic concern, and the higher competitiveness to which the firm aims is linked to more external reasons. In this case, the innovation is mostly developed with the aim to offer cleaner products to the market, and to exploit the environmental variable from the economic point of view. This case involves greater risks, because customers might not be interested to the environmental characteristics of the product. Hence, companies have to "invent" the way in which the product can be used and sold. This happened in the DMC case, where Enichem had to create a substantial market for the product, implementing the relative industrial applications and technology of use.

As far as public policies are concerned, government founds have been important but not fundamental in the development of clean technologies. Indeed, Enichem would have invested in the new project even without any public support, because of the strategic interest of the firm in such technologies.

Finally, the licensing strategies adopted by Enichem are strictly dependent on the strategic goals. In the case in which the technology has mainly been developed for the market, then diffusion is a natural consequence. On the contrary, if the new technology aims to increase the internal competitiveness, the diffusion results to be hindered by the need of exploiting the innovation economic benefits. In these cases, the firm selects specific areas in which the technologies could be eventually diffused.

Table 4.1 – Enichem: Summary table

Project	DMC	Cumene	Cyclohexanone ammoximation
Environmental benefits	• product with low toxicity and with low environmental impact • technology eliminating toxic and polluting chloride raw materials, by-products, and co-products	• elimination of toxic catalyst • catalyst regenerating • increase in the security of the system management	• elimination of NOX and SO2 emissions • elimination of toxic reagents
Economic benefits	• industrial exploit of the DMC potentiality and of its derivatives, like non dangerous and non polluting products • technology and market leadership	• higher degree of cumene pureness • reduction of reagent specific consumption and increasing of process outputs • reduction of maintenance costs • reduction of disposal costs and problems	• reduction of investment, management and maintenance costs (process simplification) • reduction of ammonium sulphate co-production
Funds	• public support • Industrial group	• Industrial group	• public support • Industrial group
Patents	Yes	Yes	Yes
License/selling	available in selected areas and business	no, but available in selected areas	no, but available in selected areas
Collaborations	only inside the group	only inside the group	No
Main innovative objective	Internal and external	Internal	Internal

4.3 Ciba Specialty Chemicals (Additives)

Ciba Specialty Chemicals was created in 1997, after the merger of Ciba-Geigy and Sandoz and the creation of Novartis, and the decision of making independent branches related to industrial chemicals – e.g. Additives. The firm under study is situated in Pontecchio Marconi (Bologna – Italy), where a production estate and an R&D lab is located. Indeed, the main activity of this site is research, development, and production of additives, i.e. high-value products of speciality chemicals. Such additives are used in order to improve the properties of several final products, e.g. parts of cars, accessories for domestic use, synthetic fibres employed in clothing and furniture industry, synthetic rubbers, lubricating oils. Active and synergetic principles for insecticide of domestic use are produced as well. About 90% of production goes to foreign markets. Finally, the firms employs 420 people.

As far as clean technologies are concerned, the two main interesting initiatives carried out by the firm consist in process modifications aimed to reduce process polluting emissions.

4.3.1 Optimisation of gas emissions with solvent recovering and energy production

This project allowed to recover during the production more than 90% of the substances previously assigned to destruction. Only 10% is disposed in a new incinerator. The investment of this project has been repaid after seven years thanks to the recovery of solvents, the reduction of purification costs, and to thermo-destruction with energetic recovery.

The first part of the project consisted in a detailed analysis of the situation of the plant emissions in order to individuate the main causes and define the intervention to be promoted. For example, it has been noticed that nitrogen was the bearer of the main part of polluting agents, and hence the global consumption of the inert gas has been reduced, thanks to some system modifications. It has been tried to reduce at one's best the use of certain substances, among which the chloride solvents, and the production has been organised as to reduce the emissions through the adjustment of the productive loading. Finally, much attention has been paid to the recycle of organic solvents through an under-cooling system.

This first phase allowed the reduction of 20% of emissions and the recovery of ab. 70% of organic solvents. The remaining 10% is disposed by means of an incinerator. The incinerator permitted indeed a high efficiency in the destruction of polluting agents, as well as the opportunity to elaborate high refluent capacities. Thus, it became an economically convenient solution because permitted the steam generation recovering the enthalpy of hot combustion fumes.

The development of this project imposed Ciba to promote a deep analysis of the whole process, in order to individuate where there was the need of intervention, finding each time the most efficient solution both from the environmental, productive, and economic viewpoint. In this perspective, the project cannot be "transferred" to other production plants. As a matter of fact, this is not a "radical innovation", but a range of improving interventions made inside the production process. The realisation of the system has been committed to an engineering society. Indeed, chemical companies do not generally deal with the realisation of the whole system and, apart from the case of large companies, they commit to engineering firms the improvement of the productive process.

4.3.2 Recycling of waste water.

This technology has been mainly developed in order to obtain some relevant improvements in terms of competitiveness. Indeed, one of its relevant characteristics is that it joins both economic and environmental benefits. For this reason, the company itself is trying to keep information about this technology very secret and avoid any disclosure. The attention paid by the firm in avoiding any unintended information disclosure underlines another problem regarding the process of innovation diffusion. In this case it is not the process specificity to limit its diffusion, but the willingness of the company to protect an innovation strongly affecting its competitiveness.

The objective of this technology was to modify an hydrogenation process making it cleaner thanks to the reduction of water refluents. The process has been revised both from the chemical and systemic side. Also in this case, it has been necessary a deep analysis of the process in order to individuate the crucial points of intervention. Moreover, as in the previous case, the modification of the manufacturing process is strictly linked to the possibility of obtaining economic benefits. Also in this case the development of the technology has been committed to an external engineering firm, which strictly collaborated with the company.

The present case study highlights two important elements in the stimulus to promote environmental innovations: the role of legislation and the importance of competitiveness. The need of respecting the regulation pushed the firm to find economically convenient solutions. This meant significant consequences on the competitiveness. The elements which can have and influence on competitiveness are different, from output improvements to raw materials recovery, from environmental image to customer acceptance. It seems also that research and development funds do not have a great influence, and both the projects didn't benefit of any State of European financial incentive.

Another important element of this project is the non-possibility to transfer the innovations. This aspect is linked to the great customisation of the interventions, and also to the great influence that they have on the competitiveness.

The company did not apply for any patent, preferring to protect the innovation through secrecy. It is also important to observe that the modification of the production process aiming at improving the eco-compatibility of the technology have been developed through a strict collaboration between the company and some engineering firms.

Table 4.2 – Ciba Specialty Chemicals: Summary table

Project	Gas emissions	Waste water
Environmental benefits	• reduction of gas emissions • solvent recovery	• Reduction of waste water • reduction of water consumption
Economic benefits	• solvent recovery • reduction of purification costs • energy recovery	• reduction of water consumption • other, not specified
Funds	No	no
Patents	No	no
License / selling	No	no
Collaboration relations	Engineering firm	Engineering firm
Main innovative promotion	Internal	Internal

4.4 Lonza S.p.A. (Intermediates and additives)

Lonza Intermediates and Additives is a branch of the "Algroup" multinational enterprise which operates in the chemical, aluminium and packaging sectors. Lonza Intermediates and Additives focuses its activities in research, development, and commercialisation of a wide variety of chemical substances as well as in the development of oxidation catalysts, and technology licenses. The products (mainly, anhydrous and its by-products: plasticizers for PVC, hardeners for epoxy resins, additives for food, intermediates of fine chemistry, polyester resins) are partially utilised by Lonza Intermediates and Additives to produce technocompounds (composite materials for manufacture moulding), and partially utilised by enterprises operating in the sector of production of materials for building and transport, products for agriculture, food, plastics, etc. The company has six productive sites (three of which in Italy), with a total of 1,000 employees. Also in this case we analysed the two main innovations concerning clean technologies. In both cases they are process innovations.

4.4.1 ALMA process

In the Ravenna plant it has been built a system for the production of maleic anhydride through a technologically advanced process allowing to attain better environmental results. The process, called ALMA, received two important international prizes: the *Kirkpatrick Chemical Engineering Award* (one of the main awards for chemistry engineering advanced projects of the world) by the review Chemical Engineering, and the *European Better Environment Award for Industry*, conferred by the European Commission within the UN Environmental Programme (UNEP). The prize has been assigned for the category "Clean Technology".

The ALMA technology introduces mainly three innovations:

1. the development of a new catalyst allowing to use n-butane in substitution of benzene which is a carcinogenic product. The research for developing such catalyst has been realised in collaboration with the University of Bologna;
2. the substitution of the fixed bed technology with a fluidised bed technology for a better heat reaction recovery. This innovation has been realised in collaboration with the ABB Lummus Crest regarding the engineering aspect;
3. the patented solvent process instead of wet process for the maleic anhydride recovery.

The environmental benefits realised through this technology, compared also to the previous technologies, are: gaseous emissions reduction and benzene elimination from the emissions, process water reduction, energy saving. The process presents also some economic benefits because it uses a less expensive raw material and allows to obtain a great energetic recovery. Also the investment costs are lower if compared to the previous technologies, firstly because the system complexity becomes lower, and then because the production process with a unique fluidised bed reactor is equivalent to the process with several fixed bed reactors.

The Alma process is covered by several patents and its development was mainly directed to the market. The technology in fact has been developed with the aim of being licensed and sold, even before building the system for Lonza. It is then a new technology in which the diffusion is not just available, but is the main aim of the firm. It but seems that the purchasing of the technology depends mainly on economic rather then on environmental reasons. In Japan, for example, as it demonstrates the revamping of an old system realised by Lonza with a fixed bed and catalyst technology, the benzene process results still competitive. On the contrary, in US, where according to the law benzene is banished, the diffusion of such technology is surely more likely used. In Europe, the production of maleic anhydride is 177,000 tons, of which 110,000 tons comes form benzene and 67,000 from butane using a fixed bed reactor. Given the low production cost, the environmental benefits and the excellent quality of the final product, ALMA technology diffusion in Europe is potentially high.

The development of the new catalyst benefited of a State funding for research. It has not been anyway an element considered very relevant in influencing firm decisions, both for its scarce value (10% of total development costs), and because it arrived in a further step respect to the decisions of developing the research.

4.4.2 Optimisation of the phthalyc anhydride production process

In the past years many efforts have been made to improve the output and the productivity of the phthalyc or o-xylene anhydride production process, but the attainment of such aims was hindered by the needs of obtaining high quality products. The new process allows to gain these needs thanks to the utilisation of new catalysts and to the adding of a reactor adiabatic to the principal reactor. This supplement can be made both in already-existent production systems than in the new units.

The new process allows, besides the achievement of a greater reactor productivity, to increase the purification efficiency, to reduce the liquids which should be disposed, and to realise an energetic saving. In this case, the decision to innovate came also from the regulation. In fact the firm, even respecting the legislation limits, had foreseen a worsening of the polluting standards to be respected and tried to anticipate the normative to conciliate the environmental-legislative aims together with the economic needs of the enterprise.

The technology has been developed in collaboration with the Swedish society Neste Oro, while the catalyst has been studied in collaboration with the University of Bologna. The technology is covered by several patents and the company's aims were both the realisation of the technology for Lonza, and licenses grants.

In relation to this project the firm did not benefit of financial promotions. The firm has been awarded, thanks to this innovative solution, with the *Consorzio INCA grant* (University Ca' Foscari, Venice) for clean chemical processes and products.

4.4.3 What we have learnt from the Lonza case

The present case allows us to identify the following important considerations. Firstly, the innovative promotion comes generally from elements of economic features, which in this case are linked to the possibility of selling/licensing the innovations. The great economic feature of the new processes is then exploited both to increase the internal competitiveness linked to the production processes (production improving, energetic saving, using of less expensive raw materials, reduction of investment costs, attainment of more purified products), and to offer the technology to the market.

A second relevant characteristic which induced Lonza to undertake the innovative process is the environmental regulation. In the second innovation, this element is represented by the fact that the firm is expecting a worsening of the legislative limits. In the case of ALMA, the fact that benzene has been banished in US determines a hard push to technology diffusion. In particular, the command and control regulation tool is considered an element which can promote innovation if an adequate period of time is given to firms to allow them to intervene with preventive solutions. Too short time periods force to end-of-pipe interventions.

Funding has a marginal role inside the promotion of the more eco-compatible research in the strict sense. Probably they are more helpful in diffusing the innovation rather than in their creation. Also in this case the collaboration with engineering societies as well the collaboration with the University of Bologna has been necessary.

Regarding the process of technology diffusion, the situation is very different from the previous case study. In this case in fact the firm tries to promote the diffusion both through selling than granting the licenses. Probably the main difference concerns the kind of innovation. In the previous case we dialled with incremental improving while here we have (mostly with ALMA) a very new technology. Concerning Europe, the diffusion of such technology is surely more linked to economic rather than to environmental elements.

Table 4.3 – Lonza: Summary table

Project	ALMA	Phthalyc anhydride
Environmental benefits	• gaseous emission reduction and without benzene • aqueous effluents reduction • process water reduction • energy saving	• reduction of liquids to be disposed • energetic saving
Economic benefits	• using of a less expensive raw material • energetic recovery • lower investment costs	• improving of outputs and of productivity • more pure products • energetic saving
Funds	State	No
Patents	Yes	Yes
License / selling	Yes	Yes
Collaboration relation	• engineering firm • universities	• engineering firm • universities
Main innovative promotion	To market	To market

4.5 I.C.I. Italia (Huntsman ICI "Italian Operation" s.r.l.)

I.C.I. Italia S.p.A. employs 154 people. The establishment was founded as branch of the "Atlas Chemical Industries", then it became part of the Imperial Chemical Industries Plc Group, and recently it has been sold to Huntsman Group. Now the company's names is: Huntsman ICI "Italian Operation". The establishment is located in Ternate (Italy) and its production is based on polyurethane systems. Polyurethane is obtained from the reaction between two chemical components and the addition of suitable additives. During the reaction to some polyurethane it is added an expander releasing little gas bubbles forming a cellular structure which gives origin to foams with different characteristics (light and flexible, or heavy and dense). The flexible foams are used for divans, chairs, mattress, while the inflexible foams can be moulded according to innumerable forms and structures, and are substitutes of the wood and metal.

The strong environmental policy adopted by ICI group promoted the research of new products having better environmental characteristics. From the point of view of the production process, ICI Italia has not great environmental problems, because the production occurs through blending and it does not origin any waste. The research then does not concern a new process, but is focused on the development of more eco-compatible products. Thus, this case study is focused on the development of a new material for mattress called "*waterlily*", and of some vacuum-panels, called "*Vac-Pac*", which can substitute the traditional foams. In both cases, they are products which the firm do not directly sells to the market, but supplies to other sectors (furnishing and electric household appliances). In any way, the consumer can well understand the environmental feature of the final products (recyclable water expanded stuffing, lower energetic consumption of refrigerators).

4.5.1 Waterlily project

Waterlily a stuffing which can be used by the furnishing industry with better ecological characteristics because it does not contains CFC, and is expanded with water. Moreover the products Waterlily are projected to be recycled. Also from the technical point of view it possesses an exceptional combination of comfort, softness, strength and duration. To develop such a product, a long and careful investigation of the designer, manufacturer, buyer needs has been carried out. Despite this, the product did not receive a great success and the market was not interested to this innovative product. Probably the relatively high price of the product, compared to other similar products, discouraged consumers to buy it. The development of this product did not benefit of any public fund, and the company did not collaborate with other firms.

4.5.2 Vac Pac project

The inflexible polyurethane foams are used as insulating, for example in refrigerators. Thanks to these foams, today refrigerators consume less energy, are more capacious and less bulky with respect to their precursors. The ICI realised a system prototype for the production of vacuum-panels, which should be used in substitution to the normal foams (at the moment ICI Italia is industrialising the process). Besides the product innovation it has been realised also a process innovation. The use of vacuum-panels has been applied to the refrigerator production, in partnership with Bosch-Siemens Hausgerate. The tests showed that, using such panels, the refrigerator insulating characteristics are bettered, and an energetic recovery of 20% is realised as well.

Despite the better environmental characteristics, this product did not receive much success. In Europe and in US such panels are not required. In Japan they have been sold first of all for saving space rather then for their environmental characteristics. These panels in fact permit to reduce the refrigerator dimension, which is an important element for Japan, because of the small dimension of houses. Also in this case the market did not reward the innovative effort. Probably the "environmental" element is not taken into consideration when an electronic household appliance is purchased, or however this is of lower importance with regard to other characteristics, like for example the price – in fact these appliances are more expensive than others. The introduction of such panels rather then the normal foams requires in fact some system modifications during the refrigerators manufacture and hence an increase of the final product cost.

4.5.3 What we have learnt from the ICI Italia case

The present case study underlines the difficulties which a cleaner product can find on the market. Normally such products present higher prices or lower features with respect to products of the same category. The more polluting products do not incorporate the environmental "cost", and if there is not a strong inclination of the consumer toward less polluting products, these are hardly received by the market. A study promoted in Italy (Censis-Istituto per l'Ambiente, 1993) has shown that in the recent years the Italian population is more inclined to the environmental problems, because of the diffusion of an environmental culture which has partially modified the behaviour of people. These modifications however concern only certain fields. For example, this environmental attention promoted an increase of the cleaner product demand only in relation to products which are strictly connected to the individual health and physical well-being (e.g. natural feeding). In other fields no transformation occurred, for example in the energetic recovery field. In this case an increase in the electric energy rate do not produce energetic recoveries in the domestic field, and the household appliance commercialisation attempts which underlined energetic, water and detergent recoveries had no success.

In the case of cleaner products, the following two elements can promote innovations: (i) a regulation banishing the use of certain substances or products, and which promotes in this way the search of alternative raw materials; (ii) a differentiation strategy, that is the willingness of the firm to create an ecological product which could find its own niche in the market. Obviously the success of such a strategy needs an interest for these characteristics from the consumer point of view.

In the case of ICI, the products have not been well accepted by the market. In such situations the normative can play a very important role. In particular, the legislation can influence both directly and indirectly the purchasing behaviour. The effect is direct when, through promotions and obligations, the purchasing is oriented towards more ecological products (as it happened for the catalytic cars diffusion). The effect is indirect when the addresses and the limitations are imposed to the producers.

Table 4.4 – I.C.I. (Huntsman ICI "Italian Operation"): Summary table

Project	Waterlily	Vac Pac
Environmental benefits	• water expanded foam • recyclability	• energetic recovery of final product • elimination of toxic expander agents
Economic benefits	• not direct, diversification strategy	• not direct, diversification strategy
Funds	No	No
Patents	No	Yes, only technological details
License / selling	Selling of product	Selling of product
Collaboration relations	No	Yes, for the product's application
Main innovative promotion	To market	To market

4.6 Mapei

Mapei has been created in Milan (Italy) in 1937 and today it has some 20 establishments operating all over the world, but mainly in Europe. The industrial group employs ab. 1,500 people, 700 of which are employed in the Italian branches. Mapei produces adhesive and chemical products for the construction industry, like adhesives for floors and coverings. The main problem in the use of such products is the continuous emission of volatile organic substances which can strongly contribute to indoor air pollution. The Mapei group has three research and development laboratories (in Italy, US and Canada). In 1995 the firm developed an ecological product line which groups the adhesives for buildings with very low emission of volatile organic substances.

The first important result was obtained through products based on polymers in water dispersion, rather then on those in organic solvents. In this way, the total emission of volatile organic substances during the adhesive application and in the first following hours has been strongly reduced. This produces a great benefit for the professional layer's health as well as for the environment. A further improvement has been realised through adhesives without solvent and with a very low emission potential also during a long time. The development of such products required a careful selection of raw materials while the process has not been altered – it is the case of a blending, rather than a transformation. It has been necessary also a study and a development of the systems and of the analytic control method of the different materials emissions during the time. With this project Mapei has been awarded to the INCA Consortium with respect to the prize organised for clean chemical process and products.

In this case, we have an example of green product directly realised for the market. Here, the first push to promote the innovative effort are really more linked to the public opinion course and to legislation. The strategic aim is then to differentiate the new product from existing ones, and to exploit market niches. In summary, the following elements played an important role in the decision process: market demand, international regulations more and more severe, and self-regulation laws of adhesive and covering floor producers associations. These self-regulation laws are the result of the public opinion pressures and are linked to the certification devices. In this way the laws become slowly into market laws because of the absence of certification which can determine the output from the market of a non certified product.

Table 4.4 – Mapei: Summary table

Project	New ecological adhesives
Environmental benefits	Low emissions of volatile substances
Economic benefits	Not direct, diversification strategy
Funds	No
Patents	No
License / selling	Selling of product
Collaboration relations	No
Main innovative promotion	To market

The development of the new line of products has been mainly promoted in the US, where the legislation pressures and the market demand were bigger. As a matter of fact, the new adhesives are widely sold in the US, while in Europe they do not have the same market success, despite the fact that the price and technical characteristics are very similar to traditional adhesives. It is the hard to understand the reasons of this different success, but they seem depend on different customers sensibility as well as on legislation differences. In US the development of such products revealed to be a big commercial opportunity, and the growth of the firm's purchasing in this Country depends only on the new ecological product line.

4.7 Conclusions

The case studies reported in this chapter highlight the great importance that the economic element has within the environmental innovation. In general terms, each innovation aims at increasing firms' competitiveness, but it is possible to make the following distinctions.

1) Development of process innovation.

In this case it is possible to observe two possibilities. Indeed, the innovation may be introduced with the aim of selling/licensing the technology to other firms, or with the aim of increasing the internal competitiveness. The first case typically refers to radical innovation. The characteristics of the new process are usually linked both to environmental and economic benefits, and it may occur that technology diffusion is connected to economic reasons, while the environmental element is connected to the existing (or expected) regulation.

In the second case, the firm is inclined to obtain a technical improve of production processes and aims to exploit the benefits of such innovations internally. At the same time, the diffusion of the innovation is hindered also by technical reasons, because of the high technical specificity and contextual knowledge. Often these innovations are introduced in order to reduce the pollution generated by the traditional production processes, with respect to existing or coming laws. Having to solve an environmental problem, the firm also tries to obtain an economic benefit, by adopting preventive solutions.

The development of process innovation usually requires the establishment of collaborative agreements. In some cases firms collaborate with other firms or research centres belonging to the same group. In other cases, firms collaborate with external companies or universities. Indeed, the development of environmental process innovations often requires very specialised competencies, so that hardly a firm possesses the requires capabilities and skills.

2) Development of product innovation

Also in this case there are two possibilities: the firm innovates a product for the consumer market, or for other enterprises. In the first case, the market success of the product directly depends on the market demand and on the regulation. In terms of strategic behaviour, with the development of environmental product innovations, the firm aims to exploit niches of the market.

In the second case, the impact of consumer demand is less direct, but is always important. The main actor in this case it the customer-firm, whose attention paid to the environmental aspects both regarding their own image, and the willingness to exploit the ecological niches of the market, has a direct influence on its choices. The situation in this case presents a stronger complexity, and the company which introduces a new product in many cases has also to "invent" the applications for its use. This occurs particularly in the chemical industry, which often supplies intermediate goods for other industries.

Hence, the success of a green product depends on several elements. Firstly, it is linked to the availability of the consumers to buy cleaner products despite their higher prices and their worse technical characteristics. This availability is usually not much developed.

3) Government intervention and the role of regulation

A second element is linked to the role of governments, which can intervene through the introduction of a regulation or thorough the promotion of a demand for green products.. If the legislation denies the use of certain products (i.e. CFC), then companies should substitute them with other products also if the latter are more expensive. In this case, the consumer's choice is forced by legislative elements. A second kind of State intervention consists in creating a demand for a certain product. "Government technology procurement occur when a government agency places an order for a product or system which does not exist at the time, but which could (probably) be developed within a reasonable period... government technology procurement is an interesting instrument because it may be part of strategy to open up new technological paradigms; it should be more extensively used as a means of enhancing the exploratory side of the innovation process, with specific social goals, like low energy consumption assets and environmental objectives." (Lundvall, 1998). In absence of both these forces, the introduction of a cleaner product can represent a situation of success for the firm only if besides environmental characteristics the products results to be cheaper.

As far as EMAS is concerned, this is considered an effective mean in order to stimulate environmentally-related innovations, because it forces companies to make an analysis of the production processes and to individuate any possibility of improvement. It is but an expensive instrument mainly for small enterprises. In Italy the adhesion to this rule is mainly stimulated by the bureaucratic inefficiency. In fact, companies which adhere to EMAS obtain a certificate proving the adjustment to the normative, and above all a constant improvement effort. In such a way, firms hope to reduce problems which are only connected to bureaucratic reasons. However it seems to be necessary to supply further incentives because of the high cost of adhesion to EMAS.

The promotion of initiatives such as prizes for cleaner technologies are considered useful to improve the environmental image of the firms, to strengthen a culture oriented towards the sustainable growth, and to improve the relations with the surrounding population. It is also necessary to specify that the firms analysed in this survey belong all to big chemical groups in which the environmental policy is by this time consolidated. As a matter of fact, all these companies adhere to *Responsible Care*.

Truly, not all the chemical firms adhere now at this initiative. For example, in Italy 40% of purchasing and of employees in the chemical sector belong to enterprises which do not adhere to such programme. It is then necessary to make something more to widen the enterprises' consent, mainly of smaller firms. These firms not always have the capabilities to develop innovations and collaboration agreements might play a relevant role. Controls alone are not enough to improve the eco-compatibility of production processes, and they should be preceded by some initiatives aiming to supply technical, economical and information support. In this sense, the diffusion of cleaner products and processes is strictly linked to the existence of initiatives promoting the collaboration among several subjects.

Chapter 5
Analysis of the Environmental Industry

(F. Cesaroni)

5.1 Introduction

The patent analysis carried out in chapter three has shown that most of environmental patents have been realised by independent, and probably small firms, specialised in the supply of environmental services and products. This result suggests that a division of labour has been achieved in the environmental innovative activities, and some agents have specialised in the production of equipments for controlling pollution. The upsurge of such agents can be related to the emergence of an environmental legislation, which has imposed on firms to adopt plants and equipments to reduce polluting emissions. At least in the early stages, specialised firms supplied end-of-pipe technologies.

According to this framework, it seemed interesting to us to make an empirical investigation of the sector, by trying to answer some questions. Have specialised suppliers increased their product/service portfolio by supplying both end-of-pipe and clean technologies? What are the main characteristics of these suppliers, in terms of dimension (small vs. large firms), degree of diversification and internationalisation? Do they offer standardised products and services? What are the incentives to promote innovative activities? What is the role of the chemical companies in the supply of environmental technologies?

The study has been carried out through bibliographical and empirical analyses. The latter consisted of a survey of the Internet environmentally related web-sites, aiming to characterise what kind of firms offer environmental technologies and services. We have submitted a questionnaire (see Appendix 2) to a small sample of them, in order to better investigate some relevant issues.

5.2 The supply-side of the environmental industry

In general terms it is not easy to identify the boundaries of the environmental industry, since they are not well defined. This industry is composed of a large number of heterogeneous goods and services and also includes clean technologies that are increasingly important, even if it is difficult to take them into account.

The European Commission gives a definition of the *Eco-Industry* that quotes: "...firms producing goods and services capable of measuring, preventing, limiting, or correcting environmental damage such as the pollution of water, air, soil, as well as waste and noise-related problems. They include clean technologies where pollution and raw material use is being minimised..." (European Commission, 1994). However, other definitions exclude clean technologies, both because they are difficult to detect, and because the improvements that they allow in the environmental field cannot be distinguished from other improvements (such as more efficient technologies). This topic is particularly relevant. If the environmental-improvements-related costs cannot be distinguished, it becomes difficult to make a clear definition of the sector, and at the same time it becomes difficult to estimate the value of the global environmental market. However, many studies exclude **clean technologies** from the definition of the sector, despite their important role in **changing the structure of the environment industry**.

The supply-side of this industry includes environmental equipments, environmental services, and integrated environmental technologies in industrial processes and cleaner products (OECD, 1996). The *Environmental equipments* are those devices that can be used for: waste-water treatment, waste management and recycling, air pollution control, noise reduction. Moreover this sector includes monitoring instruments, scientific, research and laboratory equipment, and natural resource conservation/protection and urban amenities.

Environmental services include operations for: water-wastes, waste handling and facilities, air pollution control, noise reduction. Moreover the sector covers technical and engineering services, consulting services, accounting and legal services, analytical, monitoring, conservation and protection services, environmental research and development, environmental training and education, and other environmental business services.

Finally the *integrated environmental technologies* are the clean production equipments, efficient energy-generating and preserving equipments, and eco-products.

The green industry began developing at the beginning of the 1970s within those countries that introduced environmental legislation and policies. The environmental regulation has been the main factor of development in this industry, and those countries with the strictest regulations are now more competitive in this sector and have larger markets. Recent estimates show that the market of environmental industry accounts for US$ 250 billion (non including most of the clean technologies), and is growing up at a rate of around 5% per year (Ocde, 1996).

The regulation is a crucial factor in affecting the demand for environmental goods and services, even though public expenditures, technological developments, social pressure and changes in life stile also play an important role (Ocde, 1996).

5.3 The agents of environmental industry in the learning economy

Firms belonging to the environmental industry are very heterogeneous. Small and large firms are equally active. Within some countries, such as Italy and Switzerland, small firms take the main part (about 90% of all firms have less than 50 employees), while Germany shows a larger share of big firms (OCDE, 1996). The US are leader in the environmental industry, and account for the largest world-wide environmental market. Japan is the second player, followed by Germany, which holds about 30% of the total European market. Western Germany is highly competitive in almost all environmental fields. France accounts for about 15% of the total European market, and the UK for about 14% (OCDE, 1996).

Firms belonging to this industry have different origins. Some of them were borne inside the environmental industry, as a consequence of the growing demand for pollution control plants. Other firms originally operated in several sectors, and only later have they entered this new industry, following a diversification process. Most large environmental firms started as specialised companies, and were created within industrial groups to solve their environmental problems. The latter type of firms exploited the competencies of plant planning and building within their industrial sector, and diversified in the supply of environmental technologies. The same happened for large chemical groups, which usually include divisions or companies operating in the environmental sector. And, again, the same pattern of diversification was followed by the engineering firms, which operated in the industrial engineering – e.g. oil, petrochemical, chemical, and steel plants (Malaman R., and Paba S., 1993).

It is not uncommon that the presence of specialised agents causes the development of downstream sectors. The vertical specialisation allows a greater division of labour, and, as a consequence, the downstream sectors benefit of the increasing returns therefore generated. All the fixed costs related to some activities (in this case, the production of new scientific and engineering knowledge) must be born only once by the specialised firms, while other firms do not bear any fixed cost (Gambardella A., 1997). So, the development of the green industry, and particularly of the plant design activities, benefited of the presence of agents, whose competencies and experience had been cumulated in the building of industrial plants. Those agents only enlarged their supply, by specialising in the environmental sector. The degree of firm *specialisation* (i.e. the ratio of environmental revenues and total revenues) often represents less than 50%, and this is especially true for large engineering and chemical firms (OCDE, 1996).

Many firms belonging to the environmental sector tend to diversify and to offer a wide range of environmental products. This pattern may ease the development of preventive solutions, since the latter require greater competencies in different environmental and technological fields.

Firm *competitiveness* can be related mainly to four elements: technological innovation, quality and service performance, marketing and export strategies and flexibility in production. Since customised solutions are increasingly demanded by firms, scale economies are relatively less important than the presence of a wide set of competencies. Performance and innovation are increasingly relevant features. All these characteristics can be related to the changes being observed in favour of clean products and processes. These changes increase the importance of research, design, consulting and other services to adapt the products to customer needs (OCDE, 1996).

As far as *internationalisation* is concerned, it has been observed that firms operating in the environmental industry are already moderately active in the international arena, even if a greater international opening is expected. "The adoption of world-wide environmental standards will expand international markets, privatisation and de-regulation of utilities such as water and electricity will expand opportunities for foreign firm participation, and consolidation of the industry and increasing firm size as it matures will increase internationalisation" (Ocde, 1996). International trade is expected to develop rapidly, particularly in developing countries, and this trend will increase specialisation and internationalisation of the environmental industry.
All these changes become parts of the present transition process towards a global economy, which involves all the industrial sectors. The new context (characterised by a growing liberalisation of trade and financial markets, increased competition, development of communication means) has witnessed an acceleration of the rate of innovation and change, and an increase of competition as a consequence. The economic performance of firms increasingly depends on their **learning ability**, since the adaptation to the rapidly evolving market and technical condition is required. The globalising learning economy imposes a greater capability to learn and use knowledge on firms. And it imposes policy makers a new

approach towards the technology and innovation policies (Lundvall, 1997). Complex scientific bases and diversified knowledge are required to develop new products and processes. However, firms do not have all the competencies required in developing an innovation. And especially the promotion of clean technologies requires the establishment of collaborative linkages among agents. So, "[t]he new contest puts a premium on interactivity within and between firms, and between firms and the knowledge infrastructure" (Lundvall, 1997).

In this context, environmental firms represent a key point for developing innovations in this sector, not only because they offer specialised technologies and services, but also because they have a direct influence on the innovation processes, and they are catalysts of the technological change. So, they can be defined as *knowledge-intensive services*, and play an important role in rising the learning capacity of the system. Their importance in the promotion of environmental innovative processes asked for a deeper understanding of their role and characteristics that we tried to carry out through an empirical investigation. The results are shown in the next sections.

5.4 Empirical analysis

It can be said that the degree of division of labour in the chemical sector originates from a “historical accident”. Until the legislation imposed firms to satisfy pollution emission levels, end-of-pipe solutions were firstly adopted. Many of them could be easily standardised, and allowed to occur a *classical* division of labour at the industry level. Specialised firms began to offer standardised solutions at an average cost that was lower than that borne by single firms for an internal development of the same solution. However recently the situation is changing, since many firms need customised solutions, and the demand for clean technologies is increasing. Is still the division of labour at the industry level a feasible solution? How do specialised firms offering standardised solutions react to these changes? Can clean technologies be standardised as well? What are the implications on the diffusion processes of clean technologies?

The present section tries to answer these questions. It offers some qualitative, preliminary evidences. In order to obtain quantitative results, a survey on a large sample of firms would be required, but it goes far beyond the possibilities of our analysis. However, the qualitative evidences that we offer can be considered as a *case study*, from which one could start for further developments.

5.4.1 Methodology

In order to explain the empirical analysis, we have collected specific information from the Internet. During the last years, the Information Technology has developed rapidly, thus providing useful tools for research activities, and thus allowing researchers to find large quantities of specific information. We are particularly referring to the presence of Web-sites specialised in the linking of firms, customer and service suppliers. As far as the service suppliers are concerned, we were able to find specific Web-sites, whose aim is to offer detailed information about suppliers of environmental services, products, and technologies. By analysing these Web-sites, it is possible to obtain a qualitative (but not systematic) view of both the sector, the global diffusion of such suppliers, the characteristics of the firms that operates in it, the different services being offered, and so on. Therefore the first step of our analysis was to search the several Web-sites providing information about the environmental sector, and to take a look at the firms reported in those sites. Then we collected some general information about the nationality of the firms, the specific environmentally-related sub-sectors in which they are active, and the differences in the services that they provide (i.e., standard vs. custom, end-of-pipe vs. clean).

While the first step aimed at describing some general characteristics of the sector, in the second step we tried to analyse in depth the features of some firms belonging to the environmental industry, by studying their size, their degree of internationalisation, their customers (whether they are other manufacturing firms, governments, final customers), the incentives for the innovative activity, and whether they patent and/or license their technologies. To carry out this second step, we sent a specific questionnaire to a limited number of firms, chosen among those listed in the Web-sites.

5.4.2 Step 1: Analysis of Web-sites specialised on environmental issues

Among many, we analysed five Web-sites in depth. Three of them can mostly be considered as databases, which collect data on firms and other organisations offering environmental products, services, and technologies.[22] The other two Web-sites are focused on different environmental issues, and offer a "Buyer's Guide" where information on environmental products, services, and technologies are reported.[23] All of them also allow one to make searches based on specific environmental sectors, or on the firm name. Only the first three allow to search about their nationalities.

The different sites provide different information. In some cases, detailed information are offered, and a personal schedule of every single firm is available. In others, only some general firm characteristics are offered, such as the sector in which they are active (e.g., water purification), their address, and their Web-site address, if available. It can be interesting to notice that most of the firms listed in the directories come from the US. In only one Web-site a significant presence of European firms can be observed.[24]

As far as the supply side is concerned, the analysis of the Web-sites revealed that most of the firms offer end-of-pipe technologies. When prevention is explicitly mentioned, it mainly refers to the energy sector, and particularly to the renewable sources and to the energy produced from wastes. In other cases, firms declare that they offer advice with regard to clean processes, but only rarely they mention a specific clean technology. This situation confirms the clean-technologies-related diffusion problems.

Within the end-of-pipe sector, specialisation and standardisation seem particularly widespread. On the one hand, end-of-pipe technologies often consist of plants to be added at the end of the production processes, and this allows a greater standardisation. In this way, in many cases firms defined precisely the characteristics of the products they offer. The same plant, then, can be easily adapted to the production processes of other firms. On the other hand, sometimes products are so specialised that firms determine specifically the industry that can adopt them. It is our conjecture that the high degree of specialisation has been caused by a

[22] They are: http://www.environline.com; http://www.eco-web.com; http://www.enviroyellowpages.com.
[23] They are: http://www.pollutiononline.com, and http://www.webdirectory.com.
[24] This is: http://www.eco-web.com.

rise of the limits on laws about the environment, And this situation increased the demand of more and more complex tools for controlling pollution.

Table 5.1 – Environmentally-related Web-sites

Web-site	Operating Sectors	Share of European Firms	Share of US Firms
www.eco-web.com	**10** Main Sectors **74** Sub-sectors	**40%** (Among the 16 largest European Countries)	**25%**
www.pollutiononline.com	**28** Main Sectors **1029** Sub-sectors	**5%** (Estimate based on a random control)	**80%** (Including Canadian firms)
www.enviroyellowpages.com	Changing, according to the countries considered	**0%**	**100%** (Including Canadian firms)
www.enviroline.com	**81** Main Sectors	**0%**	**98%** (Including Canadian firms)
www.webdirectory.com	**Not available**	**Not available**	**Not available**

In order to obtain a better understanding, we took a look at the Web-sites of some of the largest chemical engineering firms, in order to verify if they offer environmental technologies and products.[25] This analysis showed that most of them are active in the sector of environmental engineering as well, by means of subsidiaries or some specialised internal division. Furthermore, they also offer mainly standardised technologies focused on the end-of-pipe sector, even if some of them offer clean technologies and pollution prevention advice as well.

To sum it all, the first step of the analysis showed the following main results:

1) most of the environmental-related specialised firms listed in the Internet Web-sites come from the US.
2) most of those firms provide highly standardised and specialised end-of-pipe technologies.
3) clean technologies play a minimal role, with respect to end-of-pipe technologies. Examples in the opposite direction are only related to the energy sector.
4) most of the chemical engineering firms offer environmental services as well.

5.4.3 Step 2: Survey results

The firms analysed in the previous section are either large firms or branches belonging to large industrial groups. In this section we preferred to focus on smaller firms, both to obtain a complete understanding of the actors operating in this sector, and to test whether firm size affects behaviour and results. We carried out this analysis through a questionnaire survey. We sent the questionnaire to a limited number of firms, randomly chosen among those listed in the Web-pages, trying however to represent the various geographical origins, and environmental sectors (gas, water, soil handling, and so on). Some of the questionnaires received were not used because they showed inconsistent answers.

The questionnaire was organised as follows. In the first section, we wanted to analyse the firm

[25] These firms have been selected among those listed both in the "ChemExpo" Web-site (http://www.chemexpo.com), and in the Chem-Intell database (1998).

main features, such as origin, size, sector (e.g., environmental services, environmental engineering, chemical engineering, plant engineering, chemicals, petrochemical, energy), and the type of technologies available. In the second, we tried to get a deeper understanding about the technologies and services supplied. For instance, we asked to specify whether the firms offer end-of-pipe vs. clean, standardised vs. customised technologies, technological consulting services or environmental management services, and so on. Finally, the third section aimed at analysing which incentives are increasing the demand of environmental technologies and services (i.e., free market, government, industry pressure for compliance), and how firms are trying to cope with it, whether by patenting or licensing their technologies, or by collaborating with external partners to develop new technologies.

The sample analysed is composed of 33 firms, 19 coming from Europe, and 14 from the US. Most of them are small, with less than 50 employees, and do not belong to any industrial group. As first step, we wanted to analyse their degree of internationalisation and diversification, the strategic importance of which is increasing due to the growing globalisation of markets, and the enhanced complexity of the environments in which firms have to operate. So the propensity of firms to operate in foreign markets, and their capability to differentiate their supply, can be interpreted both as a proxy for their "vivacity", and as a measure of their aptitude to manage the complexity. In the previous sections, we stated about the catalytic role played by the "knowledge-intensive sectors" within the technological change. The capability of being active in more than one market, and in more than one sector can represent a first important step towards that direction. Results of our survey go on this direction, and about 80% of the firms revealed to operate in more than one country, showing a high degree of international opening.

As far as diversification is concerned, we asked firms to indicate the different sectors in which they are active, by choosing among environmental engineering, plant engineering, chemical engineering, chemicals, petrochemical, energy environmental services, and others. About 70% of firms declared to operate in more than one sector.

By merely looking at those two dimensions (diversification and internationalisation), differences between US and European firms do not seem to arise. However, some distinctions can be made by looking explicitly at the sectors to which firms belong. In this way European firms are mainly active in the engineering services, and they usually operate jointly in plant and environmental engineering. This result confirms the existence of a process of diversification for engineering firms towards the environmental sector. On the contrary, US firms do not show the same patterns, and most of them are active in the energy sector, usually combining the environmental engineering activities with the energy ones. This result reveals that the US firms promoting activities in the environmental sector are specialising in energy issues.

In Europe, a larger role is played by firms belonging to the chemical sector. Ten out 33 firms declared to be active in the chemical sector (by including both chemicals, petrochemicals, and chemical engineering), and among those only two were from the US. All in all, European chemical firms show a greater degree of specialisation in the environmental sector, than US firms. This pattern, if confirmed by deeper analyses, may have important policy implications, because it allows us to better define the "target" of such policies. If firms belonging to chemical groups or chemical engineering firms, are the agents that hold experience and know-how on environmental issues in Europe, *they* should be the targets of policies aiming at promoting innovation and diffusion of clean technologies. As a matter of fact, the patent analysis reported in chapter 3, showed that in Europe chemical firms are the most innovative agents on environmental fields.

In the second section of the questionnaire we addressed questions concerning the characteristics of technologies and services offered by firms. Answers to these questions show that the customisation of technologies and services is a key point. About 65% of firms offer customised services, mainly regarding technological consultancy. Moreover, as far as end-of-pipe technologies are concerned, only 15% of firms revealed that their technologies are completely standardised. The need of customisation represents a constraint for a greater diffusion, but it shows the relevant role played by the engineering firms within the technological change.

An interesting result emerged with regard to clean technologies. In the previous section, by looking at the Internet Web-sites, we noticed that clean technologies are rarely developed. However, when the questionnaires are considered, an opposite conclusion arises. More than 50% of firms declares to supply clean products, and clean or recycling technologies.

As a total value, firms listed 22 clean technologies, and 12 clean products. Interestingly, 5 technologies and 5 products refer to the energy sector (electric vehicle, renewable energy technologies, clean power system), by showing that a high innovative propensity can be observed in such a sector. Two main explanations can be offered. The first has a historical-economic background. As a consequence of the two oil shocks during the 70s, the industry promoted a strong effort to reduce the unit energy consumption per product. The increased energy prices, and the pressure to improve efficiency, induced new environmental solutions as well. The second explanation has a legislative background. Many legislative actions were explicitly focused on the energy issue, and different incentives were offered in this direction. For instance, think about the V European research Framework Programme. Within the programme related to the environmental issues, an entire section is focused on cleaner energy systems (by including renewables), and on economic and efficient energy for a competitive Europe.

The last section of the questionnaire is aimed at defining the different incentives that encourage the purchase of environmental products/technologies. We asked firms if their customers (usually other firms) are willing to buy environmental technologies/products either because of free market reasons (e.g., cost reduction or efficiency increase gained by the new technology), or because of government pressures (e.g., policy regulations, sanctions for non compliance, positive incentives), or finally because of pressures for compliance (e.g., industry standards, such as the ISO 14000). We did not get any answers from thirteen firms, and this situation shows how difficult it may be to define what specific factor encourage the purchase of environmental products/services. On the contrary, the answers that we obtained show that the pressures from the industry (i.e., self-regulations) are weaker than the market or the government ones. Both the latter are equally important for firms.

This situation confirms the idea that we had already stated. Voluntary programmes and self-regulation may represent useful instruments, but they are less effective than government regulations, which has to be considered as a necessary condition. To be sure, self-regulations usually determine a cost increase that is not compensated by any *direct* economic advantage, especially if customer purchasing behaviour is not oriented towards environmentally-safe products. So, the “self-regulation choice” is mainly driven by the market and legislative environment, which firms have to afford.

A final interesting feature of the research referred to the process of innovation development (i.e., if through collaborations), protection (i.e., if trough patents), and diffusion (i.e., if trough licenses). The objective of these questions was to verify the innovative propensity of specialised firms, along with the propensity of technology standardisation and diffusion.

As far as patents are concerned, about 30% of firms patented some of their environmental products/technologies. This value can be considered as a low patenting rate, but the small size of the firms in the sample may account for it. However, it is interesting to notice that in many cases patents refer to clean technologies. And this result suggests that, even if clean technologies can usually be only partly standardised, there is room for a grater transferability, since patents can represent a way to standardise technologies and ease up their diffusion. For example, the environmental improvements made inside the production processes are very difficult to be transferred. However, the development of completely new clean technologies strictly depends on their capability of diffusion. Instead the empirical evidence given by our survey shows that only three firms out of 33 licensed some of their technologies.

As we noticed in chapter 1, one of the biggest obstacles to the development of clean technologies is the low propensity of the environmental industry to face the risks of substituting traditional, standardised technologies with new technologies. And, since many firms offering clean technologies suffer from uncertain sales, the main problems may emerge on the demand-side (Cramer-Schot, 1990). In this sense, environmental regulation and policy play a relevant role. For example, consider the technology ALMA, which we referred to in the previous chapter. Obviously, the diffusion of such a technology is mostly expected in the US, where the use of benzene is not permitted by law, rather than in Europe.

Finally, the last remark refers to the role of collaborations. In a general sense, it is well known that the modern technology development does not allow a single firm to own all the relevant technological capabilities and know-how. So, collaboration is a necessary condition. The answers to our questionnaire show that about 25% of firms promoted some form of research collaboration to develop some environmental innovation. Despite this rather low value, it has to be noticed that almost all firms that patented their innovations, promoted research collaborations as well. In this sense, collaborations were implemented mostly with other firms or with universities.

5.5 Summary

It is now possible to synthesise the most relevant results emerged in the last section. Firstly, as far as the characteristics of firms are concerned, despite their small size, all the firms of our sample showed a high propensity for diversification and internationalisation. US firms seem more oriented towards the energy sector. And European firms mostly belong to the chemical, petrochemical, and chemical engineering sector.

Secondly, firms tend to offer customised technologies, also in the case of end-of-pipe ones. However, to better understand this result, a remark is needed. In a broad sense, a "custom" technology is uniquely developed to satisfy specific needs for a single customer. On the contrary, even if end-of-pipe technologies have to be adapted as well, the modification that are required have a lower technological relevance. So, the result may be affected by the fact that companies stated as "custom" also largely standardised technologies, and a misunderstanding in the terminology may have arisen. However, the need for a great customisation in the environmental sector is highlighted by the high share of technology consultancy services, which firms offer along with other products and services.

Thirdly, more than 50% of firms offer clean technologies and products. About 30% of these technologies / products relate to the energy sector. Furthermore, most of the patents developed by firms refer to clean technologies, and this result shows that such technologies can be patented and (potentially) be transferred. However, real transferability processes were carried out only rarely – i.e., only three firms offered licenses on environmental technologies.

Fourthly, the main incentives to the diffusion and the development of environmental technologies are represented by government regulations and market pressures. The self-regulations have a limited influence.

Finally, collaborations are seldom promoted. However firms that usually patented their innovations were involved in collaboration efforts as well. As it emerged already in the previous chapter, collaborations seem a relevant feature in boosting innovation development.

Chapter 6

Concluding remarks and policy implications

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6.1 Conclusion

This study is focused at analysing the way in which the European chemical industry contributes to the development and the diffusion of environmental technologies. Moreover it investigates the competitive position of the European chemical industry in the environmental field, compared with US and Japan. The analysis was performed both through a bibliographic research, patents analysis, case studies and via Internet analysis.

Patent analysis showed that innovative rates of the US, Japan and Europe in environmental technologies are similar to innovative rates in other types of technologies. This result shows that the environmental sector broadly follows the trend relative to innovation. United States generally patent in the environmental technologies more than Europe, and Germany patents more than all the European Countries.

The higher innovative rates found for Germany and the US in the environmental sector may be linked to the different government regulation and public pressure that they face. As a matter of fact, the United States have faced environmental problems through very strict standards, and Germany has adopted the most rigid standards of Europe. Moreover in these countries, the public opinion have played an important role in influencing the environmental policy and behaviour of firms. These results could bring about the consideration that rigid environmental standards and strong public pressure have a positive influence on the environmental innovative rate.

To be exact existing studies have never explicitly shown the existence of a positive correlation between strict environmental regulations and innovative rates, since strict environmental standards can also have a negative effect on other types of R&D investments. Furthermore the environmental regulation can impose significant costs to industry, by lowering its competitiveness. However, the results of our study support the idea that a strict regulation is needed. Obviously, other instruments supporting firms in the adoption and development of preventive solutions have to be implemented as well, along with regulation.

To clarify this matter, it may be useful to summarise the main results of this work, in which a relevant role of the regulation in influencing the development and diffusion of (clean) environmental technologies emerges.

a) The influence of regulation on the innovative rate could be suggested from the clear US prevalence in the class of “hazardous wastes”. The US present a wide regulation about hazardous wastes, while an equally wide system of responsibilities does not exist neither in Japan nor in Europe.
b) Some European chemical firms prefer to patent environmental innovations in the United States. This pattern shows that in the US it exists a greater market for environmental technologies, and there technological competencies are concentrated.
c) The birth and development of environmental industry is closely linked to the introduction and evolution of environmental regulation. If the innovative agents are firms specialised

in the supply of environmental technologies, then they will only pursue innovation if a wide diffusion can be achieved. So clean technologies have developed slowly *also* because very often the environmental legislation required a too short fulfilment time and the adoption of the available technologies. But this enforcement was a big pressure to adopt end-of-pipe technologies, and discouraged the development of clean technologies, whose market was not large enough.

d) The analysis of the case studies shows that the innovative behaviour of firms has to satisfy economic constraints, and that environmental issues are conditioned upon the search for technology efficiency and effectiveness. At the same time, when the government regulation defines precise standards, and imposes precise prohibitions, these are clear targets that have to be considered in the innovative activity. They represent a clear reference point, especially when standards are imposed at an international level, and are kept fixed for a sufficiently long time. Hence, innovative problems encountered by firms are not within the regulation by itself, but they are related to the time needed by firms to satisfy the standards according to the regulation. If this time is too short, firms are forced to develop end-of-pipe technologies, even if they are less efficient and effective than clean solutions.
e) Self-regulation represents a useful instrument. However, its costs can be sustained only in the presence of a strict regulation and/or a high pressure by customers or by the public opinion. If the two conditions are not satisfied, there are no incentives for firms to allocate resources on environmentally-safe solutions.
f) To be effective, taxes should be set up at such a high level, that rarely they can be pursued. Furthermore, firms seem to have better reactions when other policy instruments are used, rather than taxes.
g) The same happens for government financial support to firms. To be effective they should be set up at a very high level. But, at the same time, they can represent a windfall gain for innovators.

By looking at the patent analysis, another interesting result refers to the fact that the US have a greater innovative rate in the recycling technologies than Europe, while Europe is more oriented towards end-of-pipe technologies. Europe has a grater innovative rate in the recycling field only in the US database. This situation suggests that a larger market for such technologies does exist in the US, while European environmental innovative activities are still devoted to the development of *ex-post* solutions.

The chemical companies (both from the US and Europe) patent in the environmental sector more than firms from different industries. Furthermore, chemical companies patent more in clean technologies rather than end-of-pipe ones. Taken together, these results confirm the efforts made by the chemical industry in reducing pollution of chemical processes. According to this fact, the European chemical industry behaviour is similar to the US one, since European chemical companies are specialising in recycling technologies, both at home and in foreign countries.

So, the European chemical industry plays a relevant role especially in the recycling sector. This result emerges by the patent analysis, and is confirmed by the questionnaire survey. The share of environmental innovations held by the chemical industry in Europe is larger than that of any other innovative agent in the same region. This means that the chemical industry is proportionally more important in Europe than in the US, with regard to environmental innovations. If confirmed by other evidences, this result suggests that policy makers should focus their policies towards the chemical industry, thus allowing it to gain a higher competitiveness in clean technologies. And a greater attention of policies in the chemical industry could also be suggested by the fact that this industry supplies many inputs to different production processes. So, an intervention in the chemical industry – in the sense of pollution reduction – has beneficial effects on the downstream sectors. As the patent analysis revealed, it is also to be noticed that the largest European chemical companies have an average number of environmental patents smaller than the US largest companies. And the same can be said with respect to the patent quality, as measured by means of patent citations, where the US patents are cited, on average, more than European patents.

As far as collaboration agreements are concerned, the growing complexity and globalisation of markets imposes firms to look for external relationships. The same can be said in the case of clean technologies, where the development of such agreements plays a relevant role. The reason for this results can be traced in the higher complexity of preventive solutions, whose development usually requires wider technological and scientific competencies. In this contexts, engineering firms represent an important partner, both in the case of radical and incremental innovation development.

As far as clean technologies are concerned, the small number of licenses related to technologies that our case studies and the questionnaire has stated, highlights the problems of their diffusion. However, the presence of patents may represent an organisational instrument to ease up the diffusion processes. So, the thing that limits the transferability of clean technologies has to be related both to the demand-side, and to the competitive gains that clean technologies induce, and that push companies to pursue secrecy.

6.2 Policy implications

6.2.1 An environmental innovation policy for chemical industry

The reason for a public intervention in the chemical sector aimed at inducing a greater development and diffusion of clean technologies lays in three main reasons:

1) *the relevance of the chemical industry within the national economies*: the chemical industry supplies a large part of inputs for the production processes of different sectors. By allowing a greater environmental attention to chemicals, some pollution reductions can be achieved also in the downstream sectors;
2) *any innovation in the chemical industry has to take into account the environmental issues*: both in the US and in Europe the public opinion is becoming more attentive to environmental problems. As an answer to this new situation, public policies (not only innovation-related) are including in their programmes a greater attention to environment;
3) *European environmental patents are mostly developed by the chemical industry*: as the analysis in the previous chapters has shown, the European chemical industry has a leadership position in the development of environmental (*ex-ante*) technologies. Furthermore, both large chemical groups and chemical engineering firms are very active in offering their technologies and in providing environmental products and services. In so doing, they show to possess experience and know-how on these matters, and public policies aimed at solving environmental problems could benefit of their competencies.

6.2.2 The instruments: some suggestions

According to the results obtained from the case studies, the innovative activity in the environmental sector is mainly driven by competitive forces. Company strategies have either a “internal” or a “external” justification. In the first case, technology diffusion faces technical obstacles – i.e., technology are mainly developed to solve internal, specific problems –, and firms usually prefer capturing all the returns of internal innovations before diffusing them to others, for instance through licenses. On the contrary, in the second case, technology are primarily developed to be diffused, and to earn grants from licensing. In both cases, however, an efficient development of environmental innovations requires the presence of complementary conditions: a) the presence of a market for such innovations; b) the presence of a regulation setting low pollution standards.

To be effective, an environmental policy has not only to fix low pollution standards, but it has to aim to promote the transition towards cleaner production processes. A new technological system can be encouraged by the following actions (Lundvall, 1997):

- by establishing standards in an interaction between users and producers. Markets for green products have to be created (also by using procurement policies), and both private and public users have to be involved;
- by systematically measuring and evaluating the crucial environment parameters. This action can be carried out by means of specific institutes;
- by stimulating experimental new initiatives in crucial fields, usually by combining different elements from a small number of disciplines;
- by promoting a co-ordination between environmental policy, innovation policy and general economic policy.

To pursue those actions, specific policy instruments can be used:[26]

- the development of programmes focused on the green chemistry, and the promotion of financial support to environmentally-related R&D, according to strategic concerns of the European Union;
- the definition of training programmes at the different levels, aimed at diffusing the culture of a cleaner chemistry;
- the elaboration of specific actions aiming both at the diffusion of best practices within the green chemistry (e.g., through workshops and meeting), and at the diffusion of relevant information (e.g., through demonstration projects, information campaigns, environmental management and auditing systems for firms, green labels, awards for clean technologies);
- the development of voluntary agreement, covenants e technology compacts whose purpose is to foster collaboration agreements between firms, universities and government agencies;
- specific government procurement aimed at the creation of environmental market niches;
- the definition of institutions providing technical, economic and information support to small and medium enterprises.

[26] It has to be noticed that the European Community already developed some of the instruments suggested in the following. However, a recent survey showed that the EC legislation has not been as effective as it could have been in curbing pollution-inducing activities. The main reasons include: lack of effective communication at EU level, lack of consultation during the development of legislation, too frequent legislation changes, absence of incentive as well as enforcement mechanism and resource constraints.

Appendix 1

The patent search in the fields of recycling and end-of-pipe technologies has been realised by using a key-words approach. We made a census of all patents having in the title or in the abstract certain key-words connected to the classes of predefined technologies. In particular, in the field "end-of-pipe technologies" we considered three sub-classes of technologies, and each sub-class has been further divided into two sub-classes. Concerning the field "recycling technologies", we considered only one class, because it was not possible to find more specific key-words to be used in the search.

The final classification was the following:

A) End-of-pipe technologies

- A.1) *Purification*. This field has been distinguished in:
  - A.1.1) *purification of gases;*
  - A.1.2) *purification of liquids*.
- A.2) *Decontamination*. This field has been distinguished in:
  - A.2.1) *decontamination of soil*;
  - A.2.2) *decontamination of ground water*.
- A.3) *Treatment of wastes*. This field has been distinguished in:
  - A.3.1) *treatment of solid wastes*;
  - A.3.2) *treatment of hazardous wastes.*

B) Recycling technologies

The following key words have been used in the search for end-of-pipe technologies:[27]

Purification of liquids	"waste stream*"; "waste water*"; "water purif*"; wastewater*;	"liquid waste*"; "sewage treatment*"; "effluent treatment*".
Purification of gases	"waste gas*"; "gas clean*";	"exhaust gas*" and "purif*".
Decontamination of soil	"contamin*" and "soil/soils"; "decontamin*" and "soil/soils";	"contaminated site*"; "remediation* and "soil/soils".
Decontamination of ground-water	"contamin*" and "groundwater*"; "contamin*" and "ground water*";	"decontamin*" and "groundwater*"; "decontamin* and "ground water*"
Treatment of solid wastes	"solid waste*"	
Treatment of hazardous wastes	"hazardous waste*"	

Concerning Recycling technologies, we provided only one class because it has not been possible to find more specific key-words to be used in the search. The key-word used for this search is: "recycl*".

In sum, the query that we used present an error rate that, according to the classes, varies from 5% to 20% (only in the case of the dangerous wastes in the European database the percentage

[27] The symbol * represents a wildcard and allows to select all the words that begin with tightens indicated. Moreover, within all classes we accounted only patents that did not contain in the title or in the abstract the words "recycl*" or "recover*". This has allowed us to include in the end-of-pipe classes only those patents that aimed at to "cure" and not to prevent, which is typical of clean technologies.

is of 35%).[28] This problem cannot be eliminated and is inherent at the same nature of the searches by key-words. If the key-words used are too specific, they present a reduced number of patents, while if they are more generic, they include patents in which the words are used in a way different from the purposes of the research.

The analysis of the US, European and Japanese innovative ability in the end-of-pipe and recycling technologies has been carried out considering the applicant patent presented to the US Patent Office, to the European Patent Office and to the World International Patent Office. The more important differences existing in the databases and in the methodology used for the search are the following.

1. The American database consists of all patents of all US states, while the European database consists only of the patents that have explicitly demanded an extension of the protection to the European Patent Office. Each European Country possesses its own Patent Office, therefore it is possible that an agent decides to patent his invention only in his Country, so that the patent will not be present in the European database. If she does patent his invention in another European Country, she can present the application directly to the patent office of that country, without considering the European Patent Office. Also in this case the patent will not be present in the database that we used. It must be specified that the European patent office is not a real patent office, because it does not release any patent. In fact, a European patent is not a unitary title. It is an unique European question, an unique European examination, but once issued it becomes a collection of national patents. It confers to the holder the same rights that would be conferred from several national patents of the designated states (Zeri, 1998,).

2. In order to assess the nationality of the patents it is necessary to use a different methodology in the two databases. In the US database the patent nationality corresponds to the nationality of the agent which patents. In the European database the nationality corresponds to that of the first Country in which the patent has been patented (normally, however, such Country corresponds to the Country of the agent which patents).

3. The key words used in the search are the same ones, but in the search on the title, we had to use different logical expressions. The results obtained are however comparable: in particular, in the US database it has been possible to search on the title some "double" words like "waste water" while in the European database we had to search "waste" and "water". Clearly, in this way a greater number of patents is obtained because the two words can be situated in opposite location one another. All the way, the difference is negligible because the title is normally composed of only few words.

4. The item "others" comprises also the "single inventors" in the US database, while in the European database patents by independent inventors have been assigned to the respective Countries.[29]

[28] The error rate was calculated as follows: once all patents belonging to one class have been found, a sample has been analysed. Titles and abstracts have been read to understand whether they were relevant for environmental problems and whether keywords were used with the right meaning.

[29] We defined single inventors' patents all patents whose owners are persons (not firms or other organisations).

Appendix 2 – The Questionnaire

SURVEY OF THE ENVIRONMENTAL TECHNOLOGIES

ORGANISATION NAME:
E-MAIL ADDRESS:

1) Status of your organisation:
   1.a) Company
   1.b) Institutional Subjects (Government or Independent Agencies)
   1.c) Research Institute

2) Number of employees of your organisation:
   2.a) 1-49
   2.b) 50-199
   2.c) 200-499
   2.d) 500-1000
   2.e) more than 1000

3) Organisation's nationality:

4) Do you belong to a group?
If yes, please indicate:
* the ultimate parent company's name:
* the ultimate parent company's nationality:
* the industrial sector where the ultimate parent company is mostly active:

5) In which regions do you operate? (Please indicate all regions)
   5.a) North America
   5.b) Middle and South America
   5.c) Western Europe
   5.d) Eastern Europe
   5.e) Middle Asia
   5.f) Asia and Africa
   5.g) Africa

6) In which sector do you operate? (Please indicate all sectors, not only environmental sectors, in which you are active):

   6.a) Chemical Engineering
   6.b) Environmental Engineering
   6.c) Plant Engineering
   6.d) Chemicals
   6.e) Petrochemical
   6.f) Energy
   6.g) Environmental Services
   6.h) Other

7) In which percentage do environmental activities contribute to the turnover?

8) Do you develop/trade environmental technologies or products?

IF YES, FILL IN THE FOLLOWING SECTIONS, CHOOSING AMONG THOSE OF INTEREST:

A) END-OF-PIPE TECHNOLOGIES
(purification, decontamination, treatment)

1) Technologies for purification/treatment of air/gases

1.1) Percentage of turnover generated by such technologies:

1.2) Kind of customers served (percentage of turnover):
  1.2.1) Individual consumers
  1.2.2) Industrial or commercial companies
  1.2.3) Institutional subjects (Government or independent agencies)

1.3) By which industrial sectors can be exploited the developed technologies?

1.4) In which percentage are the technologies:
  1.4.1) Standardised (easily adaptable to different requirements):
  1.4.2) Customised (aimed to solve specific problems and requirements):

2) Technologies for purification/treatment of water/wastewater/liquids
2.1) Percentage of turnover generated by such technologies:

2.2) Kind of customers served (percentage of turnover):
  2.2.1) Individual consumers
  2.2.2) Industrial or commercial companies
  2.2.3) Institutional subjects (Government or independent agencies)

2.3) By which industrial sectors can be exploited the developed technologies?

2.4) In which percentage are the technologies:
  2.4.1) Standardised (easily adaptable to different requirements):
  2.4.2) Customised (aimed to solve specific problems and requirements):

3) Technologies for treatment of wastes
3.1) Percentage of turnover generated by such technologies:

3.2) Kind of customers served (percentage of turnover):
  3.2.1) Individual consumers
  3.2.2) Industrial or commercial companies
  3.2.3) Institutional subjects (Government or independent agencies)

3.3) By which industrial sectors can be exploited the developed technologies?

3.4) In which percentage are the technologies:
  3.4.1) Standardised (easily adaptable to different requirements):
  3.4.2) Customised (aimed to solve specific problems and requirements):

4) Technologies for treatment of soil
4.1) Percentage of turnover generated by such technologies:

4.2) Kind of customers served (percentage of turnover):
  4.2.1) Individual consumers
  4.2.2) Industrial or commercial companies
  4.2.3) Institutional subjects (Government or independent agencies)

4.3) By which industrial sectors can be exploited the developed technologies?

4.4) In which percentage are the technologies:
  4.4.1) Standardised (easily adaptable to different requirements):
  4.4.2) Customised (aimed to solve specific problems and requirements):

B) PRODUCTS FOR ENVIRONMENTAL TREATMENT
(for instance, additives for water purification)

1) Percentage of turnover generated by such technologies:

2) Kind of customers served (percentage of turnover):
   2.1) Individual consumers
   2.2) Industrial or commercial companies
   2.3) Institutional subjects (Government or independent agencies)

3) By which industrial sectors can be exploited the developed technologies?

4) In which percentage are the technologies:
   4.1) Standardised (easily adaptable to different requirements):
   4.2) Customised (aimed to solve specific problems and requirements):

C) RECYCLING TECHNOLOGIES

1) Recycling of wastes (not industrial wastes)
1.1) Percentage of turnover generated by such technologies:

1.2) Kind of customers served (percentage of turnover):
   1.2.1) Individual consumers
   1.2.2) Industrial or commercial companies
   1.2.3) Institutional subjects (Government or independent agencies)

1.3) By which industrial sectors can be exploited the developed technologies?

1.4) In which percentage are the technologies:
   1.4.1) Standardised (easily adaptable to different requirements):
   1.4.2) Customised (aimed to solve specific problems and requirements):

2) Recycling of industrial wastes
2.1) Percentage of turnover generated by such technologies:

2.2) Kind of customers served (percentage of turnover):
   2.2.1) Individual consumers
   2.2.2) Industrial or commercial companies
   2.2.3) Institutional subjects (Government or independent agencies)

2.3) By which industrial sectors can be exploited the developed technologies?

2.4) In which percentage are the technologies:
   2.4.1) Standardised (easily adaptable to different requirements):
   2.4.2) Customised (aimed to solve specific problems and requirements):

3) Recycling of water
3.1) Percentage of turnover generated by such technologies:

3.2) Kind of customers served (percentage of turnover):
   3.2.1) Individual consumers
   3.2.2) Industrial or commercial companies
   3.2.3) Institutional subjects (Government or independent agencies)

3.3) By which industrial sectors can be exploited the developed technologies?

3.4) In which percentage are the technologies:
   3.4.1) Standardised (easily adaptable to different requirements):
   3.4.2) Customised (aimed to solve specific problems and requirements):

4) Recover of resources:

4.1) Percentage of turnover generated by such technologies:

4.2) Kind of customers served (percentage of turnover):
4.2.1) Individual consumers
4.2.2) Industrial or commercial companies
4.2.3) Institutional subjects (Government or independent agencies)

4.3) By which industrial sectors can be exploited the developed technologies?

4.4) In which percentage are the technologies:
4.4.1) Standardised (easily adaptable to different requirements):
4.4.2) Customised (aimed to solve specific problems and requirements):

D) CLEAN TECHNOLOGIES
(pollution prevention)

Please consider the three clean technologies whit the highest proportion of turnover and fill in the following:

CLEAN TECHNOLOGY 1
1.1) Short description of the technology:

1.2) Environmental benefits obtained with respect to the technology that has been replaced:

1.3) Typology of polluting substances eliminated or reduced:
1.4) Percentage reduction of polluting substances:
1.5) Can the introduction of new technology produce a sensible cost reduction and/or efficiency increase?

CLEAN TECHNOLOGY 2
2.1) Short description of the technology:

2.2) Environmental benefits obtained with respect to the technology that has been replaced:

2.3) Typology of polluting substances eliminated or reduced:
2.4) Percentage reduction of polluting substances:
2.5) Can the introduction of new technology produce a sensible cost reduction and/or efficiency increase?

CLEAN TECHNOLOGY 3
3.1) Short description of the technology:

3.2) Environmental benefits obtained with respect to the technology that has been replaced:

3.3) Typology of polluting substances eliminated or reduced:
3.4) Percentage reduction of polluting substances:
3.5) Can the introduction of new technology produce a sensible cost reduction and/or efficiency increase?

E) GREEN PRODUCTS

Please consider the three green products with the highest proportion of turnover and fill in the following:

GREEN PRODUCT 1
1.1) Short description of the product:

1.2) Environmental benefits obtained with respect to the technology that has been replaced:

GREEN PRODUCT 2
2.1) Short description of the product:

2.2) Environmental benefits obtained with respect to the technology that has been replaced:

GREEN PRODUCT 3
3.1) Short description of the product

3.2) Environmental benefits obtained with respect to the technology that has been replaced:

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9) Do you offer environmental services?
If yes, fill in the following sections

TECHNOLOGICAL CONSULTING SERVICES
(for instance, advices for prevention pollution, waste minimisation, purification, reclamation, planning....)

9.1) Kind of services offered:

9.2) Percentage of turnover generated by such service:

ENVIRONMENTAL MANAGEMENT SERVICES
(for instance, environmental audit, impact assessment, environmental policy....)

9.3) Kind of services offered:

9.4) Percentage of turnover generated by such service:

OTHER ENVIRONMENTAL SERVICES
(for instance, laboratory services, recycling services....)

9.5) Kind of services offered:

9.6) Percentage of turnover generated by such service:

10) Please indicate the kind of incentives offered to customers to buy your environmental products/technologies/services. (Select one or more)

- 10.1) Free market (for instance cost reduction, efficiency increase):
- 10.2) Industry pressure for compliance (for instance informal expectation, industry standards i.e. ISO 14000):
- 10.3) Government (positive incentives, sanctions for non compliance, policy regulation...)

11) During the last 5 years, how many patents did you realise?

How many patents did you realise during the last 5 years with reference to environmental technologies?

- 11.1) End-of-Pipe technologies:
- 11.2) Recycling technologies:
- 11.3) Clean technologies:
- 11.4) Green products:

12) During the last 5 years, did you realise environmental patents in collaboration with:

- 12.1) Other firms:
- 12.2) Research institutes:
- 12.3) Universities:
- 12.4) Governmental agencies:

13) During the last 5 years, did you licence any environmental technology (including both End-of-Pipe and Clean technologies)?
If yes, referring to the three most important transfers, fill in the following:

LICENCE 1
1.1) Date (year):
1.2) Type of technology:
1.3) Licensee name:
1.4) Presence of a patent:

LICENCE 2
2.1) Date (year):
2.2) Type of technology:
2.3) Licensee name:
2.4) Presence of a patent:

LICENCE 3
3.1) Date (year):
3.2) Type of technology:
3.3) Licensee name:
3.4) Presence of a patent:

14) During the last 5 years have you been granted for any environmental technology licence?
If yes, referring to the three most important transfers, fill in the following:

LICENCE 1
1.1) Date (year):
1.2) Type of technology:
1.3) Licensor name:
1.4) Presence of a patent:

LICENCE 2
2.1) Date (year):
2.2) Type of technology:
2.3) Licensor name:
2.4) Presence of a patent:

LICENCE 3
3.1) Date (year):
3.2) Type of technology:
3.3) Licensor name:
3.4) Presence of a patent:

15) Did you use know-how and experience acquired in the environmental sector in order to develop not environmental businesses?

15.1) If yes, please indicate which businesses

16) Did you introduce any environmental technology thanks to know-how and experience acquired in different sectors?

16.1) If yes, please indicate which sectors

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