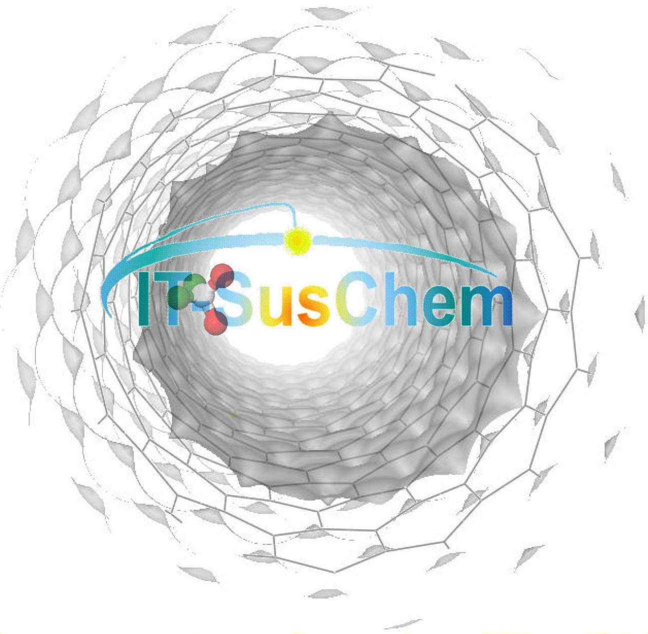
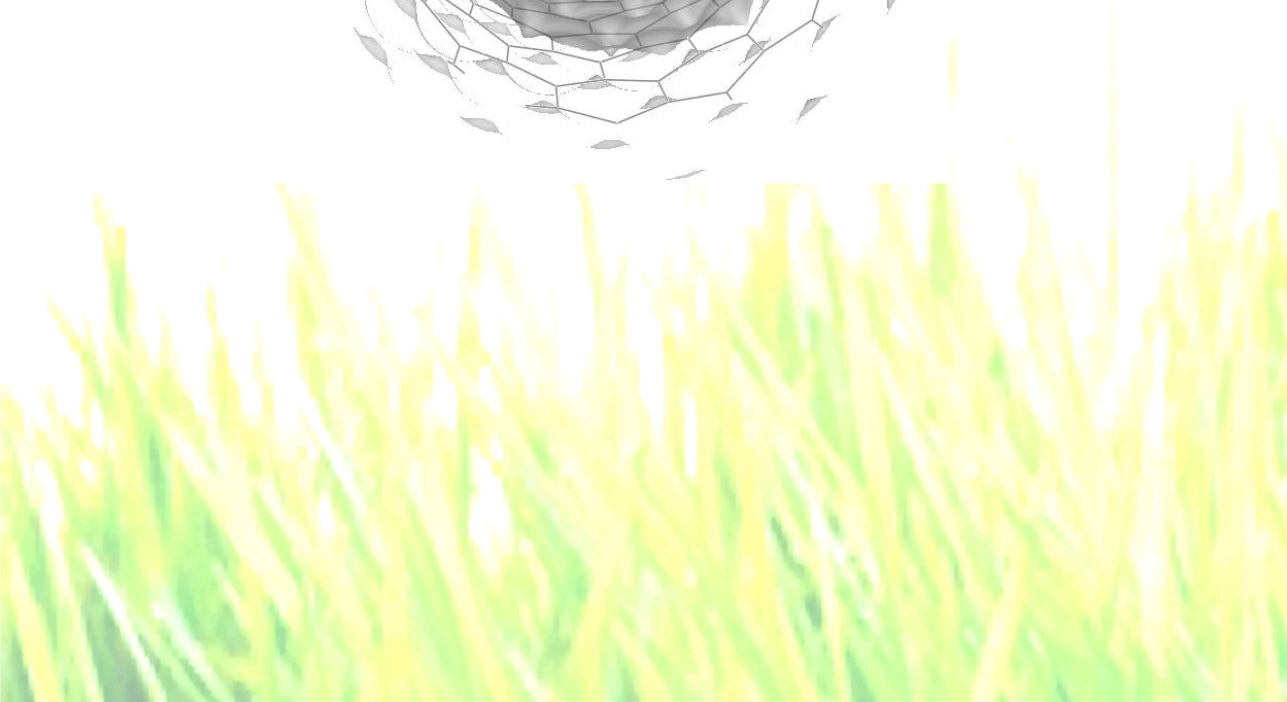
IT-SusChem





Structuring and Planning Research & Innovation for a Sustainable Chemistry in Italy

Contents

1. Introduction

1.1 - Background

Italy and Europe are witnessing dramatic changes whose relevance and signals of transitions are often undercover or underestimated in societal perception:

- The extremely fast growing new economies with low labour cost and huge market potential are progressively altering the actual production model and depleting the availability of natural resources and raw materials.
- The globalization of environmental problems, from water to greenhouse gases, makes it necessary to avoid further delays in introducing new technologies to decrease the impact of industrial production on future society.
- "Local action" to preserve the quality of life and environment is becoming a key element for societal decisions. This also requires changing to a new model of delocalized production and energy.
- Securing and safeguarding raw materials, food, energy and resources are becoming crucial factors for decision strategies.
- Progressive climate changes and poverty will increase immigration problems.
- Climate changes, together with environmental problems, decrease the local availability of critical resources for societal life. For example, the decreasing water availability and quality in various areas in Italy have an impact on agriculture, life, and society.
- The progressive transition to an ageing society is modifying the indicator parameters for quality of life, with increasing relevance to healthcare, personal care, and wellness.
- Science, nano- and bio-technology, for example, are opening new possibilities and creating new solutions to societal problems.
- The progress in telecommunication and data transfer opens new prospects for a network society. It will also make it possible to manage a distributed model for production and energy.

These changes create threats to our society, but also opportunities, if society is able to react positively to them. It is necessary to foster a transition to a knowledge-based society and production, which will balance the effort between economics, environmental protection, and quality of life.

To accelerate this transition, it is necessary to build strategic and intellectual alliances that are conducive to a long-term concerted effort, continuously and fully supported by all stakeholders. By creating a comprehensive and structured approach, these alliances will also allow a parallel dialogue for establishing regulatory and economic frameworks that stimulate innovation, whilst maintaining effective public safety.

1.2 - Chemistry, an Engine for Innovation

Chemistry, the science of creating, mastering and tailoring products and materials by controlling them at the molecular level, is pervasive in all aspects of our life. Chemistry starts from natural resources (crude oil, gas, natural oils, fats, sugars, etc.) and by progressive functionalization transforms them into most of the products we use every day. Chemistry helps to feed, clothe, house and entertain us, and keep us healthy. It provides us with energy and transportation, and continues to do all these things as advances in chemistry and biochemistry are helping us both to conserve scarce resources and to protect the natural environment.

The best chemistry is yet to come: novel anti-cancer, anti-ageing, and disease prevention therapies based on the exploitation of the human genome; cleaner and more sustainable energy production, storage and supply; reliable and fast high-capacity information storage, distribution and processing; increased food quality and production with less demand on agricultural land. Chemistry will provide functional materials which will make our vehicles lighter and stronger and therefore safer and more energy-efficient, and make our buildings safer and with lower energy consumption, thus reducing greenhouse gas emissions. True sustainable development requires more and more the eco-efficient processes and products that chemistry will provide.

Chemistry was one of the pillars for the wealth and growth of the European economy during the 20th century: it was based on an ever-improving understanding of interactions at a molecular level which enabled the increasingly sophisticated manipulation of the physical world. Chemistry will continue to be a primary driver for both the growth and sustainable development in the European economy and the well-being of its citizens.

The next challenges for chemical science will be the key to solving the challenges that society will face in the near future. Chemistry provides technological solutions to solve our problems. By building on Italy's strong points, chemistry will have a pivotal role in stimulating the Italian economy by providing new opportunities and creating wealth that will benefit all citizens.

Chemistry is also an important economic player for Italy. Chemical production in Italy accounted for € 55 billion in 2006, ranking fourth in Europe with 12% of the chemical production and 6% of the manufacturing production. Exports totalled € 21 billion in 2006, with a relative growing rate (together with the pharmaceutical industry) of 3% versus the figures for Italian exports between 1991 and 2005 (third sector for exports). Around 200,000 people work in this sector, but the number of workers indirectly involved in chemical production is more or less double that figure. Lombardy is the 2nd chemical region in Europe in number of workers (after Rheinland-Westfalen) and the first in number of companies. (*Source*: FederChimica).

1.3 - Creating a Strategic and Intellectual Alliance for a Sustainable Chemistry

Therefore, the creation of a strategic and intellectual alliance for a sustainable chemistry among all the stakeholders in Italy is a critical factor that will make it possible to start a virtuous path, which leads to accelerating innovation and achieving our common goal of a "knowledge-based" and sustainable economy. It will be also a key factor in the improvement of the industry's eco-efficiency and social contribution.

Innovation is the key to the survival of the chemical industry, and requires concerted action on the European, national and regional level. Therefore, integration with the common European effort is required in order to reach this objective . The European Commission has encouraged the independent self-organization of various strategic areas for Europe through some European Technology Platforms. One of them is devoted to chemistry.

1.4 – The European Technology Platform for Sustainable Chemistry

The European Technology Platform for Sustainable Chemistry (ETP SusChem) was launched in July 2004 in order to bring together the academic world, industry, SMEs, NGOs and other major stakeholders in the chemical and associated sectors in boosting investments in chemical research, development and innovation in Europe. It is a multi-stakeholder platform.

ETP SusChem is structured into three main sections:

- **Industrial Biotechnology,** which focuses on the approach for making Europe's industries become leaders in biotechnology processes and technologies for various sectors, including chemicals, food and nutrition, textiles, leather, animal feed, pulp and paper, energy and waste processing. The guidelines for R&D in industrial biotechnology are the cost- and eco-efficient development and production of new, innovative products and processes, while using increasingly renewable raw materials, thanks to the discovery and optimization of microorganism strains and biocatalysts.
- **Materials Technology,** which focuses on materials for humankind's future surroundings, which will be designed to enhance the quality of life; this section defines the role of nanoscience and related nanotechnologies in providing the knowledge necessary to lead to new innovative products and process methods. Application areas of interest include (i) functional and intelligent materials, (ii) smart energy creation, storage, transport and conversion, and (iii) synthesis of rationally designed materials.
- **Reaction and Process Design,** e.g. the integrated approach to improving the production process and the quality of chemical products. These fundamental technologies will contribute to the entire lifecycle from product development via catalyst and process development, plant development and operation, to product handling and logistics. Reaction and process design integrate the complementary approaches of chemical synthesis, process design and engineering, by providing key contributions to all the related steps, from reaction to viability of process plants, and apply to all areas of chemistry and biotechnology.

An additional area regards the **Horizontal Issues,** e.g. those activities such as educational issues that are horizontal to the entire area of sustainable chemistry. This section takes into account the necessary political, social and structural reforms needed to maintain and increase Europe's edge within the increasingly global world of innovation.

The top-level goal is to ensure that the citizens in the EU benefit from the development and use of innovations based on the SusChem strategic research agenda. Priority areas include how to stimulate support for innovation, and addressing societal concerns associated with new products and processes.

Three key documents (available at the web site http://www.suschem.org) have been produced:

- **The vision for 2025 and beyond** (March 2005) describing a European sustainable chemical industry characterized by enhanced global competiveness, which provides solutions to critical societal demands and is powered by a world-leading, technologically innovative drive.
- **Sustainable Chemistry Strategic Research Agenda (SRA) 2005** (November 2005) which outlines the future priorities for European research efforts. The SRA identifies key areas of research as well as the limitations and hurdles faced by researchers.
- **Putting Sustainable Chemistry into Action Implementation Action Plan (IAP) 2006** (December 2006). This document defines the specific steps for putting the SRA into practice. Each priority is defined in terms of key activities, players, budget lines, and time frames. Priorities and activities are organized around eight main topics: 1) Bio-based economy. 2) Energy. 3) Healthcare. 4) Information and communication technologies. 5) Nanotechnology. 6) Sustainable quality of life. 7) Sustainable product and process design. 8) Transport.

The main goal of these documents is to provide a coherent framework for the next twenty years, through which all the stakeholders in the area can work together on shared long-term objectives. General objectives are also to:

- Provide the innovative drive for Europe: chemistry does not simply deliver raw materials – it is a major source of innovation in areas from clothing to energy and pharmaceuticals.
- Be at the heart of the new technologies that underpin the knowledge-based economy: chemistry is the core science of nanotechnology, biotechnology and environmental technology.
- Invest for sustainable development: chemistry is improving the eco-efficiency of products and processes in order to optimize the use of resources and minimize waste and environmental impact.
- Protect and extend employment, expertise and quality of life: chemistry is providing the innovation for knowledge-based enterprises all over Europe. Chemistry is already a knowledge-led sector with a highly trained labour force and stimulates significant growth and wealth creation across Europe.

The future role of ETP SusChem will be that of linking and networking stakeholders, 7^{th} Framework Programme (7FP) and other European programmes, and National activities, platforms, and funding programs. The activity will also continue implementing three *visionary projects* proposed in the above-mentioned documents:

- Smart energy housing
- Integrated biorefinery
- F^3 factory (fast, flexible, future).

1.5 – Creating a Synergy between National and Regional Initiatives with Those at European level

integration of national and regional initiatives with those at European levels is a key to the success of putting the SusChem vision and action plan into practice. An Italian platform for Sustainable Chemistry (IT-SusChem), which efficiently integrates the national and regional interests and specificities into the European effort for innovation in sustainable chemistry, allows fostering the alignment between 7FP and national programmes on chemistry, chemical engineering and biotechnology.

A national platform for sustainable chemistry will also promote the participation of SMEs in European programmes, and develop efficient mechanisms that facilitate the knowledge and technology transfer and innovation. This is particularly pertinent to chemical technologies due to their enabling role in downstream innovations.

A joint alliance can: support more effective research infrastructures and engagement in EU research funding programmes; improve involvement and alignment with other relevant EU and Member State initiatives; increase the access to venture capital; build early confidence in new technologies both with the general public and political leaders.All this is possible thanks to the capability to bring stakeholders together, at the onset of the innovation process.

Teaching activities in science and chemistry will greatly benefit from an Industry-Academia research collaboration. The availability of a skilled labour force is essential to the long-term viability and innovative capacity of Italian industry. The building of skills in young people is a critical factor toward providing support to the society's economic, ecological and social needs. A joint alliance will contribute to these objectives by improving science education, skills, training, and mobility for researchers.

Therefore, a national platform will be a bridge to Europe, but also a key instrument for planning the future, creating shared objectives and concerted actions, responding faster to Italian society's needs for chemistry, and boosting the transfer of ideas to foster innovation.

Thus, the creation of an Italian Platform for Sustainable Chemistry will make it possible to:

- Integrate the national and regional interests and specificities into the European effort for innovation in this area.
- Foster the alignment between FP7 and national R&D programs in chemistry, chemical engineering and biotechnology.
- Obtain a rational strategic alliance among companies, research and educational institutions, stakeholders and society for providing solutions to social needs (including education).
- Improve public-private partnership in the Italian sectors of the chemistry, chemical engineering and biotechnology.
- Boost the innovation and competitiveness of SMEs and industries responsible for the economic growth of the Chemistry sector.

1.6 – The Italian Platform for Sustainable Chemistry

The Italian Platform for Sustainable Chemistry (IT-SusChem) is an *open and transparent* group activity. Its aim is to create a strategic and intellectual alliance among companies, research and educational institutions, stakeholders and society to provide solutions to critical societal demands, to boost innovation, strengthen competiveness and foster effective public-private partnership.

Since March 2006, the Italian industry - under the coordination of Federchimica - and academia - under the guidance of Bologna University, on behalf of CRUI (Conferenza dei Rettori delle Università Italiane) - have been working together closely on the establishment of an Italian SusChem Platform. A Promoting Committee was formed to guide the formation of the IT-SusChem. Its purpose is to create the critical mass around the national implementation of the ETP SusChem in Italy by involving all the potentially interested stakeholders. The governance and structure of IT-SusChem is close to that of ETP SusChem to facilitate the link.

The Platform activities are managed by a **Promoting Committee** and a **Scientific Committee**, appointed by the stakeholders groups and representing the following technology sections:

1. Industrial Biotechnology.
2. Material Technology.
3. Reaction and Process Design.

The integration among the common scientific subjects and complementary methodologies used by the three technology areas to permit the overlapping of research subjects will be carried out by the **Horizontal Issue** area. The IT-SusChem Governance and the members of the Scientific Committee are described at the end of this document. Further details on activities can be found at the IT-SusChem web site:

http://www.unibo.it/Portale/Ricerca/Servizi+Docenti+Ricercatori/finanzeuropei/ITSuschemPlatform.htm

After a series of preliminary activities, the official launch (http://www.unibo.it/Portale/Ricerca/suschem.htm) of the IT-SusChem Platform was held in Bologna on 23rd October 2006

Around 350 people attended this event, with about 100 stakeholders (Industrial Companies & Private Research Laboratories, Associations, Italian Universities & Inter- University Consortia, Italian Research Centres and Other Companies & Groups, including banks) who formally agreed to take part in the platform activities. The number of stakeholders has grown to over 150 as of January 2007. A list of them is provided at the end of this document.

During the preparatory phase of this event, the IT-SusChem Scientific Committee prepared a draft Vision and SRA document. This document was broken down into the four above-mentioned sections. It was distributed during the launch of the IT-SusChem, and made available on the Web for downloading. This document identifies the national social and industrial needs in the areas of industrial chemistry and biotechnology as well as the strategies to address them, to boostcompetitiveness, to exploit the research expertise and skills in transnational R&D programs in the same sectors.

After its presentation during the IT-SusChem Platform launch (Bologna, October 23, 2006), this document was made available for national consultation (http://www.unibo.it/Portale/Ricerca/consultazionenazionale.htm).

Some feedback from interested stakeholders was collected in the period from October 23 to end of January 2007. This feedback was incorporated into the revised documents, which are described in section four.

2. Structure and Aims of This Document

This document is divided into several different parts. The introduction states why an Italian Platform on Sustainable Chemistry should be created as a bridge to Europe, but also as a unique opportunity for better structuring and planning research and innovation for sustainable chemistry in Italy. The second section provides a brief introduction on the importance of R&D in sustainable chemistry in solving society's main needs. The third part reports on the specific section documents prepared by the IT-SusChem Scientific Committee for the three technology sections (Industrial Biotechnology, Material Technology and Reaction, and Process Design) and the Horizontal Issues area. The final section describes the details on the governance and structure of IT-SusChem, and the list of the stakeholders who joined it.

The section documents represent the main technical contribution of this document. After a specific introduction on the sector defining the state-of-the-art of the Italian chemical industry in that sector, this section's documents identify the specific R&D priorities in terms of goals and the resulting necessary actions. They also include considerations on the strategies necessary for boosting Italian R&D and industry in the sector.

Thus, these documents represent a shared vision of companies, research Institutions and academia, sector associations and groups of interest on the specific thematic area. The documents identify the priorities, and define a R&D plan and research agenda to meet these priorities. However, they do not define specific implementation plans. In fact, these plans could derive only from a subsequent step, when the national resources to be devoted to the implementation of the plans are identified. Nevertheless, these documents are the basis for the preparation of a strategic national plan in the area of Sustainable Chemistry.

This section's documents could be also the basis for both the definition of national priorities in the area of chemistry, materials and biotechnologies to be taken into account by the European Commission when preparing future work programmes for the 7FP, and the strong synergy between national and European R&D programmes. In this respect, the ERA-NET and ERANET+ EU programmes, whose specific aim is to foster this integration, are especially noteworthy. These documents could be the basis for such an activity in the chemistry, materials and biotechnologies areas.

Lastly, these documents could have a significant role in planning a national structural reorganization in these areas: a reorganization aimed at making both the research in Italy and the transfer of ideas to foster innovation more effective.

3. Meeting Society's Needs: The Contribution of IT-SusChem

The IT-SuChem Platform is divided into three technological sections (Industrial Biotechnology, Materials Technology, and Reaction and Process Design), and a Horizontal Issues section, in order to match the organization of the equivalent European Platform. This allows a better link, synergy and integration between the National and European Platforms on Sustainable Chemistry.

However, this structural organization is not functional for highlighting the platform's contribution to societal needs. For similar reasons, and in order to provide a closer parallelism to the 7th European Framework Programme, the Implementation Action Plan (IAP) of the ETP-SusChem was also organized into eight main topics and priorities:

1. Bio-based economy.
2. Energy.
3. Healthcare.
4. Information and communication technologies.
5. Nanotechnology.
6. Sustainable quality of life.
7. Sustainable product and process design.
8. Transport.

For each of these topics, the IAP of the ETP-SusChem outlines the priorities and necessary activities, and identifies barriers to, and opportunities for, chemistry innovation. IAP thus provides a coherent roadmap of technology developments for energy, information and communication technology, healthcare, quality of life, citizen defence, and transportation:that shows how pervasive chemistry is in solving societal needs. The section documents reported on in the next chapter could be read by following a similar approach. There is a fair agreement with the priorities defined in the IAP, notwithstanding the specification of national priorities, because the latter often overlap European priorities.

Nevertheless, it is useful to examine the contribution provided by emerging technologies to chemistry for the solution of societal needs, while identifying six main challenges to the Italian society to which R&D in chemistry could provide enabling solutions:

1. Securing energy
2. Smart living
3. A clean environment
4. Rational use of resources
5. Products for a better quality of life
6. Job creation through research-driven innovation and knowledge-driven sustainable society

3.1 - Securing Energy

The securing of energy by improving efficiency, delocalizing production, and creating technologies to improve the use of renewable resources is crucial for Italian economy and society. There is a critical need to rethink energy supply and usage, since existing energy resources are limited in both volume and geographical distribution in the perspective of exploding global energy requirements.

As a result, several priorities in this document deal with this topic and can be summarized into the following main areas which also represent active areas of investigation in Italy:

- *Developing alternative energy sources*: (i) new materials and approaches for photovoltaic cells, (ii) catalytic processes for fuel production from biomass, (iii) fuel cells (low and high temperature), (iv) efficient production of H_2, (v) use of sunlight by photocatalytic processes to produce H_2 or convert CO_2, (vi) exploitation of wastes and residues to produce energy.
- *Saving energy by reducing energy loss through the smart application of materials and technologies*: (i) efficient lighting by LEDs and electrochromic devices, (ii) novel nanostructured materials (nanofoams, for example) for better insulation technologies, (iii) improved materials to reduce energy losses during tranport, (iv) technologies for distributed energy production, (v) reduction of energy consumption in processes, (vi) materials aimed at reducing energy use for mobility.
- *Ensuring the safer and better storage of energy through innovative ways of using and transporting it*: (i) new batteries and supercapacitators, (ii) new energy networks based on renewable resources, (iii) thermoelectric devices to convert heat into electricity, (iv) new materials for H_2 storage and transport, (v) high-capacity hybrid materials for safe gas storage.

These topics find resonance in the SusChem visionary project, the Smart Energy Home, in which the IT-SusChem platform also takes part.

3.2 - Smart Living

Smart living indicates the range of chemistry technologies and products for healthcare, wellness, enhanced diagnostics, improved indoor air quality (homes, cars), self-cleaning surfaces, etc. aimed at improving the quality of life.

There are many and varied examples of aspects of our daily lives which can be improved. At home, numerous innovations are possible with the application of new materials and technologies ranging from improvements in the efficiency of laundry processes by using new formulations or catalysts, to the implementation of low energy devices. Furthermore, activated surfaces incorporated in paints or wall decorations can counteract bad smells created by cooking or household wastes, while self-cleaning surfaces will reduce the amount of detergents and time spent on cleaning activities. Photoactive coatings will protect hospitals and houses from viruses and bacteria in the air, and also provide efficient routes for improving indoor air quality by detoxification from micro-pollutants.

Catalytic system and biosensor coatings on the internal surfaces of food packaging are able to either decompose residual oxygen, thus prolonging shelf life, or indicate whether the food is still safe for consumption by a change in colour, or even provide both functions. Smart materials can be designed which incorporate diagnostic functions for monitoring their characteristics.

New nanopatterning techniques (enhanced inkjet, micro-contact printing, etc.) and the use and integration of these techniques will allow the production of high-performance low-cost products (plastic electronics, for example) which will represent a revolution for our lifestyle. By integrating these low-cost electronics with the progresses in sensors and IT technologies (smart dust, for example), it will be possible to develop new intelligent and self-adaptive houses.

Exploitation of these nanoscale functions for new applications promises to have an immense impact in improving healthcare and quality of life. New materials are available for target drug delivery, intelligent diagnostic agents (theranostics which combine diagnosis and therapy), and regenerative medicine. The miniaturization of the imaging system will make it possible to perform image-based diagnostics everywhere, and not only in vanguard hospitals. Nanosensors will be able to provide live online data to physicians during surgery, thereby increasing safety, lowering radiation doses and improving patients' prognoses. In addition, these sensors would be able to provide the continuous monitoring of important parameters such as blood pressure after surgery.

These are only some of the many examples showing how the new devices, technologies and materials deriving from the R&D in chemistry could completely change our way of life.

3.3 - A Clean Environment

Catalysis provides innovative solutions for solving urgent environmental issues. In order to achieve and maintain a clean environment, technologies for water treatment, soil and water remediation, waste treatment, and the prevention of air pollution are required. Through a better understanding of the pathways involved in waste treatment/remediation processes, new technologies will be available, for example in the following areas:

- (Bio)catalytic solutions for soil and water remediation and purification of drinking water, targeting the conversion and removal of a wide variety of substances at low concentrations.
- An efficient conversion of greenhouse gases with high global warming potential, in particular N_2O and CH_4, in diluting process streams. New technologies for converting CO_2 back to fuels by using solar energy are also being developed.
- Technologies for end-of-pipe treatment in process systems including separation methods, catalysis, and plasma surface etching, microwaves etc., thereby integrating efficient recycling and re-use strategies.
- Photocatalysts added to the pavement either as a filler or as a film coating, to decompose noxious compounds from car emissions and improve the quality of air in cities.
- New catalytic technologies to further reduce emissions from cars, especially from diesel engines, which are characterized by higher energy efficiency than gasoline engines (lower CO_2 emissions) but for which the presently available catalytic converters are not efficient.
- New polymers for tyres which cut energy consumption and, at the same time, reduce the formation of particulate.

3.4 - Rational Use of Resources

Reliance on a few limited sources of energy is detrimental not only to the environment but also to the future economic stability of the country. The future lies in a diversification of energy sources, tailored to the requirements and resources of Italy. An increase in the use of solar energy, by both photovoltaic systems and alternative solutions is a must for a sunny country like Italy. The preservation of agriculture in rural areas and the availability of large amounts of agricultural waste are driving forces for a fast implementation of new technologies and the use of biomasses for both energy and materials applications. The shortage of some raw materials foster the introduction of alternative solutions, such as polymer conductors to substitute copper wires, for example. The high energy consumption necessary for producing metals - aluminium for example - foster the diffusion and mass production of high-performance composite structural materials presently used for specific high-value applications only (i.e.in aeronautics).

The rational use of resources implies a decreased dependency of chemical production on oil by shifting the feedstock base towards alternative feedstocks. Biomass as a renewable resource is the preferred option, but efficient exploitation of gas and coal is also required, due to their more extensive reserves, as compared to oil.

For larger scale exploitation of biomass-derived feedstocks, whole value chains will have to be adapted and redesigned. Since the chemical industry is highly integrated, this is a key challenge; therefore, a large-scale analysis which goes far beyond a single transformation is necessary.

The introduction of new routes for natural gas conversion to chemicals and the efficient exploitation of coal as a feedstock requires the integration of knowledge on: the selective activation of alkanes, development of new catalysts, new reactor engineering, and value chains in the chemical industry. The diversification of raw materials in petrochemical production by introducing new processes based on the direct use of natural gas as a raw material (e.g. acetic acid from ethane, acrylic acid from propane, methyl methacrylate fromisobutane) will reduce the dependence of chemical production on oil and create competitiveness incentives. The conversion of natural gas produced in remote areas to a liquid state will allow low transportation costs and enable its use as an alternative raw material, thus decreasing greenhouse gas emissions. New catalysts for the selective functionalization of alkanes and gas-to-liquid conversion are required. These catalysts should be integrated into smart and efficient reactor concepts, for example, for the "at-source processing" of natural gas.

3.5 - Products For a Better Quality of Life

A sustainable quality of life implies low environmental impact through the consumption of less energy, the use of fewer resources, and reduced emissions, either directly in citizens' own homes, or indirectly through the products they buy. While most homes still rely on traditional means for their energy requirements, technological advances and resource management techniques have made it possible today to cut energy consumption by up to 90 %. With the development of new technologies covering energy generation and consumption, it will be possible for a home to generate enough energy to meet and even exceed its daily requirements. Energy conservation and home owner comfort, health and convenience are all integral parts of the concept of a Smart Energy Home.

Industrial biotechnology can contribute to make the pharmaceutical industry more competitive either by developing more efficient pathways for drug production or by using bioprocesses to produce drugs which are difficult or impossible to synthesize chemically. Advanced Pharmaceutical Intermediates (APIs) are key building blocks for the synthesis of sophisticated drug molecules. Nutraceuticals and food additives can be produced directly by microorganisms. Production can be enhanced through improved efficiency and new production pathways developed by metabolic engineering.

The quality of people's life is expected to be enhanced dramatically by the use of new materials for devices enabling greater mobility, e.g. mobile phones, portable computers, etc.; more efficient and sustainable transportation; cosmetic preparations for better appearance and protection from external environmental elements; and improved nutrition thanks to increased stability and bioavailability of vitamins and food additives through innovative formulation techniques.

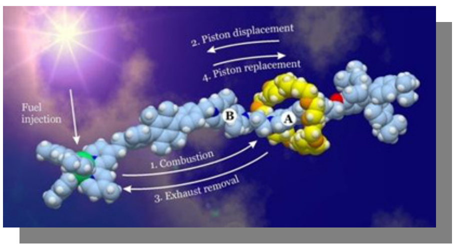
The development of smart internal and external coatings with self-cleaning properties and which are switchable depending upon changes in the environment can be expected. Surfaces with anti-fouling properties capable of recogniying and destroying pollutants and corrosion agents can be produced. New materials will enable the production of longer lasting batteries; smaller and more stable sensors, functional clothing that is self-cleaning, -fitting and -protecting; and prosthetics and implants.

Next-generation catalysts from the reaction and process design area should contribute to achieving zero emissions. New catalysts will also enable the development of new biomimicking catalytic transformations, new clean energy sources and chemical storage methods, use of new and/or renewable raw materials and reuse of waste, thus solving global issues (greenhouse gas emissions, water and air quality) and creating smart catalytic devices for health protection and the improvement of the quality of life.

3.6 - Job Creation Through Research-Driven Innovation and Knowledge-Driven Sustainable Society

Chemistry is already a knowledge-led sector with a highly trained labour force. By providing the innovation for knowledge-based enterprises all over Italy, chemistry will stimulate a significant growth and wealth creation in Italy, by protecting and extending employment, expertise and quality of life.

The Italian model of society requires a competitive industry as a basis for the economy's growth and jobs, while maintaining its commitment to social and environmental sustainability. Investment in innovation and R&D means creating new job opportunities, also for all the production sectors that are related to the chemical industry.
The chemical and associated industries will remain competitive only if based on technology leadership and innovation. Mastering the molecular scale (as in nanotechnology and biotechnology) will yield new generations of products with enhanced properties leading to new applications in many industrial sectors, at the same time creating new jobs.



4. Structuring and Planning Research and Innovation in Italy

4.1 - Industrial Biotechnology

4.1.1- The Biotech Industry in Italy.

Over the last few years Italy has finally witnessed the birth of an industrial biotechnology sector, although much later than other countries of similar economic importance. This sector has shown a rapid and remarkable growth, especially in diagnostics, therapeutics and related fields, by highlighting its remarkable potential, in terms of small or medium-sized R&D dedicated biotech companies. However, it is still "young", small, mainly located in the country's north, and dominated by "red" or healthcare biotech productions.

A survey conducted by Assobiotec in 2006 (after *Assobiotec-Blossom Associati, "Biotechnology in Italy, Strategic and Financial Analysis, 2006"; "www.blossomassociati.com"*) identified 163 Italian companies operating in the sector of biotechnology along with 16 technological parks hosting biotech companies or/and research centres. According to the Report, about 80% of all biotech organizations (companies, biotech-related national science parks and research centres, etc.) are located in northern Italy and mostly active in niche markets in the diagnostics, therapeutics and related fields. Many of the R&D biotech companies have sprung from spin-off processes and buyouts of research laboratories from multinational companies. Furthermore, some well-established pharmaceutical and chemical companies recently turned to biotech. Around 60% of these companies have a project portfolio that is predominantly in the research stage, 26% are at an early development stage (Stage 1 or 2), and 18% of them have projects in Stage 3 or in the approval stage. Lastly, only 46% of the companies obtained patents on their own research products. About 50% of them have fewer than 15 employees; more than 90% of all the Italian biotech companies are classified as SMEs according to the criteria of the European Commission (fewer than 250 employees and a turnover below €27 million euro per year).

The Italian biotech industry grew markedly during the last few years (growth rate: around 10% per annum) with an impact of R&D investment on sales that grew from 34% in 1999 to 46% in 2004.

The geographic distribution of biotech companies shows a high level of territorial fragmentation. In fact, only 21 Italian provinces have a biotechnology presence in their territory and only one third has set up incubators to support the development of start-ups. About 70% of all biotech companies are located in northern Italy, whereas about 14% and 16% of them are located in central and southern Italy, respectively.

The biotech industry in Italy is primarily focused on the production of human health products (about 33% and 25% of the total Italian biotech production consist of therapeutic and diagnostic products, respectively). On the contrary, agro-foods and bioprocesses currently represent minor fields of activity: only 22% of the Italian biotech companies seem to be active in these fields, where they mostly focused their production on specific market niches not covered by the big international companies.

4.2 - Industrial/White Biotechnology and Environmental Biotechnology and Their Impacts on the Future Economy.

4.2.1 - Industrial/White Biotechnology Sector

On the agenda of every responsible government, humanitarian organization, economic entity and analyst there are major issues or concerns regarding all of humanity that can no longer be avoided.

With a fast growing world population, the two major concerns are the supply of energy and water. The demand for energy and water is rising rapidly. New economies with a double-digit growth rate like China and India are absorbing more fossil fuels. It is forecasted, for example that China's energy consumption will be 5 quadribillion BTU higher than the US by 2030[1] (from *http://www.eia.doe.gov*).

The consequences of this situation are multifold (from environment to politics, to economics) and need to be tackled from various standpoints (energy and water saving and equal distribution, lifestyle changes, increased efficiency in industrial processes, and energy production, to name just a few). Locally, the consequences on the environment are already apparent, with high levels of pollution in all industrialized countries: all major Asian cities are good examples of fast economies which are not sustainable from an environmental point of view.

On a global scale, we are experiencing climate changes. As a consequence of the increased concentration of the so-called greenhouse gases in the atmosphere, the earth is expected to become warmer worldwide. Eleven of the latest 12 years are amongst the warmest 12 years on record since 1850[2]. The main contributor of global warming is CO_2, primarily resulting from the burning of fossil resources (coal, oil and natural gas) in addition to other factors such as the deforestation of tropical forests. In 1997 the Kyoto protocol was signed by numerous countries with the aim of reducing their emissions of greenhouse gases within a short time; as of today, this protocol has been accepted by most countries, Italy included.

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[1] www.eia.doe.gov

[2] *Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: The Physical Science Basis. Summary for Policymakers. http://www.ipcc.ch/SPM2feb07.pdf*

The consequences on our life style may be significant. As already mentioned, there are many strategies for solving these issues. An innovative approach might come from industrial biotechnology (IB).

IB, also known as white biotechnology, like health care (red biotech) and agricultural (green biotech) applications, is the application of biotechnology for the processing and production of chemicals, materials, and energy. White biotech uses enzymes, microorganisms and cultured cells from plants and animals to make products in sectors such as chemistry, food and feed, paper and pulp, textiles and energy. While its application in the production of fine chemicals and pharmaceuticals is already well established (e.g. insulin, interferon, erythropoietin, hepatitis B vaccine, vitamin B12, etc.), now IB is being increasingly applied to produce bulk chemicals such as biofuels (e.g. ethanol) and bio-plastics. Other fields of application include food additives and supplements, colorants, vitamins, nutraceuticals, cosmetics, pesticides, solvents, enzymes, bio-energy, etc. White biotechnology also provides new products and services by producing enzymes and cells at sustainable costs and in protected environment proteins.

IB has the potential to develop clean processes with (i) reduced water consumption, (ii) reduced energy consumption, (iii) less or no waste generation, or recycling thereof and (iv) reduced or neutral CO_2. Thus, industrial biotechnology is a key underpinning technology that may contribute to the transition of our current society, towards a more sustainable one, where renewable resources provide a growing contribution to our energy, chemical and material needs.

To explain the process by which biomasses are transformed into energy and products, the concept of "biorefinery" has been introduced. A biorefinery is a fully integrated manufacturing facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass, with minimal waste and emissions. A biorefinery is analogous to today's oil refineries, which produce multiple fuels and products from oil.

These factories of the future will integrate agriculture and a part of the transformed chemical industry. By providing new markets for crops and crop by-products and residues, the chemical industry may support agriculture and the rural economy which can, in turn, become less dependent on subsidies. Recent reports[3,4] predict annual growth rates of nearly 5% for fermentation products (compared to 2-3% for overall chemical production) in the coming years. McKinsey & Company[5] predict that by 2010 bio-based products will account for 10 percent of sales within the chemical industry, accounting for $125 billion in value. Starting with the chemical industry, white biotechnology will make inroads into a number of other industries. For example, enzymes will transform production processes in the pulp and paper industry, and new polymers will find multiple applications in the automotive and consumer industries. The greatest impact of white biotechnology may be on the EU fine chemicals segment, where up to 60% of products may be produced through biotechnology by 2010. A key driver here is the growth of biological pharmaceuticals such as antibodies for cancer treatment – drugs for which no traditional chemical synthesis exists. The impact on the specialty chemicals segment could vary broadly.

For instance, fermentation and enzymatic processes are commonly used in the fine chemicals sector to produce, for example, vitamins, pharmaceutical intermediates and flavours. They are also making their first inroads into larger volume segments such as polymers, bulk chemicals and bio-fuels, and many more industrial sectors. As of 2005, products made from biobased feedstocks or through fermentation or enzymatic conversion account for 7% of sales and $77 billion in value within the chemical sector, and different studies agree that these products will play an increasingly significant role in the chemical and other manufacturing industries in the future. Therefore, white biotechnology will be the key to the competitiveness of many European industries, including chemicals, textiles and leather, animal feed, pulp and paper, energy, metals and minerals, as well as waste processing. Two factors would contribute to this. One is the low costs for raw materials and processing, combined with small-scale investments in the fermentation of plants. The other is additional revenues from innovative, new, or performance-enhanced products (from *Industrial Biotechnology SRA of ETP SusChem, http://www.suschem.org*).

Currently, two types of feedstock can be used in the industrial biotech value chain for the production of fuels, bulk chemicals, materials and specialties. Fossil feedstock is used for the bioproduction of certain compounds by enzymes and/or microorganisms. These types of conversions are typically confined to biospecialties, such as fine chemicals, and are thus conducted on a relatively small scale compared to most industrial biotech processes based on renewable resources. At present, the use of renewable feedstock, such as agricultural by-products, is gaining importance. To that end, agricultural materials containing (ligno)cellulose or starch are first converted into sugars, which are subsequently transformed into a wide range of products via fermentation. In addition, agricultural or even household organic wastes could be valorized in this way.

However, in order to address these challenges, new or improved biocatalysts have to be developed, and new or improved and tailored biotechnological processes have to be designed, developed and assessed. Recombinant DNA technology allows

3 *World Market for Fermentation Ingredients, Study GA-103R by Business Communications Company Inc.,Norwalk, - March 2005.*

4 *Fermentation Chemicals, Industry Study 1921 by The Freedonia Group Inc., Cleveland, May 2005.*

5 *Presentation Jens Riese – World Congress on Industrial Biotechnology – Toronto – July 13, 2006*

microorganisms to be tailored to give higher yields of particular chemicals, or even to produce new ones. The increased efficiency of the reaction allows more and more scope for replacing established conventional processes by cleaner, low-temperature fermentation, in a safe contained environment. The highly specific nature of individual enzymes means that chemicals can be produced in the purest form, and biological processes not only require fewer chemical inputs, but also result in smaller and more manageable waste streams. In general, most of the industrial biotech processes developed so far use the most effective and convenient biocatalytic form, which is often a whole microorganism. However, this does not exclude the use of higher organisms, in particular plant, animal and human cell cultures, or the use of isolated enzymes combined with chemical catalysts.

In all cases the main driver is the cost- and eco-efficient production of the desired compounds by developing: a) the best biological catalyst for a specific function or process; b) the best possible environment for the catalyst to perform; and c) the most suitable strategy for the recovery, purification and further chemical conversion of the desired products from the fermentation process.

The first aspect deals with the search for the best possible biocatalyst, with improved or new functionalities. Another important aspect of white biotechnology deals with the containment system or bioreactor within which the catalysts must function. Here, the combined knowledge of the scientist and the bioprocess engineer interact, providing the design and instrumentation for the maintenance and control of the physiochemical environment such as temperature, aeration, pH, etc. Chemical engineering plays a crucial role in the research and development of innovative technologies for the design, creation, and conducting of enzyme or whole-cell bioreactors. A detailed fundamental analysis of the thermodynamic and kinetic aspects and the transport phenomena involved in bioreactors is the necessary basis for the scaling-up of laboratory plant processes to pilot or industrial level. The formulation of transport models accounting for the simultaneous transfer of momentum, heat and mass, and the subsequent identification of both the limiting steps and significant process variables, make it possible to properly design the bioreactor in its most suitable configuration (batch vs. continuous, stirred vs. plug flow, free vs. immobilized or confined biocatalyst, etc.), as well as to define the process control strategies and the integration of the bioreactor with other units in a complete process plant. The third aspect, the downstream processing, can be a technically difficult and expensive procedure. Downstream processing is primarily concerned with the initial separation of the bioreactor medium into a liquid phase and a solid phase, and subsequent separation, concentration and purification of the product. In addition, it includes the further chemical conversion of the fermentation product to yield the final desired compound. Improvements in downstream processing will benefit the overall efficiency and process cost and will make the biotechnology-based processes competitive with the conventional chemical ones. Chemical engineering principles also play a vital role here as well in terms of designing and operation of the separation systems.

Based on these observations, the following 7 R&D strategic areas have been identified for an effective future implementation of white biotech in Europe:

- Selection of novel enzymes and micro-organisms
- Improvement of biocatalysts (enzymes and micro-organisms) through microbial genomics, proteomics, metabolomics and bio-informatics
- Metabolic engineering and modelling
- Biocatalyst characterization and optimization
- Innovative biocatalytic process design
- Innovative fermentation science and engineering
- Innovative downstream processing

They should be integrated and applied properly to generate three different product categories: input of the process (biomass defining and usage, recovery of waste, conversion into fermentable sugars, etc.), (new) bioprocesses and bioproducts, and biofuels.

The specific key scientific and technological challenges related to the first type of product category, i.e. biomass to be applied in the processes, are:

- Identification of competitive biomass feedstocks which are best suited for EU needs (availability and competitive price)
- Conducting of LCAs and eco-efficiency studies to identify optimal biomass feedstocks for the EU
- Development and optimization of viable processes for the conversion of biomass materials into fermentable sugars (e.g. enzymatic, physical, chemical, or combinations thereof)
- Creation of added value for the co- and by-products of bioprocesses, to improve the economics
- Development of bioprocesses based on other alternative feedstocks such as lignin or glycerol, for the chemical and energy industry
- Development of a closed-loop fermentation cycle (where the “biowaste” of one process can be recycled as input for another process), e.g. sugar beet pulp as an untapped biomass feedstock for future use.

In the *Bioprocesses and Bioproducts* area, the main challenges to be dealt with are:

- The development of more efficient processes and new properties for bioproducts, in order to make them more competitive versus the existing ones, which are sometimes cheaper than bioproducts.
- The development of new bioproducts with higher performance in existing applications
- The development of innovative bioproducts with new applications and properties.

In the Bioenergy area, the key technological challenges are:

- The development of optimal enzymes and robust fermentation systems (e.g. thermophilic microorganisms and enzymes) capable of converting lignocellulose directly and fermenting it into ethanol or other biofuels.
- Making these technologies cost effective
- The development of new fermentation processes based on biodiesel-deriving glycerol and CO_2 as carbon sources.

Lastly, another key challenge will be to effictively boost the political and economical environment stimulating research and innovation, entrepreneurship, product approval and market development in the EU sector of white biotechnology.

4.2.2 - Environmental Biotechnology for the Contaminated Site Characterization and Remediation, and Groundwater/Wastewater Clean-up

Biotechnologies may also offer special tools and strategies for a sustainable and effective management and reclamation of degraded or/and contaminated sites and wastewaters which make up one of the main environmental issues that the enlarged Europe must deal with over the coming years. Indeed, in many areas of Europe, soil is being irreversibly lost and degraded as a result of increasing and often conflicting demands from nearly all economic sectors. In Western Europe, pressures come from the concentration of population and activities in localized areas, economic activities and changes in climate and land use. Air depositions and cultivation systems are among the most important influences on the quality of soils in agricultural and natural areas. Consumer behaviour and the industrial sector are contributing to ane increase in the number of potential sources of contamination such as municipal waste disposal, energy production and transport, mainly in urban areas. In Central and Eastern Europe, many of the problems stem from past activities and poor management practices.

The combined action of these activities affects quality and limits many soil functions, including the capacity to remove contaminants from the environment by filtration and adsorption, and consequently increase the possible transfer of contamination to groundwater. This capacity and the resilience of soil mean that damage is not perceived until it is well advanced. This partly explains the low priority given to soil protection in Europe until recently. Moreover, since soil is a limited and non-renewable resource, when it is damaged, unlike air and water, it is not easily recoverable.

The geographical distribution of soil degradation depends on several factors. Soil problems are influenced by the diversity, distribution and specific vulnerability of soils across Europe. They also depend on geology, topography and climate and on the distribution of driving forces. Better integration of soil protection into sectoral policies and better harmonization of information across Europe are needed to move to more sustainable uses of soil resources and a promotion of sustainable models of its use. In particular, soil contamination from diffuse inputs and local sources can result in the damage of several soil functions and frequently causes the contamination of connected water bodies (most often groundwater, but also surface water and related sediments).

The solution and prevention of soil and ground water degradation problems has recently become a policy issue in Europe. Soil contamination is considered a priority threat within the issue. The status of site contamination, the state of the art in assessment and remediation, and strategic harmonized solutions have been analyzed over the past 10 years by the EEA and several European networks (CARACAS, CLARINET, NICOLE, Common Forum for Contaminated Land in Europe).

The current activities for the development of the EU Soil Thematic Strategy are clearly oriented toward risk-based solutions of historical contamination problems. The work carried out by European cooperation programmes provides the grounds and the technical and scientific references for the formulation of the strategy. Several Member States have already formulated risk-based oriented policies for the management of contaminated land at their national level, and favoured the adoption of innovative technological approaches to remediation. In addition, many Member States have established criteria for distinguishing new and historical contamination.

According to a recent survey, there are over 1,500,000 sites, often former industrial sites, contaminated by organic pollutants and/or heavy metals in the European Union (EU). EU candidate states also possess a large number of contaminated lands, often located in areas within or near highly populated cities. Such sites constitute an enormous environmental problem, which the recently enlarged EU must take care of over the next few years. To address it, innovative and effective site-monitoring tools and strategies along with remediation technologies capable of combining high decontamination efficiency with low costs and impacts on the site infrastructure and living organisms are necessary. In terms of monitoring, biosensors, along with ecotoxicity tests and molecular microbiology measurement techniques, have become essential tools to reinforce the modern analytical chemistry tools, as they can offer specific information on the actual toxicity and microbial life occurring at the site. In terms of decontamination technologies, the biological ones, i.e. those that typically exploit the activity of pollutant-degrading site-occurring organisms, are greatly preferred over the chemical and physical technologies currently available on the market, as they fully fit the requirements listed above.

The *in situ* application of biological degradation processes of soil and groundwater pollutants on a field scale is approximately 10-15 years old. Numerous laboratory and mesocosm studies have been published to form a sound basis for the application of these techniques. During the last decade, many biological degradation processes of various pollutants in different soil types and groundwater have been developed into *in situ* bioremediation techniques. Among these techniques, we also classify spontaneous biodegradation processes in soil and groundwater (natural attenuation), provided that it is adequately monitored for acceptable prolongation of this process with time. At present, *in situ* biological soil clean-up has evolved into a full-fledged and cost-efficient alternative to other bioremediation techniques.

It is also a priority of the European Union to develop promising wastewater bioremediation technology to encourage SMEs from different industrial sectors to accept the challenge of treating their wastewater (ecological image and money saving) and to benefit from this new technology. This objective supports the "Environmental Technologies for Sustainable Development" (COM 122-2002), a communication from the European Commission approved by the Barcelona European Council in March 2002 stating that "environmental technologies contribute to sustainable development by boosting our economies, protecting our environment and providing new jobs", as well as the "EU Water Framework Directive".

However, today remediation technology development is evolving differently and at different rates in unconnected, isolated pockets of Europe, without a joint sharing of experiences, successes, and lessons learned through technology demonstration. Despite the successful development and demonstration of novel technologies with these features, conventional methods still generally prevail in the market (EURODEMO Newsletter 1. 2006. Available from: http://www.eurodemo.info).

Making national remediation efforts and especially innovative remediation efforts visible and accessible on a European level would support international experience exchange and transnational knowledge transfer. Thus, planned remediation activities and especially innovative applications – often connected with high learning costs – could be optimized with regard to improved technology performance and more sustainability with optimal cost-efficiency. By better connecting European remediation efforts and thus minimizing the duplication of efforts, an overall increased effectiveness of remediation activities and a faster advancement of innovative technologies could be achieved to the benefit of all involved parties. Finally, the competitiveness of European technologies could be strengthened in a global market and a European State-of-the-Art in remediation could be approached.

4.3 - State-of-the-Art on the White Biotech R&D and Industry in Italy and Some Notes on the Environmental Biotech for the Contaminated Sites Reclamation.

A few very small Italian companies are involved in the biotech production of primary metabolites, microbial starters and enzymes and in particular of the main white biotech products, such as fine chemicals, microbial polymers and biofuels. However, a large number of qualified applied research projects focused on the use of enzymes and microorganisms for making new and conventional products such as fine and bulk chemicals, pharmaceuticals, food and feed, energy, and polymers, are in progress in Italy at universities, research centres (belonging to CNR, ENEA, etc.) and/or national science and technology parks.

In particular, according to a recent survey performed by the scientific committee of the Industrial Biotechnology section of IT-SusChem, around 130 large and interdisciplinary projects have been just concluded or are in progress in the country; these are mostly national but also international, and focus on improving the production of conventional or innovative primary and secondary metabolites, enzymes and proteins, new or improved fine chemicals, bioplastics, lubricants, and biosurfactants, and on intensifying the production of biofuels (mostly biogas and, to a lesser extent, bioethanol, biodiesel and biohydrogen (bioH2)) from a variety of biomass sources and agroindustrial wastes and wastewaters. Over 40 different universities, several CNR Institutes and ENEA centres, along with private/public research centres (Stazione Sperimentale Olii e Grassi, Stazione Sperimentrale per la Seta, CRPA, etc.), some spin-offs, and small private companies are involved in such projects. Most of the projects have been supported through public funds provided (on a competitive basis) by the Ministry for the University and Research, the Ministry for Productive Activities, and the Ministry for the Environment (through programmes such as PRIN, PNR, FIRB, FAR, FISR, PON, etc) and, to a minor extent, by some local institutions (i.e. Campania, Emilia-Romagna, Friuli Venezia Giulia, Liguria, Lombardy, Marches, Piedmont, and Sardinia regions, Province of Ravenna, etc.), small biotech or chemical companies (mostly located in the northern part of Italy), or the European Union (through the 6 FP).

The reviewed projects can be grouped into the six clusters reported below.

1. Isolation and characterization (also through bioinformatics, proteomic and synthetic biology approaches) of new enzymes and microorganisms and improvement (through in vivo and in vitro manipulations) of the existing ones specifically for white biotech applications. Among the new or improved enzymes are: laccases, penicillin acylases, nitrilases, mono- and di-oxygenases, cheratinolytic enzymes and enzymes from marine organisms, thermophilic or cold-adapted bacteria, and a variety fungi. Among the new isolates or improved microorganisms there are a large number of probiotic bacteria, thermophilic bacteria, and fungi, all capable of displaying new or improved properties of industrial and/or environmental interest. There are over 30 projects, mostly carried out through national cooperation among universities, research centres (belonging to ENEA, CNR, etc.), and technological parks, thanks to the economic support of the Ministry of the Uni-

versity and Research (PRIN, FIRB, CNR grants), the universities, or together with some private companies (mostly of the Chemical area) and foundations. A couple of projects were funded by the Friuli Venezia Giulia, Emilia Romagna and Piedmont regions; six of the projects were funded through the 6FP.

2. Development of innovative/improved bioreactors, production and downstream procedures and procedures for bioprocess design and modelling. Development of innovative/improved integrated strategies for recycling and valorizing (via recovery and biotech transformation of main constituents) agro-industrial wastes, wastewaters and surplus (biorefinery concept), as well as for closing the carbon cycle in farms (i.e. biomass for producing biogas and hydrogen and successive carbon storing in soils: "carbon sequestering farm"). Around 30 projects are carried out through the cooperation among universities, research centres and companies, and funded through grants provided by the Ministry of University and Research (i.e. PRIN, FIRB, CNR grants), the Ministry of Agriculture, some Regions (Campania, Lombardy), single universities or together with private companies. Five of the reviewed projects have been funded through the EU 6 FP.

3. Development of innovative/improved strategies and/or processes for the direct enzymatic/fermentative production of chiral drugs and synthons, aminoacids, vitamins (ascorbic acid),organic acids (lactic acid), flavours (bio-vanillin, xilitol), pharmaceuticals (glutathione, polyunsaturated fatty acids), etherologous proteins, fructooligosaccharides (FOS), microbial enzymes, and microbial biomass (probiotics) from conventional media and agroindustrial by-products or wastewaters. Around 15 projects are mostly carried out through national cooperation among universities and research centres (belonging to CNR, ENEA, etc.), thanks to funds provided by the Ministry of University and Research, (via PRIN, FIRB, CNR grants), single universities or together with private companies (mostly of the Food and Feed area).

4. Development of innovative strategies for the recovery of fine chemicals, such as antioxidants, phenols, carbohydrates, FOS, etc., from agroindustrial by-products or wastewaters, and tailored application of new/improved existing biocatalysts for the bioconversion of remaining products/molecules into new fine chemicals, chiral molecules, antibiotics and pharmaceuticals, aminoalcohols, fatty acids, phospholipids and lipopolysaccharides, etc. (biorefinery concept). These are over 20 projects, mostly carried out through cooperation among universities and research centres (belonging to CNR, ENEA, etc.) and grants provided by the Ministry of University and Research (PRIN, FIRB, CNR grants), interuniversity consortia, universities or together with private companies (mostly of the Chemical area). A couple of projects were funded by the Emilia Romagna and Sardinia regions and two others through EU funds (COST and IP programs related to the FP6).

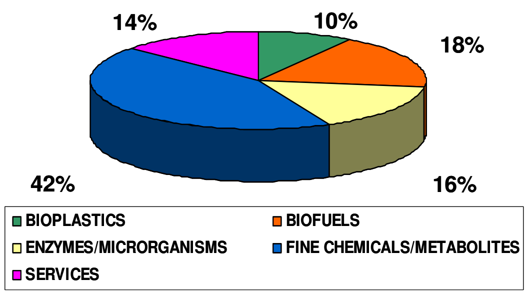
5. Development of innovative/improved strategies and/or processes for the production of microbial polymers (polyhydroxyalkanoates, protein matrices, polylactate, exopolysaccharides, etc) and biodegradable polymers (natural fibers, nanofibrils of chitin, fuel latent bioplastics, biodegradable polyesther blends, etc), as well as lubricants (hydraulic oils) and biosurfactants from biomass and agroindustrial wastewaters and wastes. These are around 20 projects, mostly carried out through by uuniversities and research centres (belonging to CNR, ENEA, etc.), thanks to the economicl support provided by the Ministry of University and Research (PRIN, FIRB, PON, CNR grants), universities or together with private companies (mostly of the Chemical area). A couple of the projects were funded by local institutions (Piedmont and Lombardy regions, Ravenna province). Nine of the reviewed projects are international and mostly funded through EU 6FP money.

6. Development of innovative/improved strategies and/or processes for the production of biofuels (biodiesel, bioethanol, biogas and bioH2) and bioenergy (via biofuel cells) from a variety of agroindustrial and municipal wastes, agroindustrial wastewaters and sludges (also through dry fermentation, in the case of biogas and bioH2). About 15 projects, mostly carried out through the cooperation among universities and research centres (institutes of CNR, ENEA, and CRPA), and within dedicated spin-offs, thanks to the economic support provided by the Ministry of University and Research (via PRIN, FIRB, CNR grants), single universities or together with private companies (mostly of the Food and Feed area), local institutions (Sardinia, Emila Romagna, and Veneto regions). Six of the reviewed projects are international and funded through EU 6FP money.

Taken together, the information provided indicates the existence of solid R&D expertise in all the 7 strategic research priority areas identified in the Industrial Biotechnology section of the ETP SusChem SRA and retained by ETP SusChem IAP, "http://www.suschem.org"). The main Italian IB R&D elements of excellence are in the areas of a) development of improved enzymatic and microbiological tools and technologies (freely suspended and immobilized biocatalytic systems, reactors with tailored configurations) for the production of new fine chemicals of interest for the pharmaceutical, chemical and food industry, as well as of vitamins, proteins and organic acids from simple and complex substrate mixtures, and some agroindustrial by-products, wastes and wastewaters, b) recovery and characterization of biomolecules (antioxidants, vitamins, etc) from agroindustry and food-industry by-products, wastes and wastewaters, and c) biotransformation of main components of agroindustry and food-industry by-products, wastes and wastewaters into flavours, biopolymers, biosurfactants, enzymes and/or biofuels, such as biogas, biomethane and biodiesel. A possible Italian weakness evidenced by the national R&D scenario described above is a widespread lack of knowledge and expertise in the area of biotransformation of lignocellulosic biomass and agroindustrial by-products, and in the production of "second generation bioethanol". Some R&D activities on the enzymatic hydrolysis of cellulose, including pretreatment technology, have been and are presently being carried out only at ENEA (Trisaia centre) and by a couple of University research groups.

The Italian R&D scenario described above also indicates that Italian researchers are already accustomed to cooperating and sharing their scientific specialisms within large multi-disciplinary collaborative projects; this feature is essential for successfully performing high-standard industrial biotech R&D.

A considerable number of qualified publications (over 700 in the last 3 years, on the basis of the data provided) resulted from the reviewed projects. On the other hand, only a few patents (fewer than 15 during the last 3 years) were produced through the same projects. This evidence, along with the fact that the majority of the reviewed projects resulted or are going to result in laboratory-scale bioreactors or/and processes, indicates a certain lack of aptitude and/or knowledge in the technology transfer phase of new or improved processes and technologies.



According to a recent survey conducted by the Fondazione Rosselli (Turin)[6], Italian projects performed in the fields of production of heterologous proteins/enzymes, primary metabolites, biopolymers and bio-energy have already generated a qualified know-how justifying its transfer to the large scale. Some Italian small, often "single-product", R&D biotech companies, along with some spin-offs, have currently been producing and selling specific IB products. In addition, some Italian chemical or biotech-related SpA companies are gradually orienting some of their R&D activities into the industrial/white biotech area. According to a national survey promoted by *IT SusChem*, around 45 companies (joint-stock or limited-lliability companies) along with 5 spin-offs can be ascribed to the white biotech sector. As shown by the chart below, some of them, including two joint-stock companies (i.e. FAB-Fidia and Novamont), are active in the production of new or advanced biopolymers, others, including joint-stock companies like ENI and Marcopolo Technologies, are active in the area of bioenergy/biofuel production or in the production of microbial starters, probiotics, and enzymes (including CSL Centro Sperimentale del Latte, Biosphere as joint-stock companies), but the majority of the reviewed companies (including several joint-stock companies such as ACS DOBFAR, AGROLABO, DIASORIN, DIASPA, FLAMMA, FATRO, GNOSIS, LONZA, LAMBERTI, NORPHARMA, PRO.BIO.SINT and SEDAMYL) are active in the sector of the production of primary and secondary metabolites, fine chemicals, flavours, prebiotics proteins, hormones and pharmaceuticals. There are also several SMEs providing services to companies and research centres operating in the sector. The majority of the information provided comes from the national survey performed by the scientific committee of the *IT-SusChem* platform, while some of it was collected through a website search.

With regard to the application of biotechnologies for environment protection and remediation, a similar inventory is presently being conducted. Thus only a qualitative picture can be given here, just to highlight the high potential they have in Italy.

Indeed, it is noteworthy that biological processes are well-established in several traditional sectors of environment protection such as end-of-pipe treatment and disposal of wastewater, sludge and wastes (e.g. activated sludge process, biofilm processes, sludge stabilization, anaerobic digestion, composting, etc.). In these sectors, biological processes are much more developed than in traditional sectors of the chemical and process industry, and they also have a leading role with respect to chemical and physical processes. Presently, it can be estimated that in Italy several thousand plants include at least a biological reactor as a key step of the overall process. Most of them are of small-to-medium size, and SMEs are usually in charge of their design, operation and control. On the other hand, in spite of such a large background in traditional bioprocesses, a rather limited use is still made of the modern tools offered by chemical engineering and industrial biotechnology, for both design and control.

Now, as often required by increasingly stringent regulations, there is a growing trend toward combining typical bioprocesses with more advanced approaches in terms of both increasing efficiency of traditional bioprocesses and broadening their application to cope with emerging problems. Among the latter, the bioremediation of contaminated soils and groundwater is particularly important, with particular reference to sustainable remediation of xenobiotic-type organic micropollutants.

In a recent survey by Federambiente (http://www.federambiente.it/) among companies providing environmental services (http://www.federambiente.it/moduli/Rapporto%20Bonifiche%202007/Rapporto%20Bonifiche%202007.htm), about 25% of these companies are active in site remediation, most often in combination with more traditional services. Interestingly, most

[6] Report on "National Priorities of Reserach 2002; "http://www.pdf4free.com"

companies are SMEs (less than €30 million/year) but a higher average size is found for companies involved in the remediation of more complex industrial sites. Even though they must be confirmed by a specific analysis, these few figures indicate the potential for the development and application of advanced biotechnologies in the field of site remediation. Moreover, academic and industrial research is quite active at the lab and pilot scale. Several field tests for advanced bioremediation are presently operating in Italy (e.g. in Rho, Naples, Ferrara) and a few projects are under evaluation for full-scale application (e.g. Marghera site).

4.4 - Main R&D Priorities for the Italian White and Environmental Biotech Sectors.

Given the type and the localization of white biotech R&D expertise already available in Italy, the current situation of the industry in the sector and, importantly, the socioeconomic priorities of the country, future national R&D efforts in the white biotech area should be focused on implementing and boosting the development of:

a) new and/or improved biocatalysts and biocatalyzed processes to foster a shift in chemical manufacturing, to enable cleaner, safer and more cost-efficient processes or novel chemo-enzymatic processes with the integrated use of biocatalysts;

b) innovative and/or improved strategies and biotech tools for the integrated valorization of national biomass and agrofood industry by-products, wastes, wastewater and surpluses through the direct recovery of biomolecules and biobased compounds and the biotransformation of the resulting products into biofuels, fine chemicals, biopolymers, biosorbents, biosurfactants and biofuels (biorefinery concept);

c) improved bioprocesses for the production of biofuels (both “second generation Ethanol” and biogas/bioH_2) from Italian biomasses and agro-industrial surplus, by-products and wastes;

d) innovative and/or improved strategies and biotech tools and processes for the integrated monitoring and remediation of Italian contaminated lands and sites.

4.4.1 Priority a).

New and/or improved biocatalysts and biocatalyzed processes to foster a shift in chemical manufacturing to enable cleaner, safer and more cost-efficient processes or novel chemo-enzymatic processes with the integrated use of biocatalysts

Enzymes are increasingly used as efficient biocatalysts to perform a range of chemical reactions. As an example, global sales of single-enantiomer compounds are expected to reach $14.94 billion by the end of 2009, and the share of the market occupied by traditional technology would drop to 41%7. The share of chemocatalysis would rise to 36% and the share of biocatalysis, to 22%, (1.9 billion $). Demand for enantiopure chiral compounds continues to rise, primarily for use in pharmaceuticals but also in three other sectors: agricultural chemicals made up 14.1% of the revenues, and flavours and fragrances accounted for 4.7%. However, natural biocatalysts are often not optimally suited for industrial applications and the major limitation for their commercial use is their price and availability. To develop this sector and the use of enzymes in industrial processes, it is important to expand the range of biocatalysts and improve them for specific uses. Specific types of enzymes such as racemases or oxido-reductases are of particular interest for industrial processes. In this respect, the development of new hosts for the production of endogenous and/or heterologous enzymes is also necessary.

Goals:

a) Optimized enzymatic activity.

Since the major industrial players in the field generally do not sell their own enzymes, it is a major priority to have access to extensive strain and enzyme collections for screening and development. Easy access to protein expression and production, even at a scale that enables preliminary tests on pilot plants, is also a prerequisite.

b) Rapid and efficient screening methods

From an analysis of the European situation[8], it emerges that one of the biggest problems is the still highly empirical nature of catalyst selection.

c) Easy-to-use formulated enzymes

Strategies such as substrate modulation and reaction engineering can often help overcome bottlenecks faster than directed evolution can. The understanding of reactions and catalytic mechanisms is far from complete. Understanding the nature of the catalyst and the optimal process conditions is crucial for successfully identifying and scaling up a biocatalytic process, just as it is for any catalyst. Stronger integration between chemistry and process engineering expertise is crucial on this respect.

d) Improved reaction design and engineering

- Solving reaction and process problems of industrial relevance and accelerating the move to sustainable chemistry by searching for novel biocatalytic functions;
- Overcoming thermodynamic barriers, avoiding high environmental impacts due to the chemical catalysis (both in terms of catalysts applied and reaction conditions required), or reviving natural product biosynthesis;

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[7] Frost & Sullivan survey; “http://www.frost.com/prod/servlet/svcg.pag/CMCM”

[8] Chemical Engineering News, August 14, 2006 Volume 84, Number 33

- Multiphase bioreactors - research projects and network on methodology for high substrate/product concentrations. Methodology for in situ product removal;
- Engineering for complex biocatalytic reactions involving multiple phases – research projects, network;
- Development of cascades of (chemo-)enzymatic methods - R&D projects to make chemo- and biocatalysts compatible with each other.

Actions:

- Multidisciplinary research needed involving molecular biology + enzyme technology + organic chemistry + biochemical engineering;
- Improved and novel protein production systems for efficient and large-quantity enzyme production (including study of protein secretory pathways);
- Fundamental research on understanding of catalytic enzyme/ substrate interactions;
- Integrating evolutionary and computational approaches to rationally design biocatalysts with improved efficiency and (enantio)selectivity, thus shortening the timescale of enzyme discovery;
- Screening and development of new enzymes for specific applications (lyases, racemases, oxidases, oxygenases, peroxidases, and oxido-reductases);
- Development of fast and efficient methodology for screening and activity assay;
- Creation of new functions in existing enzyme scaffolds;
- Search for new biocatalysts and new enzymes from extremophiles and other organisms with the integrated use of bio-informatic approaches;
- Computational tools used in combination with metagenomic and directed evolution to shorten the timescale of enzyme discovery;
- Development of high-performance integrated multiphase bioconversions: enzymatic processes tested under industrial conditions. Research projects and network on methodologies for high substrate/product concentrations;
- Methodology for in situ product removal;
- Biocatalytic reaction engineering - Engineering for complex biocatalytic reactions involving multiple phases – research projects, network;
- Development of cascades of (chemo) enzymatic methods - R&D projects to make chemo- and biocatalysts compatible with each other;
- Formulation and solution of accurate transport models based on the analysis of momentum, heat and mass transfer and capable of predicting the behaviour of enzyme or whole-cell bioreactors.

4.4.2 Priority b).

Innovative and/or improved strategies and biotech tools for a more extensive and efficient valorization of national biomasses and agro-food industry surpluses, by-products, wastes, and wastewater

4.4.2.1 New/improved biotech tools and strategies for the valorization of biomass and agroindustry by-products and wastes.

4.4.2.1.1 Improved national biomass use and alternatives to carbohydrates

The diversification of biomass used in industrial processes from the currently available carbohydrates to lignocellulosic biomass, use of agricultural or food industry wastes/by-products, surpluses and wastewater, can provide cheaper biomass, as well as helping to secure the feedstock supply and, in some cases, to reduce the environmental impact associated with their accumulation in the environment. In addition, the use of some national agro-industrial surpluses, such as those associated with sugar beets or cereal cultivation, should be considered. It is also crucial to focus on current Italian biomass, and to develop appropriate biomass sources for industrial processes in conjunction with plant scientists.

Biomass conversion must be adapted to more complex feedstock via improved enzyme cocktails and adapted, robust fermentation microbes which can deal with complex sugar streams. Lipids and glycolipids, with the exploration of specific enzymes for their modification and activation, are a potential source of new bioprocesses and bioproducts, especially for the integration of bioprocesses with traditional oleochemistry.

Activities include:

- Availability and development of biomass for non-food use;
- Conversion of biomass (pretreatment and hydrolysis; robust fermentation systems);
- Alternative feedstock to classic carbohydrates (by-products of pulp factories, biofuel production, food industry (cheese whey, olive mill wastewater, lipids…).

4.4.2.1.2 Development of the next generation of high-efficiency fermentation processes

The main objectives to be achieved are:

- Increase in product yield;
- Facilitation of the scaling-up of processes;
- Development and intensification of novel bioprocesses for bioproducts;
- Reduction of waste production from bioprocesses.

Fermentation processes are commonly used today for the production of numerous products; however, the meeting of growing demands in very competitive markets is still in need of microbiological and technological improvements.

To improve the efficiency of fermentation processes, it is important to better understand the metabolism of microorganisms under extreme environmental conditions and, based on this information, to select better microbes for either axenic or mixed microbial culture processes.

Current technological challenges include low volumetric productivity due to harsh fermentation conditions for microorganisms (pH, temperature, substrate concentration…), the difficulties of scaling-up processes from lab to large-scale fermenters, and the investment needed to develop and implement new or improved bioprocesses which account for a significant part of the whole production costs.

New challenges are also emerging, among them the design and construction of micro-bioreactors and high-throughput screening needed by industry for new and improved processes. Future efforts will also concentrate on the development of new or intensified technologies that can provide a reliable and renewable energy supply (bioethanol, but also bioH_2 and CH_4). These new expectations for fermentation processes require the use of highly advanced technologies and the strong cooperation of experts from various scientific areas.

To improve the product yield, the following issues have been identified:

Microbial genomics and bio-informatics

Availability and usability of genomics information:

a. Functional microbial proteomics, metabolomics and genomics. Analysis of gene knocks out and over-expressions of industrial relevant organisms on a larger scale by chip proteomics and flux analysis to identify unknown functions and regulations;
b. Development of high-performance cell/animal platforms amenable to cost-effective high-throughput technologies for experimental approaches up to the genomic level, since their genomes are entirely sequenced [e.g. *Escherichia coli* (prokaryote), *Saccharomyces cerevisiae* (simple eukaryote), *Caenorhabditis elegans* (small multicellular animal)]. This set-up can deliver fast answers for a wide range of discovery problems. The assortment ranges from screenings of new therapeutics to the assessment of environmental risks, and can ask questions ranging from the bioavailability of the molecule(s) being studied to the definition of their primary target site and/or their putative systemic effects;
c. Bioinformatics, support for acquiring novel genes with a given function and system biotechnology by tools/strategies for high-quality functional annotation of genes and gene products, and management of databases by integrating in silico and experimental data and applying machine learning / data mining techniques. Consequent improvement, standardization and implementation of ontology-based annotations.

Metabolic engineering and modelling for robust fermentation microorganisms

a) Increasing the understanding of cellular regulation under industrial fermenting conditions (stress, “zero growth”, quorum sensing, fluctuation in nutrient or substrate concentration) to include these parameters in mathematical models: regulatory systems in cells via protein-protein interaction, protein-DNA interactions; product export from cells and metabolic compartmentalization in eukaryotic cell factories, kinetics of membrane transport, product inhibition in relation to product recovery;
b) Studying the physiology of microorganisms under extreme conditions such as: pH and temperature, slow growth rate, dynamic stress and unbalanced growth, high concentration of substrates and products, regulation of gene expression by quorum sensing; screening the most suitable (or improved) variants for a desired process or completely new variants for particular purposes;
c) Studying the population dynamics in mixed microbial cultures for improvement of efficiency and strength of low-cost mixed culture fermentation processes;
d) Developing methodological tools for the mathematical modelling of microbial metabolism in both steady and dynamic models: flux analysis and measurement of intracellular metabolites (industrial conditions).

Process scale-up and intensification:

a) Development of a new generation of reactors: alternative novel reactor concepts that allow for more intensified production, and create optimal environmental conditions for the production of certain metabolites by microorganisms in fermentation processes;
b) More extensive application (for both bioconversion and fermentation processes) of tailored intensified bioreactor systems, such as those relying on specialized bacterial biomass, either passively immobilized on porous carriers or self-granulated, in packed bed or expanded bed or fluidized bed loop reactors, capable of providing higher volumetric productivities, higher stability (genetic and also vs adverse chemical and physical parameters), higher tolerance towards high and variable organic loads, and often an easier product recovery than conventional freely suspended cell bioreactors;
c) Development of engineering tools to design strategies for process intensification, advanced control strategies (non-invasive, highly sensitive, inexpensive), mainly with reference to new biotechnology-based analytical methods, sensors and screening techniques;
d) Development of micro-bioreactors based on realistic large-scale production conditions as a screening tool to shorten the process development time, accompanied by research on scale-dependent differences in microbial

behaviour; development of advanced monitoring and controlling strategies of various parameters with the use of advanced simulation techniques (artificial neural networks, hybrid models, etc.) and sophisticated instruments, tools and high-tech equipment;

e) Development of simulation tools for modelling and optimization of fermentation processes on different scales;
f) Improvement of continuous fermentation processes: solving problems of strain instability during long cultivation times by genetic methods (deleting phages in the genomes, creating selective pressure), solving contamination problems by minimal media, selective pressure, harsh conditions like high temperature, solving microbial population shift in mixed microbial systems, increasing process strength in the presence of highly dynamic feeds (organic load and compositions).

Downstream processing:

Development of downstream methods to isolate fermentation products during the fermentation processes and chemical methods to convert fermentation products to interesting chemicals without prior purification of the fermentation product from the broth.

For more advanced combined processes, the following issues have been identified:

a) Development of combined technologies enabling the parallel production of different products;
b) Development of bioprocesses & technologies that make it possible to generate energy from wastes (waste utilization); development of bioprocesses that combine the production of desired products with energy generation (example: integrated valorization of by-products/wastes through the bio-catalytic conversion of some of their specific macromolecules into fine chemicals followed by alcoholic fermentation or anaerobic digestion - resulting in bioH2, fatty acids, CH_4 generation - of remaining organic material - zero waste processes;
c) Development of bioprocesses based on or with recirculation of waste by-products.

4.4.2.2 Process eco-efficiency and integration: the biorefinery concept

Widespread implementation and use of integrated and diversified biorefineries, in order to use our agricultural/forestry resources in the most efficient (cost and energy) way.

Biorefinery is a concept that has been developed in the food and paper industries and is now applied in biomass-based energy production. It relies on the best use and valorization of feedstock, optimization and integration of processes for a better efficiency, optimization of inputs (water, energy…) and waste recycling/treatments. The production of bioproducts, especially for bulk chemicals, biofuels, sorbent matrices, and polymers, can improve their competitiveness and eco-efficiency by process integration and economy of scale. Many improvements are yet needed to improve the process first: total use of the plant, by-product or waste (better fragmentation and fractionation) and development of processes to add value to all fractions of lignocellulosic material and to valorize by-products, effluents and wastes of other industrial systems (e.g. black liquor in wood/paper industry, glycerol from biodiesel, whey from cheese production, olive mill wastewater …), agro- and food-industry surpluses or products damaged or contaminated and not suitable for food use (e.g. micotoxins in cereals), and downstream processing strategies (low-cost recovery and purification). It is also necessary to study the whole value chain as well as the “biorefinery value chain” for optimization of costs, CO_2 reduction, water and energy minimization.

4.4.2.2.1 Action 1.

To develop new and general strategies to meet the energy- and cost- efficient requirements to be competitive on the market

- Industrial research and development, user groups and forums to define and discuss criteria for sustainability, optimalization of CO_2 reduction potentials, analysis and optimalization of energetic/exergetic use of biomass production/biorefining chains, economic optimalization strategies throughout the whole value chain from the field production to the industrial and/or consumer use use;

- Academic research projects, industrial collaborative research, user groups and forums to develop and validate new business models, criteria for sustainability evaluation, CO_2 reduction potentials, analysis and optimalization of energetic/exergetic use of biomass production/biorefining chains, and economic optimalization for biorefinery value chains.

4.4.2.2.2 Action 2.

Improvement of biorefining technologies

Academic research projects, industrial collaborative research projects, industrial research on:

- efficient harvest and storage technology of various crops directed towards large-scale biorefining;
- whole crop biorefining methods for separating different components such as sugar, starch, lignocellulose, fats, proteins, aminoacids, organic acids from seed, leaf, woody and root parts of various crops;
- the utilization of abundantly produced plant fractions that remain after the use of plant materials for the production of biofuels;
- development of a sustainable closed-loop approach for water saving, through both efficient water use and wastewater reclamation and reuse, in either the fermentation processes or the crop production;

- development of process equipment to open plant/lignocellulose tissues and to fractionate plant components with little energy input;
- Academic research (with industrial support) for the selection of plants that accumulate specific bulk chemicals (precursors);
- development of new processes for bio-ethanol production and valorization of glycerol (resulting from biodiesel production) for incorporation in diesel fuel or base chemicals;
- development of new processes for transforming saccharose to base chemicals.

4.4.3 Priority c),

Improved bioprocesses for the production of biofuels from Italian biomasses and agro-industrial surpluses, by-products, wastes and wastewaters.

Biofuels are the focus of growing interest for transportation. They can provide a reliable and renewable supply of energy as well as reducing greenhouse gas emissions into the atmosphere. The European Union has recently set ambitious new targets[9]: by 2010, 5.75% of both petrol and diesel fuel will comprise biofuels, rising to 20% in 2020.

To be competitive, bioethanol production relies on cheap and reliable sources of renewable raw materials and efficient fermentation processes. At the present time, sugar prices in Italy are too high to allow a competitive production of bioethanol, and only a part of the crops are being used. Therefore new technologies need to be developed to efficiently convert cellulosic, fibre- or wood-based waste biomass into fermentable sugars. However, the availability of such sources of substrates is limited in Italy. Conversely, there is an enormous availability of agrofood industry by-products, wastes and wastewaters, as well as of domestic organic wastes from which ethanol but also biomethane and bioH2 can be generated, with the concomitant reduction of the environmental impacts associated with their accumulation in the environment.

Goal 1

To have “second generation” bioethanol based on Italian specific biomass, such as crop waste (straw, corn cobs), energy crops, wood-industry wastes, agro-food surpluses and wastes**,** available on a commercial scale within 10-15 years.

4.4.3.1.1 Action 1: Improved biomass conversion by hydrolysis based on diversified, cheaper sources of renewable raw materials

Biomass hydrolysis technology involves the breakdown of carbohydrates into its component sugars by a range of chemical and/or biological processes. Biomass is first subjected to pre-treatment to hydrolyze the hemicelluloses and expose the cellulose for subsequent enzymatic degradation. The cellulose then undergoes enzymatic hydrolysis to produce glucose, which can be converted to bio-fuels and chemicals by fermentation.

The following actions are necessary to allow the commercial development of 2nd generation bioethanol:

- Research projects on understanding pre-treatment technologies and designing new more reliable reactors and equipment, minimizing the energy input;
- R&D frontier projects to create a new generation of cheap enzymes for the hydrolysis of cellulose and lignocellulose into fermentable sugars;
- Industry-academia partnerships in developing new catalysts for the selective functionalization of alkanes, gas-to-liquid conversion, use of biomass and waste for energy and chemical applications;
- Industry-academia partnerships in process improvement, including: reduction or economic removal of inhibitory substances in sugar streams for fermentation; introduction of novel feedstocks from biomass fragments, e.g. glycerol in the short term, for chemical production;
- Research, feasibility and impact analysis to develop biotechnological production networks in bio-refineries, including energy management and diversion of by-products to parallel processes.

4.4.3.1.2. Action 2:

Improved biomass fermentation to ethanol

The microorganisms used must be able to fully convert the carbohydrates into ethanol, be robust, and tolerate the toxic compounds formed during the pre-treatment process. They must be able to withstand the stress of high ethanol and substrate concentrations, low pH, etc. At present, no such strains are available and significant challenges still lie ahead in the development of such robust micro-organisms. Developing such strains requires a multidisciplinary approach involving various aspects and research areas through industry-academia partnerships:

- research on microbial metabolic pathways and metabolic engineering to expand the substrate usage spectrum of micro-organisms;
- identification of microbial stress response mechanisms and tolerance to industrial conditions, and subsequent engineering of the system into the production micro-organisms;
- engineering of positive industrial characteristics to increase yield, such as high ethanol tolerance, fast growth, high ethanol yield and productivity, but also production of hydrolytic enzymes to complete the biomass hydrolysis during fermentation.

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[9] Directive 2003/30/EC of the European Parliament and the Council of 8 May 2003 on the promotion of the use of bio-fuels and other renewable fuels for transport (OJEU L123 of 17 May 2003)

Goal 2

To improve the qualitative and quantitative production of biogas (biomethane and bioH2) through dark fermentation of agro-food industry by-products and surpluses, domestic organic wastes, the organic fraction of municipal wastes, etc. through the optimization of the already existing medium- and large-scale technology and the development of innovative tailored biotech processes.

4.4.3.2.1 Action 1.

Academic research projects, industrial collaborative research projects, industrial research on the development of innovative single- or double-phase anaerobic digestion processes in conventional or non-conventional reactors under mesophilic and/or thermophilic conditions for an improved biomethane and/or bioH_2 production from organic wastes, residues, sludges and wastewater of national or regional interest, including the development of co-digestion processes based on the optimal formulation of different components such as sugar, starches, fats, proteins, aminoacids, and organic acids.

4.4.3.2.2. Action 2.

Industrial collaborative research projects focusing on identifying strategies for improving the performance and intensifying the use of the medium- and large-scale anaerobic digestors already existing in Italy.

4.3.2.3. Action 3.

Academic research projects and industrial collaborative research projects focusing on developing new integrated systems for producing electricity by means of MCFC (melting carbonate fuel cells) fuelled with biogas and/or biohydrogen.

4.4.4 Priority d)

Innovative and/or improved strategies and biotech tools and processes for the integrated monitoring and sustainable remediation and reclamation of Italian contaminated environmental resources and habitats (soil, sediments, water and groundwater)

Environmental resources (soil, sediments, air, water and groundwater) and their habitats must be considered of high social, cultural and economic value. All these resources are presently protected by European Directives. For soils there is a Framework Directive draft presently under discussion which defines soil as a non-renewable resource that must be preserved in all its functions (including the conservation of organic matter). The value of these environmental resources can be substantially decreased by the presence of contaminants, which can hinder their present use and/or full exploitation of future and potential uses. In a different perspective, recovery of contaminated sites to obtain new environmental resources (e.g. space for economic redevelopment, clean groundwater for any potential use) is also a "waste" upgrading instead of using fresh (non-contaminated) resources. A big effort is presently focused on restoring the environmental quality of such resources, particularly with reference to soil, sub-soils and groundwater. However, the most currently applied approaches/technologies are not able to fully recover the environmental quality of such resources: the "dig and dump" approach for contaminated soils and the "pump and treat" approach for groundwater soil do not maintain such resources in their original position and functions. Even when dealing with several *in situ* techniques like chemical oxidation or thermal treatment, some secondary damage will occur, such as loss of natural organic matter and soil texture.

Therefore, for a more sustainable approach to the soil and groundwater remediation in Italy it will be necessary:

- to preserve all potential functions of soils as non-renewable resources
- to do so by simultaneously minimizing energy and water consumption as well as waste production
- to do so by avoiding or minimizing any risks for health, also excluding possible secondary contamination (e.g. formation of toxic by-products)
- to do so at a minimum cost, also including full exploitations of economic use at the contaminated areas, even during remediation whenever possible.

For such a sustainable approach, biotechnology-based processes are the obvious candidates but they must be further investigated and implemented at level of both basic knowledge and technical application and performances.

Goal:

To study, develop and implement biotechnology-based processes for sustainable remediation of soils and groundwater

4.4.1.1. Action 1.

To improve knowledge on microorganisms (bacteria and fungi) in natural or modified habitats in order to fully exploit their biodegradation potential on pollutants

- To improve knowledge on the biochemistry and physiology of wild strains involved in the biodegradation of a range of priority contaminants, such as hydrocarbons, MTBE, chlorinated solvents and low-chlorinated and -molecular weight aromatic hydrocarbons;
- To improve knowledge on the behaviour of complex microbial consortia in soils, sediments, groundwater and wastewater, their ecology and relationships with environmental conditions, either natural or enhanced, for faster remediation
- To improve the knowledge of microorganism behaviour in the presence of non-aqueous separate phases (L-NAPL or D-NAPL), including related effects of microbial activity on NAPLs.

4.4.1.2. Action 2.

To improve process engineering

- To create and/or implement new high-performance materials and products specifically targeted to support or enhance bioremediation (e.g. slow-release of oxidizing or reducing compounds, surfactants and pollutant-bioavailability enhancing agents)
- To improve engineering aspects of in situ bioremediation processes, e.g. process configurations more specifically targeted to local constraints like hydrogeology and geochemistry
- To study and develop new processes with a higher efficiency and a more specific focus on selected contaminants, in order to minimize the addition of external compounds, decrease their interaction with natural compounds, and minimize the formation of unwanted by-products.

4.4.1.3 Action 3.

To create or implement new tools for “upstream” and “downstream” of sustainable bioprocess

- To design new biotechnology-based tools to support site characterization, process design, and/or monitoring. These will include both biosensors for the sensitive and specific determination of contaminants and biomolecular tools for microorganism identification and mapping. In situ approach, spatial-sensitive, and continuous signal tools will be preferred whenever possible

- To design sensitive tools for integral evaluation of toxicity and ecotoxicity, including in situ tools

4.4.1.4 Action 4.

To ensure the appropriate scaling-up of biotechnology-based processes and their application to contaminated sites.

- To combine lab- and pilot-scale research
- To promote research directly on real contaminated environmental resources (rather than on model matrices) and research and application directly on the field
- To contribute to removing legal barriers against performing research in the field
- To contribute to removing barriers against the dissemination of results
- To increase public awareness on remediation as a positive action towards economic and social redevelopment.

4.4.5 - Strategies for Boosting Italian R&D and Industry in the Sector of White and Eenvironmental Bbiotechnology.

In conclusion, from the white biotech scenario described, it can be summarized that in the sector of industrial and environmental biotechnology, Italy performs well in science, inputs and vision, but poorly in patenting activity and technological transfer, innovative entrepreneurship (start-up), resources (both public and private) and R&D employees.

Therefore, in Italy, scientific and technological breakthroughs and the aptitude for patenting and developments must be stimulated. Some possible strategies to achieve these results are:

- Translate vision, strategy and input better into roadmaps and action plans;
- Identify selected laboratories (on the basis of their pertinent productivity in terms of qualified papers and international patents produced during the plast 5 years) that have substantial potential to replace fossil-based fuels, power, heat, chemicals, and materials (including water recovery/replacement) with bio-products and/or bio-energy, and support their R&D projects over (5+3) years;
- Selection of a limited number of R&D themes with prospects;
- Selection of tailor-made programs based on marked demands for innovation (> R&D), flexible instrumentation;
- Decrease administrative burden;
- Use targeted demonstration programs to collect data over time and quantify benefits and costs of biobased products and bio-energy use in selected facilities. Demonstration programs must include partnership of national and/or international companies. Adopt six-month evaluation;
- Identify clear indicators to evaluate the state of progress;
- Enhance professional training and development (i.e., attention to critical mass) to support these R&D programs;
- Reserve a portion of the R&D funding for high-risk frontier science opportunities for future innovation;
- Identify in detail the principal barriers against research, development, demonstration programs, and deployment of biobased products and of bio-energy, and systematically develop coordinated policy mechanisms to overcome them. This may include tax incentives, environmental offsets, risk mitigation mechanisms in early employment, buy-down mechanisms, and others;
- Link environmental benefits of biobased products and bio-energy to public policy development;
- Endorsement by national and local istitutions of the integration among different players on specific innovation (R&D) objectives (agriculture, industry, universities, associations);
- Strongly back the use of the most advanced standards for evaluating the innovative products and processes in order to support the competitiveness and the quality level of the territory;
- Use advanced information technologies to collaboratively assemble, analyze, and publicly disseminate information on relevant environmental and ecosystem impacts,

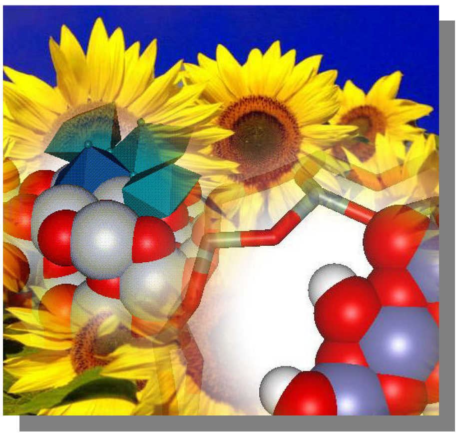
informing consumers about the benefits of biobased products and bio-energy so they will support the effort.

- Improve the patenting activity by involving the leading team researchers in any and all stages of the entire process (NOT just the research activities) and actually, not virtually, provide them an opportunity to develop a business activity of their own. Good rules and laws are not sufficient;

Lower the cost of intellectual property protection for SMEs;

- Adopt new ways of communicating to consumers about the technology or production process (biotechnology concept), which will create trust and market pull for such products; Adopt the Life Cycle Assessment tools (such as Environmental Declaration Product) in order to evaluate the overall impact of new products and processes;
- Form consortia of technology providers.

Biocatalysis, and more in general IB, is a strongly multidisciplinary sector and, as a consequence, only major industrial enterprises can afford to integrate the different technologies and translate them into commercial products. Many recent examples indicate that the future expansion of the business will be played on the formation of consortia and alliances of companies sharing synergistic technologies to offer customers broader solutions for solving problems related to the synthesis of compounds. The end-product manufacturers should have access to a wide portfolio of technologies in order to implement that technology which best satisfies the quality and economic requirements of each manufacturing process.The opening of two centres of excellence on biocatalysis in Manchester and Graz is a demonstration of how industries consider that establishing alliances with academia can also represent a route for accessing multidisciplinary expertise and ultimately for generating integrated technologies and products ("from gene to kilo").



Universities, Research centers and Companies acknowledged for their participation in the Industrial Biotechnology national survey

Universities	Companies & Spin offs	Research Centers
Polytechnic of Milano Polytechnic of Torino Polytechnic of Marche University of Bari University of Basilicata University of Bologna University of Cagliari University of Calabria University of Camerino University of Caserta University of Catania University of EasternPiedmont University of Ferrara University of Firenze University of Genova University of Insubria University of L'Aquila University of Messina University of Milano University of Milano-Bicocca University of Modena e Reggio Emilia University of Molise University of Napoli II University of Napoli- Federico II University of Padova University of Palermo University of Parma University of Pavia University of Perugia University of Piacenza University of Pisa University of Potenza University of Roma-La Sapienza University of Salerno University of Siena University of Teramo University of Torino University of Trieste University of Verona University of Viterbo	*Agrifutur srl*, Alfianello, Brescia *Agri2000 Soc. Coop.* Bologna *Agrolabo S.p.A*, Scarmagno, TO *AlfaWassermann S.p.A.*, Bologna *Biospehere SpA,* Bertinoro (FC) *BioDec srl.* Casalecchio di Reno (BO) *Bioman Srl,* Colleretto Giacosa (TO) *Biopaint Srl,* Colleretto Giacosa (TO) *Biosearch* *Ambiente srl.* Torino *Biotecnologie BT Srl* Todi, Perugia *Baxter Manufacturing SpA,* Rieti Cestec S.p.A.Milano *Consorzio Stabile COSINT s.c.r.l.*, Milano *CSL SpA*, Zelo Buon Persico (LO) *Diaspa S.P.A.* Corana, PV *Diasorin S.p.A.,* Saluggia (VC) *Eurolab srl* Torino *ENI SpA* S- Donato Milanese (MI) & Monterotondo (RM) *ESI Italia srl*, Milano *Fatro SpA,* Ozzano Emilia (BO) *Flamma S.p.A.*, Chignolo Isola, BG *Gnosis SpA*, Desio MI *Granarolo SpA* Bologna *Krabe Chemie Italia srl.* Bernate Ticino (MI) *Ktedogen SRL* Malnate (VA) *Lesepidado srl.* Bologna *Marcopolo Eng. S.p.A.*, Borgo S. Dalmazzo, Cuneo *Naturmed,* Chieti *Novamont S.p.A.* Novara *Phenbiox*, Bologna *Resindion* srl, Binasco (MI) *SERECO BIOTEST* Perugia *Sograf Chemicals srl* *Studio Consulenza Scientifica Oreste Piccolo (SCSOP)* Sirtori (LC) *SPES s.c.p.a,* Fabriano (AN) *Synbiotec srl*, Camerino (MC)	Center for Biocatalysis & Bioeng. of Macromolecules(NSF) CIRPEB Napoli CNR Bari CNR Istituto di Chimica Biomolecolare, Catania CNR Istituto di Chimica Biomolecolare, Napoli CNR Sesto Fiorentino (FI) CNR, Istituto di Chimica del Riconoscimento Molecolare, Milano International Centre for Genetic Eng. & Biotech. (ICGEB) Stazione Sperimentale Oli e Grassi Stazione Sperimentale per la Seta ENEA C. R. Casaccia (RM) ENEA C. R. Trisaia (MT) ENEA Bologna, Bologna CRPA, Reggio Emilia CRPV, Imola **Others** Associazione Italiana Energia del Legno (AIEL) Associazione Interreg. Olivicola Medio Adriatico (AIOMA) Confederazione Italiana Agricoltori (CIA) Consorzio Nazionale Olivicoltori (CNO) LIBI, Laboratorio Internazionale di Bioinformatica, Bologna Bioindustry Park Canavese spa, Via Ribes, 5, Colleretto Giacosa (TO) Parco Tecnologico Padano, Lodi ICGEB, Area Science Park- Trieste CIRB, Bologna Associazione Biocatalisi e Bioseparazioni ANBI (Associazione Nazionale Biotecnologi Italiani) Interuniversity Consortium INSTM Interuniversity Consortium CIRCC Interuniversity Consortium CIRCMSB Interuniversity Consortium INBB Interuniversity Consortium CIB Consorzio di Ricerche Applicate alla Biotecnologia (CRAB)

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4.2 Material Technology

4.2.1 - Italian approach

Many of the stakeholders that have promoted IT-SusChem have already clearly defined their position and priorities in the different fields linked to this Platform. These inputs had to be considered in the preparation of this Vision document. In particular, the following initiatives had to have been taken into consideration:

- Federchimica research priorities[10]
- Federchimica – CNR agreement[11]
- PNR (FIRB, FISR, COFIN, Centres of Excellence)[12]
- CNR-INSTM agreement
- ENEA priorities on materials technology
- Technological Districts and Parks
- Regional Research Plans and Innovative Projects
- European Networks of Excellence
- Other Technological Platforms

The position of Federchimica with respect to Materials Technology has been defined within its Research, Development and Innovative Committee, by means of setting up a specific Working Group to analyse the impact of Nanotechnology on industry and territory in Italy. The Working Group is preparing a document, "P.I.N.C.: A Programme on Chemical Nanotechnology: how to ensure the co-leadership of a Country in Europe" and the aim thereof is to evaluate the situation of Nanotechnology in Italy, including by means of a comparison with the European context. Furthermore, the text proposes a definition of the technology used and application markets.

Within the Working Group, a limited Participant Group has been formed, whose members include Research and Development Institutions, Universities, Venture Capitalists (including Finlombarda SRG, Pino Partecipazioni S.p.A. and Fort Business Advisor S.r.l.) and actors, like the Lazio Region and the Industrial Union of the Savona Province and which is aimed at creating a large-scale group with a critical mass.

The objective thereof is to create a network of contacts that are useful in setting up R&D projects on Nanotechnology. In particular, Federchimica is following the legislative *iter* of the VII Framework Programme, which will commence on 1 January 2007, to support Associated Enterprises in the participation of calls for tenders and intends participating in the CORNET Programme of the European Community. With regards thereto, IPI (the Institute for Industrial Promotion) has been contacted for a call that should be issued in Spring 2007 and which Federchimica intends participating in with a project on Nanotechnology. For these purposes, it would be appropriate for the Ministry of Economic Development to finance the Programme with an amount equal to €1 million.

Agreements have been entered into at an international level as well: the VNCI (the Chemical Enterprises of Netherlands Federation) has been contacted in order to collaborate in a Research Project and likewise the Embassies of certain countries, who are very interested in collaborating (in particular, the Dutch and British Embassies in Italy and the Italian Embassy in Israel) therewith. Regarding contacts in Israel, Federchimica is entering into agreements for the promotion and formation of Italian-Israeli joint Venture Capital Funds.

Moreover, Federchimica intends intensifying contacts with the European Investment Bank, who has already declared that it is open to co-financing the creation of Territorial Venture Capital Funds on Nanotechnology. In particular, a €10 million Fund has been considered, of which €5 million is to be provided by the Ministry for Economic Development and €5 million is to be made available by the Participants of the "P.I.N.C." Programme.

One of the initiatives provided for by Federchimica, within the framework of the "P.I.N.C." Programme, at the beginning of 2007, is to organise the "First National Conference on Chemical Nanotechnology", which will include the participation of Officers of the European Commission.

Parallel to the Working Group, a "Nanoscience" Task Force has been activated, which is evaluating the risks and opportunities related to nanomaterials, including the security thereof in working environments.

With respect to the technology transfer referred to in Materials Technology and other industrial sectors, Federchimica has developed specific contacts with CNR to develop specific strategies. Firstly, Federchimica analysed certain successful models of technology transfer structures in European and non European countries (for example, the Canadian model, the ISIS model of Oxford University, the Fraunhofer-Gesellschaft model or Regional Competence Centres of the Campania Region). Thereafter, Federchimica reached the conclusion that the key point for chemical enterprises in Italy is to be able to count on one or more existing technology transfer structures that will provide them with applied research results, placing them in a position where they are able to do industrial research on that which they have demonstrated that they know how to operate successfully. On the basis thereof, Federchimica proposes that CNR, in the role of technol-

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[10] *See for example: The Chemical Industry in Italy, Federchimica (http://www2.federchimica.it)*

[11] *Accordo Quadro CNR–Federchimica, May 2005 (http://www.cnr.it/cnr/events/CnrEventi?IDn=683)*

[12] *Programma Nazionale di Ricerca - PNR 2005-2007 (http://www.miur.it/0003Ricerc/0141Temi/index_cf3.htm)*

ogy transfer, is a suitable interface for the needs of the enterprises.

Federchimica therefore decided to enter into a Framework Agreement with CNR (signed on 6 May 2005), in order to supply SMEs with a valid instrument and to trigger a virtual research and innovative process, placing them at the forefront and making them competitive on the global market. In this way, the SMEs could make use of CNR's competencies and of their research structures, thereby overcoming their dimensional limitations.

In fact, the Framework Agreement between Federchimica and CNR provides the following:

- Jointly elaborated specific projects, with shared objectives between CNR and Enterprises;
- Planned and controlled research with a responsible project-manager who is adequately professional and experienced;
- CNR is to assume the costs and risks related to applied research activities;
- The Enterprises are to guarantee the use of their results and assume the relative costs of industrialisation and entrepreneurial risks;
- Penalties in the event of non-fulfilment in order to guarantee the seriousness of the Agreement and the duties undertaken;
- The discipline of industrial property rights;
- Give royalties to CNR in terms of a licence for the use of the results.

In terms of the "CNR – Federchimica Framework Agreement", specific actions aimed at the presentation of the CNR offer to Associate Enterprises and the clarification thereof, with the involvement of SMEs in particular, are provided for. These meetings can favour the creation of concrete collaboration between Enterprises and CNR.

Furthermore, Federchimica transmitted the "Sustainable Chemistry" project to CNR, which was positively evaluated by the Director of the Molecular Designs Department, Prof. Viticoli and will become one of the inter-departmental projects provided for in CNR's new statutes.

4.2.2 - Description of the Materials Technology Sector

Material and material development have been fundamental for the development of our civilization and continue to be one of the most important factors and objectives of industrial development, thereby contributing in solving some emerging societal needs and to increase the quality of life. As the 21st century unfolds, it is becoming more apparent that the next technological frontier will be opened, not through a better understanding and application of a particular material, but rather by understanding and optimising material combinations and their synergistic function, hence blurring the distinction between a material and a functional device comprised of distinct materials[13]

Materials science deals with the design and manufacture of materials, an area in which chemistry plays the central role; there is also considerable overlapping in the chemical engineering, biotechnology and physics fields. Discovery of new materials with tailored properties and the ability to process them are one of the main constraints of industrial development. The demands of tomorrow's technology translate directly into increasingly stringent demands on the chemicals and materials involved: their intrinsic properties, their cost, their processing and fabrication, benign health and environmental attributes and their recycle-ability, focussing on eco-efficiency. This requires doing a complete life cycle analysis on the new developed products and considering both the ecological as well as the economic components. Converging with the various performance demands are a suite of new technologies and approaches that offer more rapid new materials discovery, better characterisation, more direct molecular-level control of their properties and more reliable design and simulation.

The ***Materials Technology*** section of SusChem focuses on materials for mankind's future surroundings, which will be designed to enhance the quality of life while at the same time minimising the use of resources and limiting environmental impact. These materials will make life simpler, easier, safer, better and more importantly, place mankind at the centre of technology. The role of nanoscience and related nanotechnology will be one of the important factors in providing the knowledge necessary for innovative products and process methods.

Materials science has made substantial contributions to many fields including: modern plastics, paints, textiles and electronic materials but there are greater opportunities and challenges for the future. Materials chemistry is vital in all areas of science and technology as well as in the needs of society respecting energy, information and communications technology (ICT), healthcare, quality of life, transportation and citizen protection. Furthermore, materials science will play an important role in contributing to solutions for some emerging societal needs and in increasing the quality of life of European citizens.

The vision of the European SusChem Platform on Materials Technology is[1]:

1. To make Europe the world's leading supplier of advanced materials.
2. Innovation in materials technology driven by societal needs and contributing to improving the quality of life of European citizens.
3. Accelerated identification of opportunities, in close co-operation with partner industries down

[13] *The vision for 2025 and beyond: A European Technology Platform for Sustainable Chemistry, EU-SusChem Vision Document, March 2005 (http://www.suschem.org)*

the value chain, leading to materials with new and improved properties.

4. The ability to rationally design materials with tailored macroscopic properties, based on their molecular structure.

5. Products based on integrated complex systems made available by improving and combining the benefits of traditional materials and nanomaterials.

6. Convergence of market demand and technology development, creating many opportunities for new enterprises in the materials sector (e.g. SMEs).

The SUSCHEM platform, should contemplate in its priorities different aspects of materials research, and integrate them:

- *Multifunctional materials* by design: polymer and organic semiconductors, polymer and organic dielectrics, conjugated liquid crystals, molecular actuators, coordination compounds and clusters; nanoparticles, nanotubes, nanopowders, nanostructured surfaces
- *Bio-functional materials*: bio-compatible and bio-degradable materials with tailored properties which include thin films and surface coatings, medical prosthetics, materials for therapeutic and diagnostic applications, formulation technologies for drugs, agrochemicals, nutrition, cosmetic and personal care products and bio-nanocomposites using, amongst others, nanotechnological and biomimetic material concepts. In this area, links to the technology section of industrial biotechnology are to be found and concerted activities will be necessary;
- *Intelligent materials* with tailored electrical (e.g. superconducting), optical, mechanical and magnetic properties for applications in electronic devices, such as, displays or sensors for the development of organic electronics;
- *Materials for new sustainable technologies* in the areas of energy creation, storage, transport and conversion, covering areas ranging from renewable energy sources, such as, solar and fuel cell technologies to nanoporous materials for insulation; nanomaterials and nanopowders able to degrade contaminants and remediate the environment.
- *Development of new methods for the controlled synthesis* of rational designed materials including novel polymerisation techniques and catalytic processes, giving access to yet unknown materials. Activities in this area will be linked to activities in the other two sections: Reaction & Process Design and Industrial Biotechnology, seeking the most eco-efficient process possible.
- *Hybrid materials:* conventional materials (polymers, co-polymers, glass, fibres) integrated with a functional or multifunctional material; systems for hybrid technologies (e.g. organic spintronics)
- *Organization, assembling and self-assembling*: growth of thin films and nanostructures; cooperativity; wetting/dewetting; capillary forces in nano- and mesoscopic channels; self-assembly; self-organisation; kinetics vs thermodynamics; structure of organic/metal and organic/dielectric interfaces; interfaces between multifunctional materials and magnetic conductors; length scales of organisation; study of spatial correlations and length scales
- *Fabrication and processes*: Advanced materials technologies based on new and optimized traditional processes. Key words include intercalation, exfoliation, dispersion, covalent and non covalent interactions, molecular and multiphase distribution and orientation, unconventional lithographies, etc.
- *Properties:* charge and energy transport; charge injection; exciton dissociation; magnetism; spin transport; actuation; intermolecular and surface forces; scaling behaviour of relevant properties
- *Tools and techniques:* for growth and characterisation. It is important to increase the use of nanoscale microscopy techniques in chemistry (scanning probes above all, still rather limited with respect to the potential), and diffraction techniques to nanostructures. Scanning probes should be strengthened not only for the morphological information, but also for the investigation of length scale dependent properties as electrostatic potential, magnetism, viscoelastic properties. Electron spectroscopy, nanoscale optical probes, micro-Raman also surface (SERS) and tip-enhanced (TERS), electron microscopy.
- *Devices:* these are crucial for the demonstration that the sustainable chemistry and fabrication approaches paves the way for a technological platform. Electronic and optoelectronic devices, photonics, sensing, memories made of one or more integrated components; microfludic systems, and their integration with other solid state devices (hybrid liquid-solid state technology). Nanotags with high information content and integrated sensitivity (e.g. time temperature integrators; security: identification)

Nanotechnology: *Nanotechnology is the design, characterisation, production and application of structures, devices and systems by controlling shape and size on a the nanometre scale.* Application areas include construction, cosmetics, polymer additives, functional surfaces, vehicles, the aerospace industry, sensors and biosensors, molecular electronics, targeted drug release and manufacturing. Although there is nothing like a single discipline called “nanotechnology”, the ability to design and control the materials’ properties through size, shape, dimensionality, positioning and inter connectivity, at all length scales will nevertheless be crucial for most high-value applications. So, Nanotechnology must be considered as being a horizontal enabling technology supporting innovation in all areas of Materials Technology. This requires the integration of different fields of chemistry and the other disciplines like physics, engineering, biology and medicine. From the cultural point of view, this is an important challenge for chemists, which traditionally operate within the disciplinary boundaries of their specialty and often experience difficulties in interfacing with researchers from other disciplines or fields, especially for device applications. In most of the chemistry curricula, the integration of the different disciplines is often weak. It turns out that traditional research approaches emerge more natural. This is a barrier for the further evolution of the chemist towards more complex and ambitious research activities. In order to boost high impact research, the programs envisioned in the platform must promote cross-disciplinary activities.

Among the fields where multidisciplinary approach in the research at the state-of-the-art is normally applied, multifunctional materials designed for electronic and optical properties, recognition and sensing, actuation, catalysis, occupy a central role. Multifunctional materials are paradigm of nanotechnology, since they combine relevant properties for applications together with the ability to give rise to precisely defined architectures, in size and connectivity, by sustainable fabrication processes. These materials are of great interest for many technological fields, from intelligent packaging, to smart textiles, to consumer's electronics, information storage media, sensors, displays.

The fabrication technology with control at all length scales is a central issue for research on multifunctional materials. In the platform, it is important that activities aimed to explore fabrication comply to several requirements:

- must be based on convergence of top-down and bottom-up approaches to ensure the control across length scales;
- must be sustainable;
- must be scalable:
- must be as versatile as possible.

Therefore, it is important to contemplate research activities not exclusively aimed to prototyping, which can be easily made by serial approaches, as for instance scanning probe lithography and manipulation, but instead put an effort towards scalable approaches which are suitable for large area and/or high throughput fabrication. Indeed, the shortcoming of many "nanotechnology" projects is that they stop at the material synthesis and characterisation, else at the proof of concept, without envisioning an evolution towards up-scaling and real applications. The integration of both "proofs of concept" and up-scaling is the effective way to direct research towards goals which are ambitious from the fundamental research point of view, but also become attractive for industry. An example is soft lithography, where the phenomenon of self-assembly at surfaces has evolved towards a patterning technology with applications in many different tech, from technological fields, from microelectronics, to micro-electromechanics, optics, photonics, biodiagnostics, printing, information storage. The impact is huge, from consumers' electronics, to health, safety and traceability of food and pharmaceuticals, and smart packaging. These industries are end-users of materials and technology developed within this frame. Therefore, it is crucial that the chemical industry increases its awareness to the fabrication aspects, and catches these new market opportunities for fine chemicals and for traditional materials which can be endowed with new properties by suitable fabrication.

The attractive feature of multifunctional materials is that they can be patterned into nanostructures of well defined size and a variety of controlled shapes, such as lines, dots, meshes, nets, etc. by exploiting sustainable approaches, as for instance self-organisation from solutions in confined environments. The control on the smaller length scales is intrinsic to the self-organisation process, whereas the larger length scales are imposed by the external agency. The control on the size and dimensionality of the material can be enforced by merging the emergence of characteristic length-scales (at the nanometer-mesoscopic scale) of self-organisation phenomena with the larger length scales, from tens of nanometers to microns, that are imposed by an external agency, either stamps, microfluidics with meso- and nanoscopic channels, or nanofabricated templates, or simply the interplay with capillary and hydrodynamic forces.

This converging approach requires a thorough knowledge not only on the materials properties and intermolecular interactions by design, but also on interfacial and surface interactions, competing interactions, nucleation and growth phenomena, capillary and viscous forces, hydrodynamic effects. Therefore, it is important to establish broad research programs where synthesis and molecular design interact with physical chemistry, polymer chemistry and engineering, theory of the condensed and soft matter, surface physics, characterisation at the nanoscale with local microscopy and spectroscopic techniques, multiscale simulation of phenomena in meso- and microscopic systems. These programs should contemplate device and bio-diagnostics demonstrators of the materials and the processing technology. As examples, fabrication of memory storage elements, field effect transistors, biosensors where the active component is made of nanostructures exactly defined in terms of size, shape and position, would make projects much more coherent and convincing for long term exploitation. The development should be in the hand of engineers, with e.g. the simulation of the circuitry and the logic boards, or the up-scaling of the patterning technique to large area or roll-to-roll processing. This may be a strong contact point between chemistry and industry.

4.2.3 - Interaction with other Technology Platforms[14]

On a European level, close interaction between SusChem and other technology platforms is of utmost importance, as chemistry and biotechnology

[14] European Technological Platforms (http://cordis.europa.eu/technologyplaforms/home_en.html)

are enabling technologies, delivering solutions and materials for a wide range of other areas like the consumer care industry, information technology or transport.

SusChem has identified several technology platforms which either promise significant synergy with SusChem activities and/or cover important technology for chemistry and biotechnology along the value chain. Bi- and multilateral consultations with these platforms will be continued or organised in the future.

The technology platforms essential for SusChem are:

- Biofuels
- Construction
- EuMaT
- Forestry
- Hydrogen and Fuel Cells
- Industrial Safety
- Manufuture
- Nanomedicine
- Photovoltaics
- Plants for the Future
- Textiles
- WSSTP
- Zero Emission Fossil Fuel Power Plants

4.2.4 - Main R&D priorities for Materials Technology in Italy

This chapter synthesizes the information provided by stakeholders on the priorities, needs and expertise on Materials Technology provided by Italian industries and public and private research centres.

As expressed above, the information will be analysed and classified according to the priorities already identified at a European level[3]. However, it is obvious that the Italian Platform should also define and propose new priorities, not previously identified, that will enhance the Italian contribution and presence in the EU-SusChem Platform.

Considering Italy's socio-economical priorities, its international position, R&D industrial needs and expertise already available in Italy, future R&D national efforts in the area of Materials Technology should be addressed to implement and boost the development of:

a) *Nanosciences and nanotechnology:* Nanosciences and nanotechnology are widely seen as a multi-disciplinary and integrative RTD approach, having the huge potential to improve the competitiveness and sustainable development of materials technology across a wide range of industrial sectors.
b) *Development of new materials with higher knowledge content:* Materials with new functionalities and improved performance must be developed in order to increase industrial competitiveness and sustainable development.
c) *New manufacturing processes:* efficient processing of new materials with tailored properties, from a resource intensive to a sustainable knowledge-based industrial development.
d) *Materials with higher knowledge content* and innovative manufacturing approach for specific industrial sectors
e) The LCA approach: a selection criterion of defining eco-materials based on their environmental performance

4.2.4.1: Priority a) - Nanosciences and Nanotechnology

The main objective is the study of the fundamental phenomena and the manipulation of matter at a nanoscale, in order to promote long-term innovation by enabling the manufacturing of new nanotechnology-based products with superior performance across a range of applications, while minimising any potentially adverse environmental and health impacts. Interdisciplinarity and the integration of theoretical and experimental approaches are required.

Main research themes for the Italian community include:

Development of self-assembled nanostructured materials and surfaces

Molecular self-assembly is a strategy for nanofabrication that involves molecule designing and supramolecular entities so that shape-complementarity causes them to aggregate into desired structures. Self-assembly has a number of advantages as a strategy: it carries out many of the most difficult steps in nanofabrication--that involve the atomic-level modification of structures, using the very highly developed techniques of synthetic chemistry. Secondly, it draws from the enormous wealth of examples in biology for inspiration: self-assembly is one of the most important strategies used in biology for the development of complex functional structures. Moreover, it can incorporate biological structures as components directly in the final systems. Finally, because it requires target structures that are thermodynamically the most stable ones open to the system, it tends to produce structures that are relatively defect-free and self-healing. The long term objective should be to take advantage of self-organization processes to develop nanostructured materials with specific and controlled physical-chemical structures and with predictable and controllable properties. Bottom-up self-assembling and self-organisation should be used in order to generate structures with new functionalities. Computer modelling should be used to help understand the fundamental aspects of self organisation and multi-scale development.

In this topic the appealing features of the DNA molecule should be considered in bottom-up nano-biotechnology. Its excellent stability and powerful molecular-recognition properties can be used to direct the assembly of highly structured material with specific nanoscale features. In fact, this biomolecule plays an outstanding role in the development of artificial biomolecular hybrid elements, since the specificity of simple A-T and G-C base pairing as well as its robust physicochemical nature allows for the fabrication of nanostructured molecular scaffolding and surface architecture, and to selectively position proteins, inorganic colloidal components, carbohydrates, organometallics, and reactive chemical compounds on the nanometer length scale.

Also in this topic mesostructured templated silicates and zeolites are considered to provide stable frameworks whose surface can be respectively modified by functonalization and ionic exchange. By this way, the properties of a single framework can be tailored according to the specific field of application for which the usage of a nanostructured material is required.

Italian research lines of interest:

- nanoscale integrated processing of self-organizing multifunctional organic molecules and polymers
- self assembly of metallic nanocrystals and functionalized semiconductors in nano-patterned 2/3 D structures for optoelectronics and sensors
- organic conjugated systems for electronic and optical applications
- development of carbon based nano and micro structures
- modelling electro active conjugated materials at a multiscale level
- self-organization of polymer blends and block copolymers
- development of self-assembled nanostructured hybrid surfaces and thin films
- systematic exploration of DNA molecules and analogues to expand and improve their self-assembly properties
- modelling and characterisation of liquid crystals for nano-organised structures
- real-time characterization and computational modelling of nucleation and growth in self-assembling organic materials
- setting up and optimisation of new methods for the preparation of nanostructured ceramic materials
- synthesis, functionalization and characterization of mesostructured templated silicates and zeolites
- synthesis and characterization of self bonded pellets containing carbon nanotubes

Development of self-repairing materials and surfaces

In recent years, the ever increasing growth of polymer-based composites as structural and functional materials has been the source of new problems that are beyond the chemistry of the synthetic process itself. Many applications not only require specific mechanical properties, but also demand suitable resistance to potential damages during their use (repeated mechanical stresses, attack by chemical or physical external agents, etc.). Usually, the damages are made evident by the appearance of microfractures (cracks) that occur in the matrix and follow chain degradation. An immediate consequence of the degradation process is a decrease in molecular mass as well as a variation in the chemical composition of parts of the polymer chain. So far, the exact localization of the events causing degradation to start is almost always rather difficult and a repairing service practically impossible. Above all, most microfractures are produced inside the polymeric material and become visible only when the mechanical resistance is irreversibly jeopardized.

The aim of this research sector is to make some of the efforts and results obtained by a few research groups in the world well-known, thereby striving to find and optimize self-repairing pathways of polymer materials, when the latter can face structural damages during their service. Hence, it is necessary to point out not only that the chemistry of the repairing process is not always fully developed at present , but also that the transfer of the research results to potential applications still requires relevant additional time to be accounted for. The interest for possible *in situ* self-healing approaches to apply to microfractures, wherever localized, has grown widely in the last few years and is centred on the development of self-repairing mechanisms, activated by the damage itself, as a key point common to most researchers.

Italian research lines of interest:

- Development of self-repairing and self-diagnosis materials and strategies for aeronautic and aerospace, biomedical (e.g. joint prosthesis, by-pass, cardiac valves and dental materials), sports and automotive fields.

Development of dendritic structures with tailored properties

Since the pioneering work of well-defined, three-dimensional structurally ordered macromolecules by Vögtle, Tomalia and Newkome, interest in dendrimers and hyperbranched polymers has increased at an amazing rate. The study of these polymers expands to all areas including theory, synthesis, structure characterization and properties and investigations of potential applications in different advanced industrial sectors. A broad range of dendrimers and hyperbranched polymers is now available; some dendrimers even commercially. Emphasis is shifting to an exploration of their potential use and application.

Italian research lines of interest:

- micelles and encapsulation
- self-assemblies and liquid crystals, layers,
- electroactive dendrimers and electroluminescent devices,
- conductive and ionic conductive polymers,
- catalysts, biochemicals and pharmacheuticals
- dendrimers in analytical chemistry
- dendrimer-nanoparticles and polymer-nanoparticles for multiple biological functions

Development of new synthetic strategies: "Click" chemistry

Recently, researchers of the Scripps Research Institute, USA, developed a new synthetic strategy named "click chemistry". This strategy is based on reactive molecular building blocks designed to "click" together selectively and covalently. Several research groups in the world are now extending the above idea by using protein binding sites, supramolecular complexes or functionalized surfaces as reaction vessels to direct the *in situ* formation of potentially functional click chemistry products. The products might be biological inhibitors, molecular-electronic components, sensor probes, nonlinear optical materials, light-harvesting compounds or compounds with any number of other useful functional properties. However, the polymer materials community has not yet fully developed the enormous potential of click chemistry in terms of new multifunctional macromolecule systems.

Italian research lines of interest:

- Development of new click chemistry strategies for innovative (macro)-molecules

Nano-scale materials and their interaction with biological systems

The objective should be to develop innovative nanostructured materials and surfaces with tailored properties and to explore the interaction mechanisms at a nano-scale between biological systems and nanostructures, in order to allow the design of nanostructured systems which interact in a predictable and controllable way with biological systems. These hybrid systems are of interest for industrial applications in view of potential benefits for health, food quality and environment. In this context, the properties of these hybrids depend in a complex manner on the interfacial interactions that determine their performance. Reactivity, diffusion phenomena and stability of the interfaces are main topics for applicative research. The design of novel nano-scaled materials with improved specific surface properties requires a detailed understanding of the underlying physical principles and the ability to control interfacial interaction parameters. The improvement of knowledge on stability, durability and performance of the nanohybrids, through the study of interactions, linkages and reactivity of new functionalities at the biomolecule/polymer interfaces are fundamental for industrial biotechnological applications in biosensing and drug delivery.

Italian research lines of interest:

- development of antimicrobial nanocomposites and nanostructured surfaces for films and fibres
- development of nanostructured antifouling materials and surfaces
- electronic interaction of photosensible proteins enclosed in polymer and glass matrices
- immobilization of proteins in membranes for biosensors.
- interaction lipids/proteins in electronic and protonic transfer processes in photosynthetic and biomimetic membrane systems.
- Development of iInnovative hybrid (inorganic-organic-biological) materials designed at nano-scale level (including nanoparticles, nanotubes, nanorods) and obtained by chemical routes or controlled self assembly for biocatalysis, biosensors and drug delivery
- macromolecular nanosized systems chelating paramagnetic ions for Magnetic Resonance Imaging (MRI) in medical diagnostics
- bio-inspired nanodevices for multiple biological functions such as drug delivery, gene therapy and medical diagnostics
- CNT as nano-substrates of DNA, RNA and proteins in drug and gene therapy
- design, synthesis and characterization of novel, nanostructured functional hydrogels and composites with tailored optical and electric properties for biotechnological applications
- use of ionizing redaition beams for structure and morphology control in nanobiocomposites

Nano-scale materials and their interaction with the environment

Engineered nanomaterials are showing high potentiality for applications in the environmental field and in particular in pollution prevention, sensing and remediation. On the other hand, the fate of nanoparticles in the environment is not fully understood and is the result of complex mechanisms arising from their small dimensions, the reactivity, the tendency to aggregate and to attach to surfaces.

Italian research lines of interest:

- development of new materials for the remediation of contaminated sites
- understanding the transport of nanomaterials in different environmental matrices

4.2.4.2: Priority b) - New materials with higher knowledge content

Research should focus on the development of new knowledge-based multifunctional materials and surfaces with tailored properties and predictable performance in order to obtain new products for a wide range of applications and taking into account potential impacts on health and the environment throughout their entire life-cycle. In particular the structure–property relationships at different scale should be analyzed using advanced characterization and modelling techniques in order to obtain design tool to improve materials performance, reliability and durability.

Main research themes for the Italian community should include:

Nanostructured composite materials

Nanostructured composite materials, mainly based on polymer matrices with inorganic nanofillers (clays, oxides and other ceramic nanofillers, metals, nanotubes and nanofibers) are emerging as materials with increasing industrial interest. These polymer nanocomposites, exhibiting radically enhanced properties, normally require a lower filler loading than composites with traditional fillers, resulting in markedly improved performance with higher homogeneity and lower density. Research efforts are still required in order to guarantee the dispersion of the nanofiller and the adhesion to the polymer. Fundamental studies on polymer-nanofiller chemical compatibilization, rheology, processing behaviour, thermal stability and life cycle analysis should allow a better understanding and control of the final structure of nanocomposites with enhanced performance in terms of mechanical properties, thermal and dimensional stability, bioresistance, fire retardancy and other barrier properties.

Among nanostructured composite materials an outstanding role is played by dispersions of metallic nanoparticles in ceramic matrices. Such materials may be obtained as follows: (i) subjecting to transition metal cation exchange various zeolites; (iii) reducing such cations to 0 oxidation number by thermally treating in hydrogen atmosphere the transition metal cation exchanged zeolites; (i) sintering such zeolitic powders

Italian research lines of interest:

- designed nanostructured hybrid materials from polymerization catalysis
- nanostructured and multifunctional polymer materials and nanocomposites by melt processing and in situ polymerization
- compounding, rheology and mechanical properties of thermoplastic matrix nanocomposites
- crystallization kinetics and morphology in thermoplastic polymers and their composites and nanocomposites
- environmentally friendly multifunctional fire retardant polymer hybrids and nanocomposites
- multifunctional barrier for flexible structures (textile, leather and paper)
- predicting the fire behaviour of nanocomposites from intrinsic properties
- design nanostructured hybrid polymers
- inorganic or organic metal/polymer nanocomposites obtained through radiation induced crosslinking reactions
- modification of nanofiller structure and surface to improve dispersion and polymer compatibility
- nanostructured, multilayered and functionally graded coatings for improved mechanical, wear, electrical and corrosion resistance properties
- nanostructured hybrids based on polymer matrix-carbon nanotubes interactions
- interactions nanotubes and nucleic acids (DNA or RNA for dispersion of CNTs)
- development of new processes for the transformation and functionalization of natural polyphenols, lignocellulosic materials, cellulose and hemicellulose derivatives for the polymers industry

Inorganic materials with tailored porosity

The interest in porous materials has grown rapidly in the recent years with the demands from new fields of applications and processing routes. The use of porous materials already assessed in thermal insulation, substrates for catalysts and filtration systems still holds great expanding potential into new technologies for energy conversion, health and environment care, transportation etc. Membranes find application in biotechnology, food processing, pharmaceutical, petrochemical, electronics; improvement of the thermo-mechanical properties while lowering production costs is necessary for further expansion of the applications. In the biomedical field porous ceramics find use in bone replacement and drug delivery systems. Innovative methods are required to modulate the functional properties (electric, acoustic, magnetic, drug delivery, etc.) of materials by tailoring the porosity. This research area is focused on the design and processing routes to develop micro to macro porous structures with controlled pore morphology, i. e. size, size distribution, shape, interconnection, volume distribution.

Italian research lines of interest:

- innovative porous structures for catalysis
- functionally graded porous materials (fuel cells)
- piezoelectric porous materials for ultrasonic applications
- porous supports as bioreactors
- biomimetic processing
- membrane and filter processing

Smart molecules and materials

This theme approaches complex molecules and advanced materials with a wide spectrum of enhanced functionalities and with the potential to replace whole devices at all scale levels (from nano to micro). Some industrial applications already exist but there are still immense possibilities of achieving improved functionality by further tailoring the material properties in many areas, from shape memory alloys and electroactive polymers to photochromic materials and tuneable dielectrics. The main objective is to design novel knowledge-based smart materials with tailored properties, releasing their potential for enhanced and innovative applications.

Italian research lines of interest:

- nanocomposites with high colouring efficiency for electrochromic smart plastic devices
- development of shape memory nanostructured polymer materials and blends
- synthesis of a new generation of molecular components for nanometric machines, suitable for photoconversion and/or photoemission, or able to control movements in response to a luminous and/or electric stimulus. In particular, multicomponent organic and organometallic

structures, featuring both the active component - imparting the specific functionality - and the appropriate structural elements.

- development of visible light-sensitive photo catalytic materials and devices for solar energy conversion

Organic materials for electronics and photonics

Organic materials have the huge potential of increasing the competitiveness of the electronics and photonics industries. New developments in polymer based electronics and photonics (e.g. flexible display technology and lighting), and related photovoltaic innovations, rely to a large extent on new organic materials development. Research should focus on the materials performance, reliability, durability and processing (patterning, multilayering, self-assembly, molecular separation and recognition, vapour growth techniques, selective laser treatment, deposition at surfaces, etc.).

Italian research lines of interest:

- synthesis and characterization of functional materials at atomic, molecular and nano levels and their nanomanipulation through electronic, photonic and thermal mechanisms, for materials with designed optical and electrical properties
- development of nanostructured organic multifunctional molecules and polymers with tailored electronic, optical and sensing properties.
- design and fabrication of micro and nanostructured organic thin film transistors
- new conductive nanocomposite plastics (via CNT and CNF) for energy transmission, sensing and lighting devices
- nanocomposites of conjugated polymer and CNT and CNF for light transmission
- development of polymer based nanocomposites and nanostructured thin films for photovoltaics for energy applications.
- synthesis of nanocrystals for optoelectronics
- synthesis and surface engineering of semiconductor nanoparticles,
- modification of nanostructurable polymers using photolithography and non conventional patterning techniques: nanoimprinting lithography (NIL) and ink-jets, for optoelectronic applications
- self assembly of metal and semiconductor nanocrystals functionalized in 2/3 D structures by nanopatterning in optoelectronics and sensors.
- molecular, polymeric, supramolecular and hybrid nanostructured materials with specific electronic and optical properties for photonics.
- design and fabrication of optoelectronic devices based on innovative second-order nonlinear organic nanomaterials
- synthesis and characterization of polymers and oligomers for organic light emitting diodes

Nanostructured materials with tailored magnetic properties

Magneto-opto-electronics is an emerging field for the realisation of novel devices with huge potential for information technology. Understanding the coupling of magnetic, optical and electronic phenomena at a nanolevel still requires much research in areas such as spintronics, magnetic data storage/processing, photonics and sensors for medical applications.

Italian research lines of interest:

- fundamental analysis of the magnetic resonance of molecules
- quantum effects in molecular nanomagnets
- molecular approach to nanomagnets and multifunctional materials
- development of magnetic nanoparticles and core-shell structures with tailored magnetic properties.
- nanostructured magnetic materials for sensors for positioning systems

4.2.4.3: Priority c) - New manufacturing processes from resource intensive to sustainable knowledge-based industrial development.

Production routes are as important as material properties in increasing performance and the added value of products. Therefore, the development of knowledge based materials cannot be industrially exploited if no efforts are devoted to the development and understanding of innovative production routes. For example PECVD (plasma assisted chemical vapour deposition) is a technology with extremely low environmental impact due to the lack of wastes that allows to treat every kind of materials because of the low temperature and low pressure employed. Extensive modelling of transformation processes are required to analyze the transformation of materials during processing and during service life. Life cycle engineering is required to understand and optimize the environmental impact of products and transformation technologies. This priority should be developed in close interaction with the working group on chemical processes.

Main research themes for the Italian community include:

Materials from renewable feedstocks

The development and use of alternative feedstocks for raw materials that currently depend on oil availability are highly interesting to the Italian industry. This concept can be applied not only to energy and to the production of current polymeric materials but also affect the production of basic raw and intermediate materials in the chemical industries. In particular, the combination of bio-materials, or of natural and synthetic polymers, offers much potential for the substitution of current materials and the development of new ones with new functionalities and applications. This is clearly highly interesting for Italy, which has a critical dependency on energy and oil from geographical areas with high potential risks. On the other hand, Italy offers much potential for agricultural exploitation which can be applied to the concepts of bio-refinery and raw materials from biomasses.

Also in this topic, the use of other organic and inorganic renewable and/or natural renewable feedstocks are considered

Italian research lines of interest:

- new monomers from natural resources- processing of plastics from natural resources
- development of new polymers based on renewable resources (bioplastics) for bulk and coatings
- development of composite materials based on biopolymers
- development of pozzolanic cement manufacture based on natural zeolite additions
- utilization of industrial residues to produce bricks and other ceramics with properties of sound proofing and thermal proofing

Optimization of the processing of polymers, composites and nanocomposites

The efficient processing of new materials with tailored properties, in many cases, constitutes the main limitation of product development in many industrial sectors. These limitations are mainly related to the lack of knowledge on the fundamentals of processing behaviour and on possible environmental restrictions (i.e. solvent use, volatile side products, energy consumption, etc.). The main industrial products and application fields affected by these limitations include plastics, paints, textiles and electronic materials.

Italian research lines of interest:

- development and processing of polymer foams (PET, LDPE, PS, PU)
- injection molding of hybrid polymer-wood composites
- processing of innovative elastomeric thermoplastic materials and functional liquid-crystalline elastomers
- polymer injection advanced moulding (PIAM)
- development and processing of advanced polymeric systems for adhesives and coating
- melt rigradation of recycled PET through reactive extrusion (including use of nanofillers)
- analysis, optimization and control of the dimensional stability of injection moulded polymers, composites and nanocomposites

New catalysts with nanostructured tailor-made functional surfaces

A new generation of catalytic materials with tailored functionality at the surface are required for new sustainable chemical processes having higher energy efficiency and selectivity, Interdisciplinary efforts, including advanced multiscale modelling and characterisation techniques, are necessary to fully understand highly complex catalytic processes based on a controlled sequence of surface reactions and of active sites.

Italian research lines of interest:

- development of novel catalytic materials
- setting up and optimisation of new methods for the preparation of nanostructured catalysts with specifically tailored properties
- integrated design of catalytic nanomaterials for a sustainable production
- new polyolefin catalysts (homogeneous and heterogeneous)
- new polymer structures for PP, PE, PB-1, APO, polydienes and polycycloolelfins
- new production technologies for polyolefins
- development of novel methods for polyolefin production research
- high throughput screening platforms
- compounds and nanocomposites of new and available olefin based polymers

Computational modelling of the structural evolution during processing and full life-cycle

Major improvements in materials design and processing behaviour can be analyzed beforehand, by means of the mathematical simulation and experimental validation of the nano, micro and macro-structural evolution of material properties and phenomena that determine the macroscopic material response, during processing and under working conditions. Modelling approaches are expected to build on the relationship between processing conditions, microstructural evolution and specific macroscopic material properties and to take advantage of new multi-scale approaches.

Italian research lines of interest:

- modelling and design of advanced composite materials
- modelling and design of advanced ceramic and cermet coatings
- computational modelling of polymer processes with particular attention to the simulation of injection moulding of polymers, composites and nanocomposites including crystallization effects
- modeling and control of morphology of semicrystalline polymers under realistic processing conditions
- advanced processes for near to shape production
- multi-scale modelling of interfacial phenomena in nanocomposites, bridging molecular-level and continuum-level descriptions
- modelling of PECVD plasma processes, for process monitoring and control

4.2.4.4: Priority d) - Materials with higher knowledge content and innovative manufacturing approach for specific industrial sectors

The development of fundamental knowledge on the processing-structure-properties of new materials with the integration of the first three sectors described above, that is, nano-, materials-, and production-technologies, will support innovative applications in bulk and coating high-demanding sectors, such as health, construction, transport, energy, environment, information technology, textiles, chemical engineering and other important industrial sectors.

In particular the thin film technology concerning a large variety of non-equilibrium processes for leading-edge surface modifications of materials is gaining increasing popularity, because it allows the design of substrate by means of the deposition or modification of thin films in an extremely versatile and environmentally friendly way, i.e. by employing low pressure plasmas, also called cold plasmas or glow discharges. The environmental considerations are becoming more and more important after the Kyoto Earth Summit and its subsequent amendments, and the world-wide initiatives as EU IPPC Directive (Integrated Pollution Prevention and Control – 96/61/CE), that requires, as a target for the different industrial sectors, the development of the best available techniques.

Main research themes for the Italian community include:

Materials for energy conversion

The research in this sector should be aimed at the development of new materials with tailored and controllable complex architecture (quantum dots, nanocomposites, thin and thick-films, mesoporous 3-D architectures, carbon and inorganic nanotubes, aerogels and ionogels, etc.) and structure (specific surface area, porosity), which should provide improved efficiency and competitive cost/efficiency ratios as well as durability in energy conversion systems (supercapacitors, stacks, solar cells, high performance batteries, etc.). Moreover, research is required in highly efficient energy conversion technologies and related materials, such as catalytic combustion.

Italian research lines of interest:

- Polymers, composites, nanocomposites and ceramic materials for fuel-cells
- development, characterization and application of supramolecular systems for energy production systems
- materials for solar concentration plants
- development of polymer-based nanocomposites and nanostructured thin films for photovoltaics for energy applications
- catalysts for higher efficiency energy conversion, e.g. for catalytic combustion
- semiconducting materials for H2 production through photoelectrocatalytic water splitting

Biomaterials for tissue engineering

This theme addresses materials for biomedical applications designed with specific bioactive properties and controlled interaction with the surrounding biosystem. Bioinspiration should be the main driving concept from the nanoworld of proteins to macroscopic soft and hard tissues.

Italian research lines of interest:

- development of biomaterials for bone regeneration and cement
- innovative materials and technology for bio-engineered prostheses
- innovative materials and technologies for tissue engineering
- injectable macroporous biomaterials based on calcium phosphate cement for bone regeneration
- smart composites and nanocomposites for bone tissue and cartilage repair and regeneration including in situ gel forming systems and Gene Activated Matrix (GAM)
- natural and synthetic polymers for applications in the peripheral nerve regeneration
- innovative biocompatible biomaterials for wound healing and for prevention of post operative adhesion

New materials and technologies for extreme service conditions

This theme addresses polymeric, composite and ceramic bulk materials and surfaces, specifically designed for use in extreme conditions and environments: very high or very low temperatures, radiation, high pressures, high electromagnetic fields, damaging chemical reactions such as, corrosive or oxidizing environments, biodegradation, or possible combinations of these conditions at the same time.

Italian research lines of interest:

- structural ceramic nanocomposites for top-end functional applications
- development of nanostructured materials with specific photocatalytic properties for the protection of ceramic materials from aerial and aqueous contaminants
- development of advanced ceramic coatings for extreme environments with self-diagnosis properties
- composites for ballistic applications
- nanocomposites with tailored electrical properties for EMI-shielding
- innovative flame retardancy polymers for coatings, cables, etc
- development of advanced multilayer surface technology for extended resistance in extreme environments
- development of nanostructured materials with photocatalytic properties for the treatment of industrial aerial and aqueous contaminants
- development of refractory synthesis from zeolitic precursors
- development of PECVD plasma processes for corrosion resistance tribological coatings

Development and application of new materials and fibres in the textile industry

The development of materials with enhanced mechanical and functional properties, with the potential use of nanotechnology, is crucial to the competitiveness of the textile industry. Enhanced fibre properties include weight/ performance ratios, strength, durability, flexibility, bio-degradability, energy-efficiency, insulation, temperature and moisture management, permeability, self-cleaning and self-healing. Given the role of textile materials, the early involvement of consumers in the R&D processes may play a critical role in improving the selection of the research paths and reducing the risk of developing research trajectories which are far from the market.

Italian research lines of interest:

- development of bulk fibres with improved mechanical properties
- development of fibres with tailored functional properties (bulk and/or surface)
- development of bio-based fibres with tailored properties
- surface modification of fibres, yarns and fabrics to enhance the manufacturing of textile- and composite-based innovative products.
- development of multifunctional natural cellulose textile materials modified with advanced processing techniques
- development of smart textiles with embedded flexible electronics and sensing systems
- exploration and assessment of ways to involve the final consumers in the process of R&D regarding new fibres and materials

Development of multifunctional materials for transport applications

This sector includes the design, processing and application of new lighter, stronger and multifunctional bulk and coating materials for transport applications, in order to improve sustainability, reliability and safety during their complete life-cycle, with a direct impact on the competitiveness of the automotive industry. Natural fibre and wood composites for automotive applications can also be considered in this application sector. Innovative materials for aeronautical applications are also considered.

Italian research lines of interest:

- innovative nanostructured surfaces and coatings and thin films with improved tribological properties for automotive and aerospace applications
- innovative nanostructured surfaces and coatings with improved high temperature stability and resistance for aerospace applications
- polymer composite-metal laminates for aeronautical applications
- development of liquid moulding processes for composites for aeronautical applications
- smart materials for the monitoring of aeronautic and aerospace structures
- foams for aeronautical applications
- thermoplastic matrix composite materials for aeronautical applications
- acoustic properties of polymers and composites for aeronautic and other transport applications
- development of nanostructured materials for sensors of gas emissions
- development of self-healing and self-diagnostic materials for integrity sensors

Development of materials and devices for health care applications.

Nanotechnology is starting to provide nanostructured materials, surfaces and devices with specific, triggered and controllable functionalities that can be used for diagnosis and therapeutic applications. The main, highly interdisciplinary research activities, should include the *in vitro* and *in vivo* behaviour of developed systems, including absorption, distribution, metabolism, and excretion analysis, toxicity, allergic or inflammatory induced responses and biocompatibility.

Italian research lines of interest:

- polymers for drug release materials
- development of smart nano and micro-sized drug delivery systems
- nanostructured functional hydrogels and composites for biotechnological applications
- multifunctional microsystems for biochemical analysis
- composites for magnetic resonance diagnosis
- development, characterization and applications of supramolecular and selfassembling polymeric systems (polymeric micelles, biocompatible copolymers) for drug delivery
- polymerization of vinyl monomers in supercritical carbon dioxide for the preparation of controlled drug delivery systems
- development of stealth nanoparticles for i.v. drug administration of antitumoral drugs
- multifunctional systems for monitoring tumoral cells under chemotherapy
- calcium phosphates/biopolymers composite scaffolds for bone tissue engineering
- innovative biomimetic coatings for metallic and polymeric substrates
- multifunctional organic electronic systems for health monitoring
- hybrid multifunctional nanostructured silica-based mesoporous materials for drug targeting
- development of polymeric cationic systems for gene and oligonucleotide delivery
- microencapsulation of active molecules for pharmaceutical applications
- hybrid nanomaterials for imaging and sensing application

Advanced materials technologies for the construction industry

The construction industrial sector has a huge potential for improvements in building energy performance, reduction of raw materials and natural resources consumption of buildings during their entire life-cycle. Design tools, new materials and structures, new construction technologies, integrated socio-economic concepts and innovative life cycle engineering models are the main instruments that should be addressed to significantly increase the energy performance of modern buildings. Moreover, the consolidation and maintenance of modern and antique buildings is a key activity in the Italian construction sector. However, most of these activities are performed by SMEs with little experience in the use of advanced materials in this specific sector. The aim is to modernise these traditional SMEs, by developing new knowledge based construction techniques, thereby improving their competitiveness and ensuring that all relevant environmental and safety requirements are met.

Italian research lines of interest:

- smart composites for the non-destructive monitoring of structures
- innovative composites and structures for construction and retrofitting applications
- innovative materials and structures for indoor climate and energy consumption control
- innovative photocatalytic coating systems for a cleaner environment and/or with self cleaning properties
- preparation and characterization of concrete conglomerates containing industrial slag
- ultra-fine additions from natural zeolites in self-compacting concrete
- Innovative coatings and thin films coatings on metallic, glass and ceramic substrates for construction industry for improved surface properties and corrosion resistance.

Surface Modification of Materials

Cold-Plasma based technologies are emerging as systems allowing the modification of materials for many industrial applications. Virtually all materials can be modified with cold plasmas, without affecting their bulk mechanical properties, in order to obtain new performances and functions. The materials include polymers, metals, fibres, textiles, glasses, wood, etc. in the form of webs, plates, fibres, pellets, items with complex structures. Thin film coating the surfaces can modify the wetability, colour, printability, hardness, scratch properties, conductivity, adhesiveness, resistance to corrosion. This way *e.g.* anti-stain fabric and glasses can be produced, de-icing surfaces of metals, super-hard blades (films of diamond-like carbon, DLC), anti-bacterial and anti-thrombotic prostheses, colourable plastics components of cars, transparent barrier films for food packaging, corrosion-resistant metal alloys, self-cleaning materials, new membranes and filters can be produced.

Italian research lines of interest:

- cold plasma deposition of nano-films
- plasma treatments of materials
- functionalization of polymers by cold plasmas
- nanostructuring, nanolayering and nanoclustering by plasma technology
- plasma produced polymers with nano-fillers
- diamond and diamond-like carbon films via plasma and laser techniques
- transparent barrier, protective and scratch resistant coatings via plasma technology

Advanced materials technologies for functional packaging applications and films for agriculture

Packaging is one of the more important industrial sectors that directly affect the use of resources and the quality of life. In this sector, innovative renewable and recyclable materials and their ecoefficient processing are required to provide novel functional packaging solutions for a global market. Important drivers for innovation using life-cycle approaches are cost reduction, improved functionality, higher flexibility and prolonged shelf life of packaged consumer goods by improved barrier (e.g. active, antimicrobial, permselective, intelligent adaptive) performance. Smart features such as displays or sensors can be incorporated into packaging materials. Films for agriculture are also approached in this topic. The focus should be on the design and processing of innovative, renewable or recyclable packaging materials and agriculture films as well as on the interactions between different types of materials,

Italian research lines of interest:

- development of innovative light weight 3D packaging systems with improved performance (mechanical and barrier properties)
- development of high speed processes for packaging production
- use of nanocomposites for packaging with improved barrier properties
- modelling of barrier properties of innovative packaging materials and systems
- biodegradable films for food packaging
- deposition of thin transparent barrier films to improve performance of biodegradable films for food packaging
- development of new cultivation systems based on the use of biodegradable containers
- advanced recycling routes for new packaging polymers and nanocomposites
- plastomers and elastomers and nanocomposites based on recyclable polymers via synthesis and melt blending
- multifunctional nanocomposites films from renewable sources and their blends based on recyclable polymers via synthesis and melt blending

- nanostructured materials for flexible films sensible to external stimuli or chemicals for active packaging
- Films containing molecular sensors and electronic or optoelectronic systems for information recording and transfer (intelligent packaging)

Materials and technologies for cultural heritage protection

There is a noticeably interest in developing highly innovative, nondestructive and reversible techniques for the remediation and protection of cultural heritage artefacts exposed to indoor and outdoor environmental conditions. These techniques could be based on customizable nano-technologies mainly related with recent advances in plasma processing and applied on mosaics, glasses and glazed ceramics, and paintings in order to obtain long lasting duration, resistance to corrosion, abrasion, UV radiation as well as to moulds, bacteria and spores (non-fouling properties). These treatments should aim to be reversible and to produce surfaces that are free of colouring, haze, opalescence and glitter. Cold plasmas exhibit some major advantages that suit perfectly to the specific application.

Italian research lines of interest:

- customized dry process (plasma, nanocoatings) for protecting paintings, glasses and other materials for cultural heritage from humidity, environment, light radiation with transparent nanocoating free of colouring, haze, opalescence and glitter

4.2.4.5: Priority e) - The LCA approach: a selection criterion of defining eco-materials based on their environmental performance

In the last years, much concern has been expressed for the rate of depletion of the Earth's limited natural resources and shortages in the foreseeable future. These considerations lead to the conclusion that there is a need for the reduced use of raw materials and fuels by all production systems and ultimately by the consumers. In order to propose sensible changes of practices that might achieve such an objective, current consumption levels as well as emissions to the environment need to be known with some precision and this led to development of the technique now known as Life Cycle Analysis. .

Recent years have therefore seen an increasing interest in describing the performance of materials in terms of the consumption of energy and raw materials and of the emission of solid, liquid and gaseous wastes. In this context, material production systems start with raw materials in the earth and trace all industrial, transport and consumer operations until final disposal of the product at the end of its useful life and is often referred to as “cradle-to-grave”.

As a consequence of the methodology, a material “eco-compatibility” value judgement should not regard only its “natural content” but all the performances - technical and energetic/environmental - during the whole Life Cycle.

This is the reason why LCA is standardized at international level by ISO 1404X series, while an accepted procedure to evaluate an eco-material has yet to be developed.

Italian research line of interest:

- Life Cycle Engineering applied to the impact of adopting and implementing proposed material nanotechnologies.
- application of Life Cycle Analysis (LCA) to the environmental impact of innovative materials compared with traditional ones.
- definition and analysis of methods for the recycling of materials at the end of life and their environmental impact
- analysis and definition of eco-indicators for the application of LCA and LCE methodologies.

Universities, Research centres and Companies acknowledged for their participation in the Materials Technology national survey

Universities	Companies & Spin offs	Research Centers
Bocconi University	Alenia Aeronautica S.p.A	ENEA
Polytechnic University of Milan	A.P.E.Research Srl - Laboratorio Nanotecnologie, Trieste (TS)	CNR CeFSA
Polytechnic University of Turin	Avio Group SpA	CNR-ICCOM
University of Bari	Basell S.p.A.	CNR-ICIS
University of Bologna	Centro Ricerche FIAT S.C.P.A	CNR-ICTP
University of Brescia	Centro Ricerche Plast-optica srl	CNR-IFAM
University of Cagliari	CIRA Centro Italiano di Ricerche Aerospaziali	CNR-IMCB
University of Cassino	Cobarr S.p.a.	CNR-IMIP
University of Catania	Colorobbia Italia SpA.	CNR IPCF
University of Catanzaro	De Nora Tecnologie Elettrochimiche Srl	CNR IRTEC
University of Ferrara	Enel Produzione S.p.A	CNR-ISM
University of Florence	Diatech S.r.l.	CNR-ISMAC
University of Genoa	EniTecnologie S.p.A.	CNR-ISMN
University of Lecce	FABER Industrie S.p.A.	CNR-ISTEC
University of Messina	Fin-Ceramica Faenza S.r.l.	CNR-ISTM
University of Milan	Green Consultino	CNR-ITAE
University of Milan "Bicocca"	Hexion	INFM
University of Modena and Reggio Emilia	H.T.P. UNITEX	Istituto Ortopedici Rizzoli.
University of Naples “Federico II”	Lonza S.p.A	Sincrotrone-Istituto Elettra (Trieste)
University of Padua	Marazzi Gruppo Ceramiche S.p.A.	
University of Palermo	MDM S.r.l.	
University of Pavia	Meraklon S.p.A.	
University of Perugia	Novamont SpA	
University of Piemonte Orientale	Nuvera Fuel Cells Europe Srl	
University of Pisa	Piaggio Aero Industries Spa	
University of Reggio Calabria	Pirelli Labs S.p.A.	
University of Rome "La Sapienza"	Polimeri Europa	
University of Rome “Tor Vergata”	PROPLAST	**Others**
University of Salerno	PROTEC Surface Technologies S.p.A	Associazione Italiana di Ingenieria dei Materiali
University of Sassari	SACMI	Associazione Italiana Zeoliti
University of Siena	Sistema Compositi S.p.A.	Assocompositi
University of Trento	Scandolara S.p.A.	Centro Europeo per i Polimeri Nanostrutturati
University of Trieste	SO.F.TER S.p.A.	Federchimica
University of Turin	STMicroelectronics Srl	Interuniversity Consortium INSTM
University of Venice	Tecnofil Srl	Interuniversity Consortium INBB

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4.3 Reaction and Process Design

4.3.1 – Introduction

4.3.1.1 - The chemical industry in Italy.

The chemical industry in Italy has undergone a profound change over the past 10-15 years. The large Italian companies have disappeared and their plants have been sold to small companies or multinational groups. In Italy there are presently around 35 medium-size chemical industries (with over 100 Ml Euro in sales, corresponding to 23% of the overall production) and more than 1,500 small enterprises (accounting for 42% of the sales), almost all "Federchimica" members (see: www.federchimica.it). A great transformation has occurred also with respect to the location of the Italian enterprises, which are now more concentrated in northern Italy (69.2% of the production), in particular Lombardy (41.2%). The production is well balanced, being subdivided into commodities and fibres (31.5%), fine chemicals (29.4%), pharmaceutical products (25.6%), and products for public consumption (13.5%). In spite of their relatively small dimensions, Italian enterprises' R&D activity is high if compared to other manufacturing industries; it is, however, necessary to increase more and more the collaboration between these industris and public research institutions such as the CNR (National Council of Research), ENEA (an Italian alternative energy research institution), and university laboratories. Another problem for these companies – as well as for any other type of industry in Italy – is the strategic issue of the cost and availability of energy. Chemical research would therefore be strongly involved in solving this crucial problem for any kind of human activity.

4.3.1.2 – New guidelines for the research of a sustainable development in the field of Reaction and Process Design.

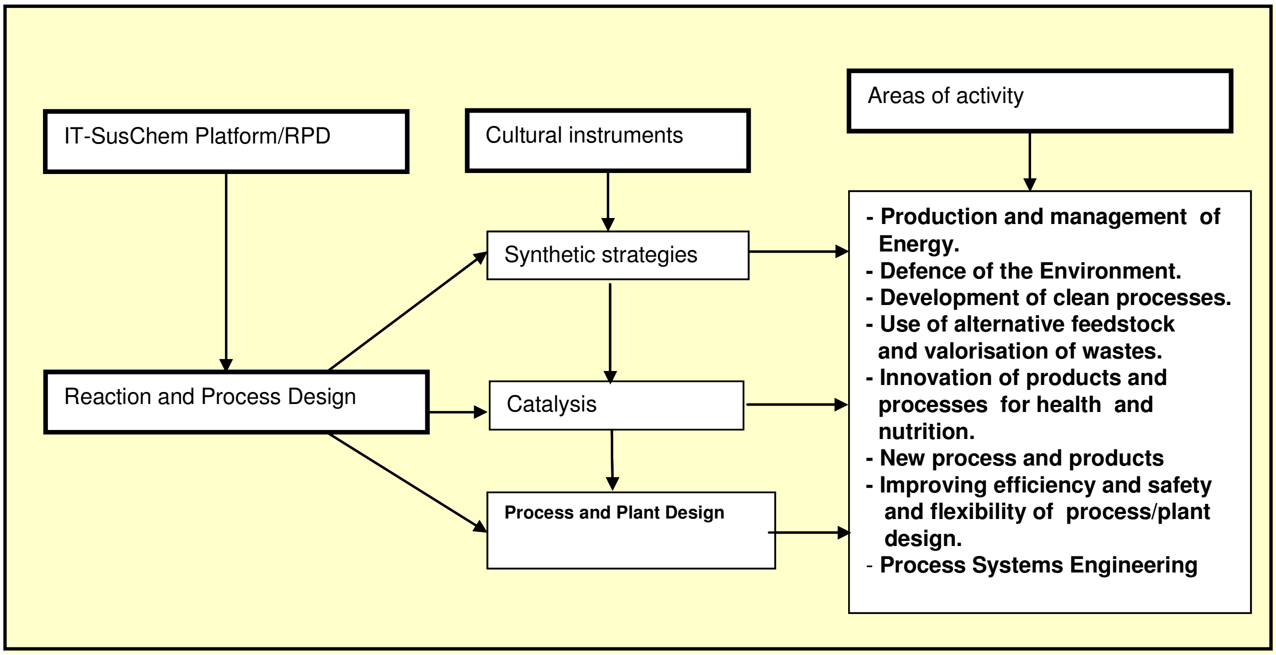
Nowadays, chemistry has a clear and important role in providing technological solutions to the many challenges which are facing developed countries in keeping their growth and competitiveness up with the pace of quickly developing economies, particularly from the Far East. The need for the development of technological processes matching the mainstays of the so-called *Sustainable Chemistry* will be a major factor in stimulating the growth of the European economy in the 21st century, by providing new opportunities that will benefit all citizens.

In spite of this general and widespread awareness, there are still too many important and large-scale processes which remain totally far from the concepts inspiring *Sustainable Chemistry*. Thus a massive flow of natural, non-renewable resources are steadily plundered from our planet every day and given back to the ecosphere in the form of economically exhausted matter. In this situation, the development of a *Sustainable Chemistry* is becoming imperative for addressing the multiform and serious problems affecting our modern technological society.

A resolute turn to the issues of Sustainable Chemistry may help to fulfil these requirements both by improving the current technologies for a more environmentally friendly use of energy, and by implementing alternative energy sources such as biomass-based resources, solar-thermal, and photovoltaic resources. The need for renewable resources for fuels and chemical feedstock is becoming a crucial topic due to: a) the decline of fossil resources (oil, natural gas, carbon) which is matched by the increased demand for oil by emerging economies, and b) political and environmental concerns over fossil fuels. In this respect, plant biomass is currently the only alternative sustainable source of organic carbon, fuels, and chemical feedstock. In particular, biofuels (fuels from biomasses) which are considered neutral as far as greenhouse effects are concerned, are expected to gradually replace fossil fuels (up to 40% by the end of 2040 in the EU). Transformation of biomasses into methanol or biodiesel fuels converts only a limited part of the total biomass (sugar, starch, or oil) into fuels. New and more efficient processes are necessary to convert a broader variety of biomasses (energy crops) into biofuels. Technologies available to transform biomasses include: pyrolysis, bio-oil refinement, gasification and Fischer Tropsch conversion. Most of these processes were developed around a century ago, in connection with the use of coal as primary resource. The need for modern, efficient and competitive processes requires an investigation of the complex chemistry involved in biomass transformation. Equally important issues to be pursued are both the study of more efficient and eco-benign technologies and the replacement of feedstocks for the chemical industry - mostly derived from fossil fuels - with renewable resources such as biomass and solar-thermal, for the short and medium/long term, respectively.

According to the European Technology Platform, the section related to "Reaction and Process Design" considers the development of products and related processes throughout their entire lifecycle. The complementary approaches of chemical synthesis, process design and engineering will be taken into account in any relevant step from the laboratory to the process plant, with the aim of introducing innovation, where possible, and of achieving a sustainable development.

As is well known, chemistry may have many interactions with human life and all the ecosystems of the environment. The social and economic impact of chemistry is impressive but not always positive. The main objective of "Sustainable Chemistry" is to save and improve the positive aspects, reducing or eliminating the negative ones. With this aim, the first important steps are to optimize the use of resources and minimize wastes and environmental impact.



This requires the obtainment of new products, new synthetic pathways, new processes and new technologies, which are more environmentally benign and address the human needs. Chemistry is also the basis for many innovations in other sectors, with beneficial effects for different manufacturing activities.

However, the main areas of activity for the Reaction and Process Design Section of the Italian Technology Platform for Sustainable Chemistry are the following:

- Products and technologies for energy management derived from alternative sources to oil, such as, for example, renewable sources.
- Products and technologies for a better safeguard of the environment.
- Improvement of active product delivery strategies for health.
- New products, new synthetic pathways, new processes and new technologies for the production of fine chemicals, pharmaceutical active principles, active ingredients for new materials and formulated products. Commodities must also be considered with the aim of studying more efficient and eco-benign technologies.
- Use of alternative feedstock, in particular renewable feedstock, and wastes used as sources for new products.
- Improvement of the efficiency of energy and water use in processes, as well as of the safety and flexibility of processes and plants.

To obtain satisfactory results in all the above-mentioned areas, it is necessary to achieve significant progress in three different cultural domains, which are: **synthetic strategies, catalysis, and process and plant design.**

A certain overlapping between synthetic strategies and catalysis cannot be avoided. The three above-mentioned cultural sectors are essential tools for all the activities of the Reaction and Process Design Sessions of the Italian Technology Platform for Sustainable Chemistry.In the development of a true *Sustainable Chemistry,* catalysis plays a pivotal role as more than 80% of all products of chemical industries are produced through catalytic processes. Catalysis is a discipline which has accomplished incredible results in the last century. However, topical problems concerning all of *Sustainable Chemistry*'s own issues have not yet been solved; thus, many conceptual advancement and technological improvements are needed to achieve better selectivity, efficiency and economy of the known processes as well as to design new catalytic cycles. A revolution in catalytic performances is expected, from the application of nanotechnologies to catalyst preparation. Also very important for the development of a *Sustainable Chemistry* is the search for new synthetic routes for reducing the number of reaction steps in the case of multistep reactions, converting stoichiometric processes into catalytic ones, and obtaining useful products from industrial waste materials.

Any new idea coming from catalysis and synthetic strategy needs to be developed at the industrial level by using chemical engineering, in order to improve the efficiency of existing processes, plant equipment and overall production systems, by promoting innovation through the development and use of more sophisticated techniques of simulation, optimization, automation and intensification.

4.3.2 - Novel Synthetic Strategies

4.3.2.1 - New reaction media.

Nowadays, reactions in unconventional media for sustainable organic synthesis focus on aqueous biphasic catalysis, supercritical media, fluorous biphasic catalysis, ionic liquids and biphasic combination. Several of these media, like fluorous and ionic liquids, allow intensified separation technologies by the selective recovery of the desired products, by-products, and catalysts in different phases, thus avoiding tedious and costly procedures which involve high volumes of organic solvents. Obviously, new systems like the previously mentioned ones need an accurate evaluation of all the requisites prescribed by Sustainable Chemistry before using them in an industrial process. The possible shift from the use of traditional organic solvents to water or supercritical systems in industrial processes is becoming more and more crucial, and several multinational companies are already extensively investigating this field. The basic idea is to identify processes of general interest that could benefit from the use of non-traditional solvents and modify them accordingly. An in-depth patent literature investigation should guarantee the possibility to protect the new processes worth being industrially developed with patent applications. The advantages of supercritical carbon dioxide as a solvent have been indicated as its low toxicity, excellent gas-like transport properties, and very high solubilizing power with numerous kinds of small apolar molecules, including gases, whereas it is a poor solvent for most other molecules. Supercritical carbon dioxide extraction of natural products from solid plant matrices is currently an established application, with over a hundred industrial facilities of various sizes operating throughout the world. Also cleaning of specific materials, such as silicon wafers in the microprocessor industry, mechanical precision parts or dry-cleaning of clothes, have gone commercial. Owing to its high critical-point parameters, working with supercritical water requires high-pressure/high-temperature technology. Problems such as the considerable metal corrosion in sc-water and salt precipitation have been holding back the full industrial-scale implementation of potentially interesting applications of sc-water for some time. Even though high-T, high-P liquid water can be regarded as just another green expanded solvent, further studies are needed. Significantly, these two green solvents, water and CO_2, can be combined in relatively mild conditions in the form of microemulsions of water in CO_2, thus opening a wide and appealing range of applications if low cost-effective surfactants become available.

Ionic liquids (ILs) can be largely used in synthesis as alternative 'solvents' to classical organic reaction media and, in various cases, can be applied with advantages such as product yields, selectivity, and recycling of the IL. These processes can be considered clean when the products are sufficiently immiscible with the IL phase and can be separated by simple decantation. Multiphase catalysis, in particular liquid-liquid biphasic catalysis involving two immiscible phases and performed in ILs, can offer the possibility of circumventing classical problems occurring with classical homogeneous and heterogeneous catalysis in the chemical industry, such as product separation, catalyst recycling, and the use of organic solvents. The association of ILs with other green fluids such as supercritical carbon dioxide, will certainly boost clean extraction/ reaction protocols and will contribute to the generation of 'sustainable' catalytic processes.

Lastly, the coupling of two or more green technologies within a single process is a better approach to sustainability than reliance on a single technological opportunity. The goal can be achieved by developing new catalytic processes in innovative reaction media, in either mono- or polyphasic systems, capable of working selectively at room temperature. By a proper combination of the catalyst and solvent structure, in principle, it is possible to pursue selectivity (meaning a minimization of waste products) at temperatures close to room temperature: this means minimizing energy consumption and, indirectly, the contribution to the green house effect, etc.

4.3.2.2 - New substrates and/or reagents

Several reactions in traditional organic chemistry require reagents which lead to large quantities of waste materials in the reaction. In this perspective, a trivial but fitting example is the use of allyl bromide for amino group allylation. In this specific case, more than 60% of the starting material is discarded as waste material, and in addition an aggressive reagent is used. Now, using allylic alcohol could produce several evident advantages such as no waste, no hydrolysis, and no special tanks for storing this starting material. Unfortunately, alcohols are not as efficient as bromide in this type of reaction. A specific study in this direction could identify the suitable catalytic system that makes this reaction sustainable. The recent evolution in the Lewis acid area is a significant exemple of the great progress achieved in moving from conventional additives, such as aluminum trichloride, to lanthanide or scandium triflates: stoichiometric reactions with excess additives have now become catalytic reactions with high atom economy, in which substoichiometric amounts of water stable Lewis acid can be recycled indefinitely.

Another way to avoid the formation of waste and increase atom efficiency is by carbonylation and carboxylation procedures using CO and CO_2. Moreover, these processes appear well-suited for exploiting methanol, which is the most important basic product deriving from carbon monoxide. They are fully suitable not only in the field of bulk chemistry but also in the field of fine chemicals and pharmaceuticals such as 'profens' and in general arylacetic acids and esters. Also, the CO and H_2 (syn-gas) system - a well-assessed building block that can be produced from natural gas, petroleum, coal and biomasses - can be engaged into the direct synthesis of alcohols from olefins though more active and selective catalysts.

The use of carbon dioxide has not yet led to important industrial processes, but it will be the subject of further studies. Efficient methods for CO_2 use as building block for C1 chemistry have not yet been developed; however, this achievement would be of paramount importance for both the reduction of the planetary global warming and the frequently invoked development of an *alcohol economy (either methanol or ethanol).* This is a very important issue, and efforts are being made to develop an efficient catalytic reduction of carbon dioxide.

To support development of new processes/products by intelligent and cost-effective testing methods/strategies, the evaluation of potentially toxic effects is necessary, with particular attention paid to priority issues as defined in REACH, e.g., *endocrine disruption.* Novel testing strategies for health effects should target *potentially vulnerable* groups, such as children (as indicated by the EU environment and Health Action Plan). Whereas the use of "conventional" toxicological testing (e.g., on rodents) cannot be fully replaced in the short/medium term, the development of such novel strategies has clear innovation requirements, which include the validation of *biotechnology-based tools*, such as "omics" approaches and sensors, as well as the development of *risk-to-benefit frameworks*.

4.3.2.3 - Introduction of alternative feedstock and novel building blocks.

The use of alternative fuels to the ones derived from oil makes available new raw materials and new building blocks derived, for example, from biomass. New syntheses can be developed starting from these new raw materials in order to obtain both new products and existing products at lower costs and with cleaner processes. Some of the most abundant chemicals on the planet that potentially have a place in fine chemical and commodities production are carbohydrates and polyphenols (lignin, residues from agroindustrial wastes and others), which represent a vast amount of biomass (in the range of hundreds of billions of tons), used by human activities only in small amounts. Despite the significant number of recent studies aimed at developing their industrial use (e.g., car mouldings, antioxidants, drugs, cosmetics, food), the systematic exploitation of this vast resource is still in its infancy. During the 1980s, a number of studies on the pyrolysis of lignocellulosic materials showed that a variety of interesting structures can be isolated from pyrolysis oils. These oils have been shown to contain heterocyclic derivatives such as 5-hydroxymethyl furfural, 2-furaldehyde (furfural), 2-methylfurfural, levoglucosenone, and levulinic acid. Consequently, there is a clear need for new and efficient technologies that effectively utilize low molecular weight compounds from lignocellulosic wastes by converting them into high-value added products in competition with classical oil chemistry. A similar strategy may be designed for organic components of other important wastes, e.g. olive oil mill, winemaking, rapeseed and sunflower wastes.

Moreover, also to be remembered is the more intensive use of coal as an energy source in power plants thanks to cleaner combustion processes based, for example, on the use of fluidized bed combustion technology. The usage of industrial and urban wastes as a raw material for new, more valuable products has both economic and environmental advantages. Examples are waste oils and fats that can be converted into biodiesel, and the possibility of re-using ash coming from coal-based combustion plants in traditional and non-traditional fields. Waste materials such as dead batteries that contain metal can be subjected to chemical treatment for the recovery of still-useful metals (commodities for national industry). Other examples are the recovery of chiral nonracemic by-products frequently discarded by the pharmaceutical industry and their transformation into valuable products.

4.3.2.4 - Reduction of the reaction steps and multicomponent reactions

The 'ideal synthesis' should lead to the desired product in as few steps as possible, in good overall yields and by using environmentally compatible reagents. In multistep synthesis, the temporal and preparation complexity increases in proportion to the number of steps in first approximation. It is reflected in many separation and purification operations, such as membrane processes, crystallization, extraction, distillation, or chromatography. Besides the multistep sequential synthesis of a target molecule, the desired product can also be obtained in one-pot reactions of a number of starting compounds. Multicomponent reactions (MCRs) are convergent reactions in which three or more starting materials react to form a product, where basically all or most of the atoms contribute to the newly formed molecule. In an MCR, a product is assembled according to a cascade of elementary chemical reactions. Thus there is a network of reaction equilibria, which all finally flow into an irreversible step yielding the product. The challenge is to conduct an MCR in such a way that the network of pre-equilibrated reactions channels into the main product and does not yield by-products. Especially thanks to their efficiency, ease of their control, and enormous number of possible products, MCRs have moved into the focus of contemporary endeavors to find new active substances in an environmentally sustainable manner and more quickly. The use of multivariate statistical instruments could be useful for novel synthetic strategies, because every single experimental result depends on many different factors which act simultaneously. In order to optimize experimental conditions, to get best results, all the occurring variables and their interactions are examined at the same time. This is possible by using the Design of Experiment (DoE) techniques. DoE techniques help the researcher plan experimental work by making different tests while changing all the factors at the same time, following a logical scheme, and obtaining the maximum information from the system being studied, with a small number of experiments. DoE techniques are useful in screening studies with many variables, in the optimization studies of different systems such as the synthetic reaction or step of an industrial process, and in finding the optimal compound or reagent composition (recipe) for the purpose studied (Mixture Design). The latter could be the keystone for facilitating the research on multicomponent reactions.

4.3.2.5 - More selective oxidation with hydrogen peroxide and/or oxygen

Stoichiometric oxidation processes, using toxic or dangerous oxidants, would be converted to catalytic processes using hydrogen peroxide and perspective oxygen, because both these oxidants are clean and non-polluting. The use of saturated hydrocarbons in place of unsaturated ones is paving the way towards the replacement, with direct oxidation processes, of the more complex processes achieved with unsaturated hydrocarbons. Butane oxidation to maleic anhydride has already been successful. Another objective is the direct enzyme-like oxidation of the terminal methyl group of saturated hydrocarbons; in the past decade, intensive research efforts in this field have led to many new oxidation systems, including biomimetic models. However, the progress towards environmentally friendly methods, which perform well in the presence of either H_2O_2 or O_2, (being highly catalytic and recyclable, selective, organic solvent-free, additive free), remains a current challenge. Catalysis is still significantly absent from industrial peroxide technologies, especially from the really large-scale processes that are found in pulp and paper manufacture, household laundering, industrial and institutional cleaning, and water disinfection, and much more is possible in environmental cleanup applications. In addition, better oxidation catalysts could contribute, among others, to the fields of commodity and specialty chemical syntheses, petroleum refining, and the decontamination of chemical and biological terrorism and warfare agents. Especially for wastewater detoxification, catalytic processes hosting multiple operating oxidation mechanisms are expected to promote an efficient degradation of the target pollutants. In this respect, photoactivated oxidations using inorganic photocatalysts and/or organic sensitizers or composite hybrids retain a major appeal.

In the fine chemical sector, an important breakthrough towards “green” oxidations has been the use of heterogeneous Ti(IV) silicalites (TS-1) as catalysts for H_2O_2 activation to effect a variety of highly interesting reactions including epoxidation of propene and other small alkenes, cyclohexanone ammoximation, the hydroxylation of aromatics and alkanes to alcohols and ketones. However, a general and efficient process for the selective production of terminal epoxides remains elusive together with the most desiderable co-reductant-free direct aerobic epoxidation. Despite the fact that water is the “ideal” solvent, catalytic systems operating in this environmentally friendly solvent are very rare and the high potential offered by the catalytic milieu of ionic liquids has yet to be explored, possibly in connection with alternative energy sources. In summary, catalyst innovation and the search for new eco-efficient processes demand a collective, multidisciplinary effort.

Finally, despite the different procedures reported in literature for the valorization of low molecular weight compounds that can be obtained from lignocellulosic wastes, little attention has been focused on their oxidative transformations, mainly in the case of low-cost, high-yield catalytic processes characterized by easy separation, purification, and efficient catalyst recovery schemes. In this case, also, the central requirement for achieving “green” transformations is the efficient activation of dioxygen and/or hydrogen peroxide with the use of novel catalysts.

Another field of interest includes selective catalytic oxidations of natural compounds such as terpenes and steroids, as well as organic molecules of interest to the pharmaceutical industry, with methyltri-oxo-rhenium in association with hydrogen peroxide or with Jacobsen catalysts.

4.3.2.6 - Special Syntheses

In the past two decades, conjugated oligomers and polymers with semiconducting properties and phosphorescent metal complexes have been considered promising substitutes for conventional inorganic materials in electronic and optoelectronic devices. The most attractive feature of these organic materials is the possibility of tuning their electronic properties by acting on the backbone structure and/or on the nature of substituents on the main chain. In this context new molecular architectures of monomers, oligomers and metal complexes may be available for high-performance applications that exploit the high versatility of the transition metal-catalyzed coupling reactions of stable and easily prepared organometallic derivatives such as silicon, boron, and tin reagents. These are examples of special syntheses. The development of these methodologies for the preparation of organic compounds of interest in electronics and optoelectronics is becoming highly challenging for the synthetic organic chemist.

Within the field of special syntheses, of significant interest would be the development of novel synthetic protocols and processes that - while providing a convenient access to functional materials for advanced applications - are also modular, wide in scope, giving very high yields, and generating by-products that can be easily removed by non-chromatographic methods. Moreover, required characteristics should include simple reaction conditions, easily removable solvents and simple product isolation. Over the past few years, some innovative metal-catalyzed processes have appeared which are based on the use of a multistep/one-pot synthetic strategy for the preparation of polymeric conjugated systems. These processes are also characterized by a “modular approach” concept. In fact, they form materials that have a backbone made of regularly alternating (different) modules with the interplaying role of impressing mechanical and functional properties to the polymer. With this strategic approach, a wide variety of conjugated materials, which display a wide range of properties, have been conveniently accessed. Compared to conventional procedures, these synthetic protocols (named *Extended One Pot-EOP*), with their multiple and sequential one-pot metal-catalyzed processes, are characterized by a very low catalyst charge load, a sizable reduction in reaction time, easy operation, and low cost. During the multi-step one-pot process, reaction intermediates are formed *in situ* by complete re-conversion of the by-products generated in the same transformation. In addition, after the formation of the polymeric materials - which are recovered by simple filtration - final by-products are easily recovered and reused to form new reagents for a successive run. Other synthetic methods based on carbon-carbon coupling reactions performed by commercially available catalytic systems are being developed for the preparation of novel conjugated polymers characterized by aryl-enyne alternating units.

4.3.2.7 - New means for energy input

Microwave irradiation (MWI) has become an established tool in organic synthesis, because of the rate enhancement, higher yield and often improved selectivity compared to conventional reaction conditions. There are several advantages when performing synthesis under microwave activation: short reaction time with energy savings; increased safety because the reaction is normally performed in milder conditions; economic and environmental advantages, because the reaction can be carried out in the absence of solvents. The use of MWI has become a common practice in the laboratory because organic synthesis performed with traditional methods requires a very long time and high temperatures. In other words, MWI is a useful tool for pursuing new synthetic strategies for laboratories. However, this very promising technique has some drawbacks, such as the high cost of the equipment and the difficulty in scaling-up. As a matter of fact, the volumes used in the laboratory for this technique are 1-5 cm^3 and no examples of industrial application are reported. The removal of the above-mentioned drawbacks would be a big step forward for the chemical industry.

Radiation processing makes use of ionizing radiation for chemical synthesis, and can be considered an alternative to other chemical processes. It can be considered an energy-saving and, in general, environmentally friendly process, thanks to the possibility of operating at low temperatures without solvents. Furthermore, generally speaking, no reaction initiators are needed, with positive consequences on the purity of the obtained products. This latter behaviour makes radiation processes strongly competitive when high--purity products are required, such as for pharmaceutical and biomedical applications. Also, it should be mentioned that this process can be controlled very easily through the control of the processing parameters, dose rate and total absorbed dose, which determine the kinetics and the completeness of the reactions, respectively.

The ability to build structures with nanometric precision is a very important characteristic of radiation processing. Nanofabrication involves nanolithography with nanopatterning, due to the small wavelength of the beam. Other studies concern the formation and synthesis of nanostructures, formed both by metallic or polymeric nanoparticles. Some examples are the radiation synthesis of nanoparticles of inorganic materials as copper, silver and other metals, as well as of polymers for the incorporation of active principles for drug delivery.

The use of plasma technology or light to trigger some reactions sometime produces exceptional results in the laboratory, but the difficult scale-up is still a problem. Similarly, in the activation of chemical bonds by means of photochemistry there are excellent premises for the promotion of organic reactions in the absence of any catalytic system, even though the serious problem concerning scaling-up remains unchanged.

4.3.2.8 - Conversion of batch processes to more intense continuous processes

Normally, fine chemicals and pharmaceutical active principles are produced in batch conditions as a consequence of the low production volume. It is well known that batch operations have lower performances than continuous devices. It can be useful, therefore, to consider the possibility of converting existing batch processes into small, more efficient continuous processes, also looking into the possible use of a unique plant, with a modular structure, for different productions (multipurpose continuous plant). Miniaturization and standardization of the unit operations, as modular systems, make it possible both to save energy and to operate more safely, simplifying the implementation of chemical plants. In the context of the development of continuous processes, the microreactor technique is offering a fast lane to optimizing processes either in the cases where unstable reactions or high exothermic/hazardous reactions (scale-up impossible for safety reasons) are involved or when products are formed which are unstable under applied reaction conditions. The already-achieved development and production of up to 5 kg of final product through microreactor tecnology envisages an environmentally safe revolution focused on improved yield and better safety for fine chemicals and pharmaceutical industries in the near future.

4.3.3 - New Catalysts for New Products and Processes

As already mentioned, catalysis is of paramount importance in order to reach the objectives of Sustainable Chemistry, because an appropriate catalyst makes it possible to selectively promote a specific reaction and obtain the desired product within a reasonable time. In catalyst preparation, the main focus must be the efficiency and specificity of the reaction in order to minimize as much by-products as possible and to maximize the yield. In this perspective, homogeneous catalysts would be more suitable than heterogeneous catalysts, as a consequence of the molecular dispersion. Unfortunately, it is difficult and expensive to recover and reuse homogeneous catalysts and the contamination of the final product with heavy metals is also a disadvantage. For these reasons, the use of heterogeneous catalysts is normally preferred in industry. Methods for heterogenizing homogeneous catalysts by grafting them onto the surface of a support which is characterized by high activity and selectivity have been developed, but this still remains a big challenge.

Sustainable Chemistry needs new and more efficient catalysts (homogeneous, heterogeneous and heterogenized) and biocatalysts for new reactions and new products. Lastly, it is interesting to observe that the characteristics of the used catalysts, together with the existence of a multiphase system, strongly affect the type of reactor to be used and the reaction procedure, either in the laboratory or in the industrial plant. The presence of different phases – that is, gas-liquid, liquid-liquid, gas-liquid-solid and gas-solid – makes it necessary to maximize the interphase surface area, in order to achieve reasonable mass and heat transfer rates. The process design and development requires a chemical engineering approach at all scale levels, from laboratory to pilot and industrial plant.

4.3.3.1 - New highly efficient catalytic systems for the production of fine chemicals, pharmaceutical products and commodities with clean processes.

Two different R&D frontier problems deal with the need to design innovative catalysts for the production of fine chemicals, pharmaceuticals and bulk commodities. A common facet of these projects is that both are aimed at exploring new reaction pathways and conditions, by reducing the number of reaction steps, introducing intensified separation technologies and increasing energy savings. The improvement of a catalytic process in term of efficiency and selectivity (regio-, stereo- and enantio-) will be the most important deliverable of these research lines to be pursued through the use of either new specialized homogeneous catalysts or innovative heterogeneous systems specifically tailored to the nanoscale level. Issues actively pursued in these strategic areas also deal with the reduction of energy and resource requirements, the study of more efficient products, and the atom economization of the process with the aim of greatly reducing or eliminating waste formation (for example the use of benign and easy-to-handle oxidants). In the development of sustainable chemical transformations, the discovery of new efficient synthetic methods, especially for carbon-carbon bond formation, remains a great challenge.

4.3.3.2 - Metal mediated processes.

The study and development of new catalytic methods for the formation of complex molecules, based on the use of mono- or bi-metallic catalysts or mixtures, is very important, particularly for the pharmaceutical industry where complex molecules have to be handled. An important challenge in this field will be the design, synthesis and characterization of novel chelating N-donor ligands and of their corresponding Palladium (II) and Rhodium complexes as potential catalysts. Among many others, the application to an important process such as the oxidative carbonylation of phenols or bis-phenols to aryl carbonates or polycarbonates could be envisaged. Aromatic polycarbonates (PCs) are one of the most useful engineering plastics because of their good heat resistance, mechanical properties, and transparency. Market growth for aromatic polycarbonates has been almost 10% a year from the late 1990s. Recently developed effective catalytic systems for the direct synthesis of aromatic carbonates and polycarbonates consist of palladium(II) complexes with N,N'-carbene chelating ligands and with disubstituted-2,2'-bipyridyl ligands. It has recently been shown that even non-resonant bioxazolyl ligands are highly efficient and that increasing hindrance in positions adjacent to N-donor atoms of chelating ligands, such as bis-oxazolynes and N,N'-carbene ligands, affords higher TON of diphenyl carbonate (DPC). In this respect, there is a lack of knowledge about the influence of different anionic or neutral chelating donor ligands on the catalyzed manufacture of aromatic carbonates and polycarbonates. It could be interesting to investigate both the possibility of tuning the steric and electronic features of ligands and the catalytic properties of new palladium complexes containing new N-donor such as those indicated here.

A special attention should be devoted to the synthesis and structural characterization of Pd and Rh complexes, which are precursors of catalytic processes, mainly of C-C coupling of Heck, Suzuki, Sonogashira type, as well as to the detailed study of their catalytic and small-molecule activation properties. It is expected that N-coordinating ligands (for example imidazoles) will create proper coordination spheres of metals to achieve high activity compared to aryl halides, which are substrates of C-C coupling. This project could make it possible to elaborate new synthetic methods following green chemistry rules for the preparation of fine chemicals, pharmaceuticals and other materials such as conducting polymers. Lastly, possible synergic effects in the use of bimetallic catalysts or mixtures of catalysts and the replacement of the traditional metals with non-toxic and inexpensive metals like Cu and Fe in the coupling reactions deserve more general and deeper investigations.

4.3.3.3 - Asymmetric Catalysis.

There is an increasing demand for enantiopure chiral compounds to be used not only for pharmaceuticals but also for agrochemicals, flavours and fragrances, and specialty materials. This is due both to the knowledge that two enantiomers of a chiral substrate could show very different biological activities and to new regulations which will no longer allow the use of racemic mixtures. Among the different methods for producing enantiopure or enantioenriched compounds, enantioselective catalysis has proved to be quite useful. Exciting discoveries in the field of β- and γ-peptides have recently provided impetus for the development of new synthetic methodologies for the preparation of β- and γ-amino acids, the study of which has been very limited up to the past few years. The use of such amino acids for biomedical applications appears to be especially interesting as, for example, the incorporation of even isolated β-amino acid into α-peptides appears to protect against peptide degradation. Moreover, conformationally constrained amino acids such as cyclopropane-, cyclobutane-, cyclopentane-, and heterocycle-β- and γ-amino acids are especially appealing for the synthesis of foldamers, oligomers which adopt specific conformations. Such oligomers are useful both for the comprehension of the forces responsible for molecolar folding in natural systems, such as proteins, and for their potential application in medicinal chemistry as well as in synthetic organic chemistry as building blocks, ligands and catalysts in asymmetric synthesis. Therefore, investigations concerning catalytic methods for the preparation of this class of amino acids seem to be particularly stimulating.

4.3.3.4 - Organocatalysis.

This can be considered as based on an enzyme-like catalysis mediated by small organic molecules, which have become extremely significant over the last few years. Their benefits include not only atom economy and simplicity, but also the possibility of performing homogeneous asymmetric catalysis in the absence of any metal. Notably, preparation advantages are that usually the reactions can be performed under aerobic atmosphere with wet solvents and the catalysts are inexpensive and often more stable than enzymes or other bioorganic molecules. These non-metallic organocatalysts have been recently demonstrated to make possible environmentally benign synthetic reaction processes; they have been used in the large-scale synthesis of useful compounds, in particular natural and unnatural aminoacids and peptides for pharmaceutical purposes, including L-Dopa, L-Azatyrosine, ACE- inhibitors which are hitherto difficult to obtain by previous industrial processes. These chiral organocatalysts, some of them highly active with a catalyst load of 0.01% mol, are already commercially available, and have attracted considerable attention from the industrial world, mainly because about 20% of the top 500 drugs contain amino acids and their derivatives. The opportunity for organocatalysts to be produced from sustainable biomass-derived chemicals (platform molecules) has been highlighted recently within the framework of the 'First International Symposium on Organocatalysis in Organic Synthesis' held in Glasgow, Scotland, on July 2006.

Besides the recent significant achievements of organocatalysis based on the use of fairly simple molecules, there is a considerable need to expand the research for the development of more complex organocatalysts that have multifunctional sites and elaborate stereochemistries. Although their initial syntheses can in some instances pose challenges, such catalysts can become economically viable if they can be recycled and if they are highly efficient. Relatively complex tailor-made macrocyclic compounds, molecular clefts and multi-component supramolecular assemblies, if they bind reagents and/or transition states, can offer a means to fine-tune reaction pathways leading from certain substrates to specific target compounds. For example, the complexation of anionic intermediates and/or transition states with appropriate molecular receptors could allow the action of natural enzymes such as aldolases to be mimicked. Indeed, the potential of synthetic molecular receptors designed to function as enzyme analogues, although pioneered by a number of researchers worldwide, is still vastly unexplored and mostly unexploited.

4.3.3.5 - Future issues in catalysis.

Further research is needed for the development of new catalysts and new ligands for asymmetric reactions of hydrogenation, oxidation, carbonylation, hydroformylation and in general of C-C coupling reactions to be applied not only to simple reactions but also to substrates of commercial interest. Also useful for synthetic applications are heterogeneous metallic catalysts modified with chiral auxiliaries, the use of chiral organic compounds (organocatalysis, see above) and biocatalysts (overlapping with industrial biotechnology). Another hot research topic in this sector refers to the catalytic activation/functionalization of the C-H bond both of the alkanes and of the aromatic molecules which could lead to a breakthrough in both bulk and fine chemistry. Examples are the direct oxidation of methane to methanol and of benzene to phenol or, in the absence of oxygen, the C-C coupling reactions. Also, the direct functionalization of the aromatic and hetero-aromatic rings with easily recoverable acid catalysts is of great importance for both bulk and fine chemistry.

Lastly, as far as the production of commodities is concerned, a new generation of more active and selective catalysts in milder conditions must be found. New techniques for a more dispersed catalyst preparation, a fast screening of the catalytic performances, and catalyst characterization are required. Progress is necessary for all kinds of heterogeneous catalysts, for example: both Brönsted and Lewis type acid-base catalysts , zeolite catalysts, redox catalysts based on the use of more dispersed transition metal oxides, semiconductor oxides, well-dispersed metal catalysts, and bi-functional or multi-functional catalysts. Computational approaches could be used with the aim of both explaining the reaction mechanism and improving the catalyst performance.

4.3.3.2 - Catalysis both for the production and management of sustainable energy and for sustainable transportation (mobility).

Great amounts of energy are consumed by the chemical industry (about 20% of the energy consumed by all the manufacturing industries). In Italy today, most of this energy is imported, often from politically unstable countries. Chemical industries are highly interested in the development of energy-saving technologies. Besides, these new technologies could be used also in other industries, and chemistry could play a leading role in a more rational production, storage and use of energy. Therefore, all the efforts aiming at reducing energy consumption and decreasing the dependence on oil and other non-renewable fossil sources of chemical production are strategic issues which will be substantiated by seeking alternative feedstock based on natural resources, in order to replace fossil fuels. Efforts are focusing on implementing the methods of biomass exploitation (bioethanol, vegetable oils, etc.).

In this respect critical points are:

Bio-Oil Upgrading - The pyrolysis of biomasses produces bio-oils, which must be upgraded in order to replace traditional diesel and gasoline fuels. Indeed, bio-oils have some negative properties (low heating value, incompatibility with conventional fuels, solid contents, high viscosity, incomplete volatility, and chemical instability) which need to be removed or reduced. Upgrading is necessary to eliminate the negative properties of bio-oils. Several procedures are available, the most promising of which are hydrodeoxygenation with hydrotreating catalysts (e.g. CoMo or NiMo sulfides) and zeolite upgrading. Alternatively, bio-oils and chars can be converted into syn-gas by steam-reforming and, consequentely into hydrocarbon fuels through the Fischer-Tropsch process.

Syn-gas and Fischer-Tropsch synthesis - Fischer-Tropsch synthesis (FTS) is an industrial process for producing alkanes from syn-gas using Co-, Fe-, or Ru-based catalysts. This technology was first developed in the early 1900s and used by Germany during the 1930s and 1940s to produce liquid fuels from syn-gas derived from coal. FTS received much attention during periods of oil shortage (in the seventies) and several oil companies are currently using or building FTS units to produce liquid fuels (e.g. in South Africa and Malaysia). The products from FTS are a range of mostly straight-chain alkanes ranging from C1 to C50. The lack of selectivity remains a major limit, in spite of the continuous effort to modify the catalytic properties to tune the product selectivity. Organometallic di- and polynuclear complexes have offered interesting models for investigating the fundamental steps in FTS synthesis, but a homogeneous catalytic approach appears still far from being successful. The shift from oil to alternative sources, including biomasses, to produce liquid fuels requires substantial progress in the current FTS technologies, and the use of new and more efficient catalytic systems.

An important role is attributed to the replacement of oil with less costly and more abundant hydrocarbon sources, such as gas and coal. The more efficient and less polluting conversion of such fuels can be achieved through catalytic combustion. This process allows burning the hydrocarbons at much lower temperatures than with homogeneous combustion, thus decreasing or virtually eliminating NOx emissions. Moreover, the catalyst pushes the reaction towards complete oxidation, thus avoiding the emission of CO and partially unburnt hydrocarbons. This technology can be successfully applied in stationary power generation plants, where very high efficiency can be obtained through catalytic combustion in gas turbines with co-generation plant schemes; moreover, it can be applied in more restricted application areas, such as domestic heating, thus achieving a better control of noxious emissions.

The improvement of well- known processes such as the Fischer-Tropsch synthesis of a liquid fuel from syn-gas - which is similar to the diesel fuel from petroleum or the Mobil process to obtain gasoline from methanol, the latter easily obtainable from syn-gas - is fundamental for reducing the dependence on petroleum. Syn-gas represents the intermediate step for obtaining both hydrogen and methanol, which, in perspective, are considered the most important energy vectors.

Production of hydrogen and biofuels - Hydrogen can also be obtained from different procedures such as methanol/ethanol steam reforming, thermochemical processes based on the use of solar energy like solar-powered reforming natural gas, and thermochemical or photoelectrocatalytic water-splitting cycles. The photoelectrocatalytic splitting of water into hydrogen and oxygen is the most fundamental and important stoichiometric reaction in artificial photosynthesis, because it has great potential for the direct conversion of solar energy into chemical energy and provides a clean, renewable source of hydrogen fuel from water. Indeed, among the various methods of solar energy conversion, the best results were achieved with semiconductors as photosensitizers. The development of an efficient artificial photosynthesis system for energy conversion by irradiation is mandatory from the standpoint of efficient solar energy exploitation.

If successfully developed with economic viability, this would be the ultimate technology that could solve simultaneously both energy and environmental problems in the future.

The development of catalytic process technology for both on-site and large-scale centralized efficient production of hydrogen is one objective. Therefore, new materials for hydrogen production, storage and purification are required. In particular, the storage capabilities of gaseous molecules such as hydrogen must be improved by novel hybrid organic-inorganic materials, porous metal organic frameworks, and mesoporous oxides. Membranes with selective permeability to hydrogen must also be developed to reach high standards of gas purity compatible with its usage in stationary and mobile hydrogen fuel cells.

The relevant increase of the share of gasoil-driven vehicles in latest years, in Italy and all over Europe as well, has pushed the development of new technologies aimed at the production of gasoil from renewables sources. The production of biodiesel by means of the transterification of vegetable oils and animal fats requires new and more efficient catalysts and opens the way to the production of chemicals starting from the by-products that are obtained in these processes such as, for example, glycerol which is a by-product of biodiesel. An alternative approach for the production of Green Diesel includes the concomitant hydrodeoxygenation, decarboxylation and hydroisomerization of vegetable oils, to produce a high quality gasoil, readily blendable with the traditional diesel fuel, plus hydrogen at mild reaction conditions.

As already mentioned, efficient methods for the use of CO_2 as a building block for C1 chemistry have not yet been developed. This is a very important issue and efforts are being made to achieve an efficient reduction of carbon dioxide through catalytic or chemical looping-based processes.

Fuel Cells - Catalytic processes operating within fuel cells, especially concerning the conversion efficiency, fuel versatility, resistance to poisons, transport within the cell, lifetime of the device, and economics of fuel cell manufacture, must be strongly improved for a large-scale commercial availability of these devices to be achieved. This represents an essential part of the exploitation strategy for transport and portable applications of fuel cells. One of the largest hurdles encountered in the development and production of fuel cells is the shortage of platinum, which is a very rare and highly expensive noble metal used as an efficient electro-catalyst for the reduction of either hydrogen or alternative fuels in the cell. In the future, fuel cells will play an important role in ensuring the mobility of vehicles and electrical devices (laptops, mobile phones, etc.) only if platinum will be completely (or almost completely) replaced by less expensive and more abundant metals. One of the main goals of this project is the replacement of platinum with nanostructured metal aggregates or alloys, mainly containing cheap and abundant metals like iron, cobalt or nickel. Research targets will also be the development of innovative membranes which may be used to selectively transport protons or anions between segments of the fuel cell. New catalysis processes should also be developed to further increase the removal efficiency of pollutants from vehicle exhaust. Such technologies are needed in order to match future emission regulations targeting a zero-emission goal.

4.4.3.3 - Catalysis and other strategies for environmental protection

One of the main purposes of “Sustainable Chemistry” is to minimize wastes and environmental impact. These objectives can be reached, first of all, by detecting more selective catalysts and devising “increasingly cleaner processes”. However, new process technologies for the maximum removal of any possible pollutant from the waste streams, including waste process water (Advanced Oxidation Processes) and fuel gases, automobile exhausts and sewage effluents, are necessary, and they will include methods which combine catalytic and separation techniques. A valorization of waste streams that contain organic pollutants will also be attempted, for example through the development of photocatalytic processes which enable both the contemporary production of hydrogen and the removal of organic substances. Recalcitrant organic molecules such as azoic colorants that could be present in leather tanning waste waters, can be destroyed by deep oxidation processes performed - for example - with heterogeneous photocatalytic processes. Cold plasma techniques can also be improved for organic pollutant destruction.

4.4.3.3.1 - Advanced Oxidation Processes for water remediation

Water shortage and security are major worldwide issues due to water-intensive lifestyles, rapid industrialization, and agricultural intensification. The current state of the art in water remediation is represented by a group of Advanced Oxidation Processes (AOPs). All these processes exploit free radical-mediated reactions to decompose hazardous compounds, basing their action on the oxidant and kinetic properties of the OH radical. Applications count on an established know-how of the OH-initiated degradation of various pollutants (halo-compounds, phenols, polychlorinated biphenyls (PCBs), aromatics, azocompounds, etc.), conducted by means of both time-proven methods like pulse radiolysis and flash photolysis, and steady state electrochemical, sonochemical, plasma discharge, and Fenton-like methods. Further studies in this field should focus on a series of persistent organic pollutants (POPs), like dioxins and furans (PCDD/PCDF), PCBs, hydrochlorobenzene (HCB) and polyaromatic hydrocarbons (PAHs), as outlined by the UN Stockholm Convention. New pollutants, particularly those from the pharmaceutical industry, deserve careful consideration.

Among a variety of AOPs, the E-beam method represents the most efficient remediation process. In fact, a) it can accomplish the production of very high concentrations of oxidizing radicals in microseconds, b) it makes it possible to control the decomposition degree of organic compounds up to their complete mineralization, and c) it destroys bio-resistant pollutants, thus being the ideal pre-treatment for a conventional biodegradation. Additional benefits with respect to conventional treatments are: a) no need for chemical additives, b) minimization of the stock of chemicals, c) operation at room temperature, d) penetration into the bulk of water even in the case of turbidity (not possible with light irradiation), and e) disinfection. Therefore, it accomplishes several environmental tasks simultaneously: a) depollution (mineralization of organics, removal of odors and colors), b) water disinfection, c) destruction of endocrine disrupters, and d) rapid action. The E-beam remediation is economically advantageous for the treatment of medium-large volumes of effluents from dye, textile, and paper mill industries, hospitals, public utilities and animal-breeding plants. It aims at rehabilitating wastewaters to new uses, some of which are firefighting, street washing, park watering and horticultural irrigation, industrial cooling and washing cycles. Today, a full-scale plant in Korea confirms the feasibility and financial convenience of the method.

Therefore, both the process optimization and the development of rehabilitation plants implementing the AOPs - and particularly the E-beam for large effluent volumes - constitute one 21st-century challenge for environmental processing and engineering.

4.4.3.3.1 - Nanotechnology in pollution prevention and remediation

Nanoscale science offers great promises for the delivery of new and improved environmental technologies. Nanotechnology can substantially enhance environmental quality and sustainability through pollution prevention, treatment, and remediation.

Environmental technologies can greatly benefit from an understanding of chemical properties at the nanoscale level. In particular, two broad application areas can be taken into account:

Pollution prevention / Nanostructured catalysts, for example, can make chemical manufacturing more efficient by providing higher selectivity for desired reaction products. The assemblage of nanostructures from biopolymers or bio-inspired materials is an example of an environmentally benign approach to fabricating microelectronics. Nanotechnology applications could also help to create benign substances that replace currently used toxic materials. For example, nontoxic, energy-efficient computer monitors are replacing those made with cathode ray tubes (CRT), which contain many toxic materials.

Treatment and remediation / Nanoparticles of various oxidants, reductants, and nutrients have been suggested as useful for both promoting contaminant transformation and stimulating microbial growth. Nanoscale bimetallic particles essentially eliminate all the undesirable by-products given off by conventional methods (e.g., bioremediation and zero-valent iron) for the in situ remediation of chlorinated organic solvents. Nanoparticles that are activated by light, such as the large band-gap semiconductors titanium dioxide (TiO_2) and zinc oxide (ZnO) - which are readily available, inexpensive, and of low toxicity - remove organic contaminants from various media. Nanoparticles could provide enormous flexibility for in situ remediation as well. For example, nanoparticles are easily deployed in ex situ slurry reactors for the treatment of contaminated soils, sediments, and solid wastes. Alternatively, they can be anchored onto a solid matrix such as carbon, zeolite, or membrane for the enhanced treatment of water, wastewater, or gaseous process streams.

Methods - The new functionalities shown by nanomaterials originate from the fact that nanoscale materials have unique structures (large surface area, small size or shape, and intimate nanoscale connectivity). These structures cannot be extrapolated from our understanding of traditional bulk materials that have been routinely used in daily life.

The experimental search for new materials suffers from a slow feedback from theoretical models and computational simulations for understanding and improving nanomaterial synthesis. In other words, the potentials of theoretical and computational tools for the design of materials with enhanced nanoscale properties have not been explored thoroughly.

This exploration can be accomplished efficiently through the development of computational methods for the search for novel materials, thereby limiting the space for experimental research.

Therefore, synthesis is a key step in what should be a tightly connected loop of synthesis, characterization, theory/modelling/simulation and design. This loop can be repeated over and over until objectives have been reached.

4.3.4 - Synthesis and Characterization of Nanosystems

Over the past few years, an increasing interest has been focused on the fabrication and study of inorganic nanocrystals, namely semiconductor, oxide and metal nanoparticles. The physical properties of such crystalline nanoclusters appear to be intermediate between those of bulk matter and of molecular systems, which are composed of just a few atoms, and are strongly dependent on their size and shape. Inorganic nanocrystals possess unique optical, electronic and magnetic behaviour that can be potentially modulated by varying the size and shape of the nanocrystals. In this field there is a clear fundamental interest boosted by the understanding of basic physical processes, but there is also a growing awareness of the potential applications of such nanocrystals as active materials in optoelectronic devices and sensing materials for biomedical and environmental purposes.

The development of such novel materials designed for specific purposes requires:

1. Setting up of scientific protocols for the implementation of colloidal nanocrystal preparation in order to have access to different types of materials with great control over size and shape as well as for nanocrystal processing, in order to modify their surface by exchanging organic capping molecules and/or growing inorganic epitaxial layers (core-shell structures).
2. Theoretical/computational characterization of nanocrystals at the structural, spectroscopic and dynamic levels
3. Conversion of processed nanocrystals into functional nano-structured materials by organizing them as building blocks into higher ordered hierarchical systems.
4. Modelling of nanostructures

4.3.4.1 - Nanoparticle synthesis, functionalization and processing

Synthesis of semiconductors (CdSe, CdS, ZnS, ZnSe), oxides (ZnO, TiO_2), metals (Au, Ag), and magnetic material as metal transition and rare earth oxide nanocrystals will be performed by colloidal chemistry methods. The preparation of nanocrystals with core-shell structures can be also performed (CdSe@ZnS and CdS@SiO_2).

The possibility of manipulating prepared nanocrystals by properly engineering their surface through capping exchange is very significant. The prepared inorganic nanocrystals can be coated with a monolayer of surfactant, rendering the nanocrystal hydrophobic. The surfactant exchange makes it possible to tune the solubility and the reactivity of nanocrystal, and thus place them in almost any chemical environment. Moreover, it is possible to functionalize the nanocrystal surface through a suitable choice of the capping agent, thus conferring specific chemical reactivity to the nanocrystal. Nanocrystals are really a new class of chemical macromolecules, and the inorganic component of materials can be organized by using the well-established principles and techniques of synthetic organic chemistry and molecular biology. Different possible strategies need to be exploited to build 3D nanostructures while taking advantage of the combined directed nanoparticle self-organization and new surface patterning techniques.

In order to optimize the synthetic conditions in terms of shape and size distribution, models simulating nanocrystal formation in different experimental conditions will be designed.

4.3.4.2 - Modelling and design of building blocks for nanostructured materials

Combined expertise is needed in a wide range of theoretical approaches and computational techniques which are instrumental for providing insight into nanoscale experimental measurements, understanding functions, virtually characterizing new materials, quantifying transport mechanism (including electron transport) on the nanoscale, predicting self-assembly, and designing and virtually synthesizing new materials.

The basic goals for any significant in-silico activity in the field are:

- To bridge a wide range of length and time scales, so that the phenomena captured in atomistic simulations can be modelled on the nanoscale and beyond.
- To develop new force fields for molecular dynamics methods and other classical, particle-based methods, which are capable of describing nano-interfaces between dissimilar materials
- To develop rigorous methods for the inclusion of stochastic effects as well as more effective methods for the characterization and solution of stochastic differential equations which are necessary in the upscaling
- To extend theoretical approaches for the analysis of high-resolution and single-molecule spectroscopies used to probe the molecular-level mechanism of energy-producing and energy-using processes.
- To improve the quantitative reliability of electronic structure algorithms in order to handle ground and electronically excited states.
- To improve our understanding of both intermolecular interactions and how to model them efficiently, accurately, and realistically in large ensembles.
- To predict the self-assembly of nanoscale building blocks by evaluating the relative contributions of various interactions, including dispersion forces, hydrogen bonding.
- To discover strategies for dealing with the “inverse problem,” where the composition and structure of a new material are designed to express a desired property.

4.3.4.3 - Conversion of processed nanocrystals into functional nano-structured materials - Nanocomposites

Significant interest in material science is devoted to the development of novel materials based on polymer modification by means of nanoparticles. In fact, there is a real possibility to modify/add new peculiar properties to polymers (for example, electrical conductivity, photoactivity, luminescence, catalytic and magnetic properties), while maintaining and improving their processing capabilities and mechanical properties. Hybrid materials consisting of nanoparticles in polymer matrices represent a novel class of nanostructured systems that are potentially able to surpass the performances of classic materials, by accessing new properties and exploiting unique synergisms among substances. The combination of polymer and nanoparticle offers opportunities for tuning the physical properties of the final materials for electronic, photonic and biological issues which can be exploited in optoelectronic, sensing and biomedical domains. In addition to the incorporation process, the local deposition and positioning of NCs by means of block copolymer, 2/3D organization of NC in polymers can be exploited.

Inorganic/biological nanostructures

Metal and semiconductor nanoparticles are of great interest not only for their new and original properties which are generated by their reduced dimensions, but also for their dimensional affinity with biological macromolecules (peptides, proteins, nucleic acids, etc.) This affinity makes possible an integration between nanotechnology and biology, with consequent progress in new material assembling, which can find applications in the sensor, biological labelling, and medical diagnostics fields. Wate-soluble colloidal nanocrystals are essential in light of their bio-conjugation with proteins for biological applications. Colloidal nanocrystals have a number of peculiar advantages over the organic dyes that are conventionally used in optical bio-detection. Indeed, their wide absorption spectrum, coupled with their extinction cross-section, makes it possible to excite different luminescent nanoparticles with different sizes using a single excitation wavelength.

Nanocrystals for photocatalysis

The photocatalytic degradation of organic pollutants assisted by seminconductors (TiO_2 and ZnO) represents one of the most appealing techniques among the Advanced Oxidation Processes (AOPs). Improved charge separation and inhibition of charge carrier recombination is essential in enhancing the overall quantum efficiency of the photodegradation process. Nanocrystalline semiconductor photocatalysts offer an interesting way to increase the efficiency of a photocatalytic process by both increasing the charge separation and extending the energy range of photo-excitation for the system.

A significant advancement is provided by the possibility of synthetizing nanostructured materials with high photocatalytic activity and different chemical composition (TiO_2, TiO_2/CdS), which are effective in the degradation of organic pollutants. Supported systems can also be developed in order to set up degradation processes (e.g. deposition of nanostructured material onto glass, glass fibre, and alumina fibre), in order to overcome the technological and economic drawbacks connected with catalyst recovery in the case of slurries.

Nanocrystals for energy conversion

Hetero-junctions composed of nanostructured semiconductor/organic molecules can be prepared using TiO_2, ZnO semiconductor nanocrystals and organic pigments such as chlorophylls, porphyrins and phthalocyanines. These large band-gap semiconductors need to be associated with molecules that absorb light in the visible range of the solar spectrum and give rise to a charge transfer on the surface. The reduced nanocrystal dimension results in a great surface extension of the nanosized semiconductor film, thus enhancing the energy transfer efficiency. The use of sensitizers modifies the surface of semiconductor materials, making them suitable for photoelectrochemical applications in the visible range.

4.3.4.4 - Modelling of nanostructures

The development of physical-chemical models suitable for interpreting the behaviour of the molecular and supramolecular systems and their transformation into silico procedures, by modifying and optimizing existing general processes, is a significant problem for the study of nanosystems in connection with environmental impact and energy conversion research efforts.

In principle, information concerning self-assembling processes and the resultant superlattices of nanoparticles is encoded in such molecular components as the nanocrystallite core, surfactant chain, solvent, and solid substrate. Simulated molecular dynamics can be used to investigate the energetics, dynamics, kinetics, and structural properties of nanoparticles and their self-assemblies under selected conditions representing different self-assembling stages.

Nanoparticles in polymer hosts are described by adapting coarse-grained simulation techniques to describe the translational dynamics of a semi-rigid core and chain conformational motions.

Suitable theoretical models can be developed with the aim of describing energy, geometrical structure and electronic properties of organic molecules adsorbed on crystals or nanocrystals. Few models exist that explicitly treat hybrid systems (molecules/surfaces), thus a new computational strategy is necessary in order to include the solvent effect in the calculations of energies, structures and properties, also extending this approach to spatially anisotropic solutions. Such an approach, for instance, is ideally suitable for describing large size molecules (e.g. derivatized porphyrins) in interfaces (liquid/solid surface), and also supramolecular systems.

4.3.5 - Process and Plant Design

In the near future, chemical productions will focus on completely new fields. New plants will be designed and operated to produce pharmaceuticals, nanoparticles, and food specialities; their design will involve knowledge and expertise in very specific areas. In this framework, multidisciplinary collaborations among chemical engineers, physicians, chemists and biologists will be unavoidable. Moreover, the processes of sustainable chemistry will produce minimum amounts of wastes or no waste at all; they will be safe and energy-saving in order to protect the environment and make up for the shortage of carbon-based fuel in the Western developed countries.

4.3.5.1 - New processes for alternative fuels and energy sources.

The interest in hydrogen as a clean fuel has been recently increasing. Hydrogen produces only water when it burns, and can be efficiently used in fuel cells; therefore, it has a great chance of being the replacement for carbon-based fuels in the near future. The anticipation of this transition has been so great that the future vision for hydrogen power has been labelled by the scientific community as the "hydrogen economy".

Today, more than eighty percent of the industrial hydrogen produced is obtained from the steam reforming of hydrocarbons in syngas production. The traditional process may be greatly improved by adopting an integrated reactor module consisting of subsequent stages of catalytic reaction and H_2 removal by means of metal- or ceramic-based membranes. Thus, it is possible to achieve very high yields for the reaction process and a high purity of the hydrogen product. In the long term, the main target is the production of hydrogen from a clean, renewable chemical source using a clean, sustainable energy source. Solar water splitting can provide clean, renewable sources of hydrogen fuel; various approaches have been studied to achieve this important goal, including indirect or direct or thermochemical, photosynthetic or photo-electrochemical solar water splitting. The simplest thermo-chemical process for splitting water involves heating it to a high temperature and separating the hydrogen from the equilibrium mixture. Unfortunately, the decomposition of water does not proceed well until the temperature is very high and the overall process efficiency is poor, whereas at lower temperatures the efficiency of a solar array is quite high due to minimal radiation losses. In order to reduce the operating temperature, the direct water splitting reaction can be replaced by a set of chemical reactions that lead to the decomposition of water into hydrogen and oxygen. The most promising among these cycles is the sulfur-iodine cycle, originally studied in the mid-1970s by General Atomics with the aim of using the low-temperature waste heat of nuclear reactors. This technique requires the catalytic reduction of sulphur trioxide to sulphur dioxide at a temperature of around 800-1000 °C, and with a high heat absorption, which can be provided by solar energy.

Natural gas can be involved in many different innovative processes depending on the use of new catalytic systems. An example might be the development of novel bi-functional (noble metal/perovskite) monolith and foam catalysts with great thermal resistance and high performance, to be used in catalytic autothermal processes of partial oxidation of natural gas to syngas as an alternative to steam-cracking processes. Another example is the development of structured catalysts for the catalytic oxidation of methane/air mixtures under fuel-rich conditions as a preliminary conversion stage for gas turbine burners which use short-contact-time autothermal reactors, thus avoiding the noble metal catalyst thermal deactivation characteristic of traditional fuel-lean operation. Other examples are: i) the development of novel structured perovskite-type catalysts as alternatives to noble metals for ethylene production from methane/ethane/oxygen mixtures under short-contact-time conditions, and ii) the development of an autothermal partial catalytic oxidation process which is an alternative to steam-cracking, but with a higher conversion and yield.

Gasification of biomass to produce syngas for gas turbines or fuel cells with a low tar content requires the development of new catalysts and new reactor design. Stable, durable and high mechanical strength in-bed catalysts for biomass tar and methane reforming in a fluidized bed reactor must be studied in order to eliminate the hot gas cleaning stage, thus reducing investment costs.

Further classes of alternative energy production processes are those concerning the production of liquid fuels such as bioethanol, biobutanol, dimethylether and biodiesel. To be competitive this production, relies on cheap and reliable sources of renewable raw material and efficient production processes. The most suitable source for bioalcohol comes from an efficient conversion of cellulosic, fibre- or wood-based, or cereal waste biomass into fermentable sugars. Biomass is first subjected to pre-treatment to solubilize hemicelluloses and to expose the cellulose for subsequent enzymatic degradation. The cellulose then undergoes enzymatic hydrolysis to produce glucose, which can be converted into bio-fuels and chemicals by fermentation. The reaction products must then be separated and purified. To purify the bioalcohols, hybrid purification processes based on the integration between azeotropic distillation, pervaporation, and molecular sieve adsorption could be implemented in the best configuration. Lastly, energy savings can also be regarded to as an alternative energy source: the optimization of energy uses in industrial processes is a task that can be easily pursued by tools such as pinch technology. This is usually known as process integration.

4.3.5.2 - Advanced product engineering

New advanced product technology requires innovation with regard to various aspects. First of all, new techniques for the production of nanoparticles, ionic liquids, pharmaceutical compounds, etc. must be developed. Then the formulation of active ingredients must be implemented to produce formulated products as nanostructured materials or systems for a quick release of pharmaceutical products. The equipment for performing the new processes in the most effective way will be very compact due to the intensification of mass and heat transfer. Moreover, in order to perform the process safely and efficiently, there is a need for equipment endowed with strict control systems based on advanced control algorithms (Archa Gambineri). Moreover, data will be monitored and analyzed by Multivariate Statistical Process Control.

Research based on close academic-industrial collaboration will focus on advanced product design, combining the industrial experience in product formulation and the academic knowledge in process simulation and control.

The major prospects for the development of new advanced products are as follows.

- New methods to carry out reaction-precipitation processes for the production of nano-scale materials. Chemical precipitations and co-precipitations in sol-gel material and in emulsion appear to be the most effective ways to control the crystal size and the crystalline nature of the products. To assure the required performance of the precipitation process, high intensification reactors – such as the rotating disc reactor – could be used. This apparatus has the great advantage of allowing an easy scale-up from the pilot to the industrial scale. Nanoparticles produced in sol-gel materials will be ready to be used for coatings either in new material applications (TiO_2) or in the healthcare area (hydroxyapatite for in situ human body implant).
- Application of hybrid systems based on the integration of more operations. Here the membrane processes may play a very important role. In fact, the combining of a membrane process with crystallization (to produce well-shaped proteins), distillation (for solvent recovery), and reactors (to improve the efficiency of chemical and bio-chemical reactions) is a meaningful example of effective hybrid processes. Some applications of membrane reactors are in the hydrogenation and oxidation reactions, the supply of high pure hydrogen, enantiomeric productions, etc. As a particular class of membrane reactors, bio-reactors are new devices for a wide range of applications. In these systems, the catalytic action of enzymes is extremely efficient and selective if compared with chemical catalysts:

enzymes show higher reaction rates, milder reaction conditions, and greater stereo-specificity.

- Desublimation and money-intensive processes like the rapid expansion of supercritical solutions (RESS), supercritical antisolvent precipitation (SAS), particle from gas-saturated solutions (PGSS), and depressurization of an expanded liquid organic solution (DELOS). These processes exploit the unique properties of supercritical fluids to develop products with new properties and morphologies; they are extremely attractive for minimizing the use of organic solvents in fine chemistry, pharmaceuticals and the food industry, thus providing innovative technologies which are fully eco-sustainable.
- Advanced process control. The chemical process industry – once characterized by product variability, cheap energy, and production capacity – is now striving to obtain massive production while using minimum energy and creating little waste. This new prospect has generated the demand for more effective operational strategies for the production line. Hence, the process control has become increasingly important in the process industries, as an effective tool for dealing with global competition in today's rapidly changing economic environment, while complying with stringent environmental and safety regulations. Process control is the only way to achieve all the design objectives of a sustainable chemical process at the production line (minimum raw materials and energy; strict quality specifications for products and effluents; safety of personnel, equipment and site). Without a properly designed and implemented multivariate process control system, sustainable processes could only be conceived, but never be put into operation.

Lastly, it is important to assess the safety of new technologies by developing integrated approaches within the context of regulatory decision-making processes for emerging and breakthrough technologies. It is also important to evaluate how the gap between risk and perceived risk can be closed for new technologies, hence defining and characterizing (i) risk, (ii) perceived risk, (iii) risk management options, and (iv) risk communication options for meeting stakeholder concerns.

4.3.5.3 - Process Systems Engineering

Process systems engineering is a typical chemical engineering approach, which is able to address the production process "from cradle to grave": from the design of the molecules to the invention of the process, from process analysis, simulation and synthesis, to process scale-up, optimization and control, including life-cycle assessment and supply-chain management of the final products.

In particular, the theoretical modelling of complex homogeneous and heterogeneous steady-state and dynamic systems must be significantly improved by including more detailed molecular approaches. Molecular dynamics models will become much more sophisticated and include such things as salvation effects and transition state calculations. Chemical reactions will have to be studied in a much more rigorous way than today, in order to carefully establish reaction cycles and kinetic models.

In addition, process simulation programs also need to be improved, so that material and energy balances can be solved together with momentum balances and population balance equations, in order to provide a complete picture of the chemical and physical phenomena occurring within each piece of equipment. Therefore, appropriate simulation programs will be developed for each process and plant. The automation of all the regulation and control systems must be strongly improved as well, while following the progress of information technology and miniaturization of sensors, actuators and electronic devices, also in view of a more efficient and safer plant operation.

4.3.5.4 - Process intensification

Process integration and intensification are enabling factors for a significant improvement in process/plant efficiency. Process intensification can be achieved, for example, through the integration of reaction/separation, heat/mass transfer. In many cases, such integrations can be optimized by means of structured catalysts and reactors with well-defined properties at the macro- and micro-scale. The use of a membrane reactor to shift an equilibrium reaction is another example of process intensification. The chemical engineering approach must be changed. A broader range of production scales must be taken into account by focusing on completely integrated production systems rather than individual devices. An example of this approach is offered by the extension of processing options for continuous operation to small plants for the production of fine chemicals, possibly with a multi-production process. This latter concept can also be extended to large-scale processes. A novel energy source (electrochemical, photochemical, microwave device) could be locally supplied in order to promote a reaction pathway.

Plant miniaturization, conceived few years ago, is a promising research topic which is worth being further developed. In fact, microprocess technologies could achieve major breakthroughs in both fine and bulk chemical areas, as well as in energy-related technology. In this respect, chemical and biochemical reaction engineering will play a major role.

Reactor intensification means the integration of the mixing of reactants, reactions, and separation of products within a single piece of equipment of consistently reduced volume, with much lower hazardous potential due to the very low material holdup. Most of these new technologies are related to multiphase catalytic and non-catalytic reactors (gas-liquid, gas-solid, liquid-solid and gas-liquid-solid). Microfluidic techniques will provide a much better control of both mixing and heat exchange, thus resulting in astonishing improvements in yields and selectivity towards the desired products, as well as in the reduction of by-products. It is also noteworthy that, whenever a new catalyst is proposed, only a properly conceived and designed reactor is able to exploit and maximize its activity and selectivity characteristics. In summary, reactor design will benefit greatly by taking the above-mentioned issues into account, and the sustainability of chemical productions will be remarkably enhanced by following the new reactor design procedures.

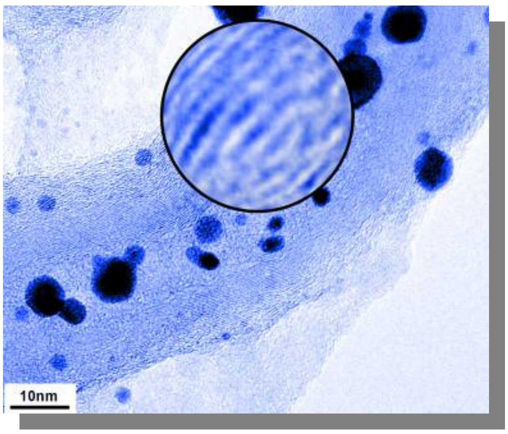
4.3.5.5 – In-silico techniques.

The recent and accelerating developments in high performance computing (HPC), process system engineering (PSE), chemical sensing technology and distributed process control will ensure that *in-silico* techniques will have a revolutionary impact on the chemical industry operations over the next 20 years.

In-silico techniques will play an ever-increasing role in all aspects of the chemical industry with the growing requirements of data storage, retrieval, harvesting, and mining. The ultimate objective of *in-silico* techniques is the integration of molecular-scale theoretical chemistry, physical chemistry and hydrodynamics through to the full-scale operation of a catalyst in steady- and unsteady-state conditions. There is a broad range of time and length scales to be taken in consideration. However, the integration of currently existing and yet-to-be-developed modelling methodologies will yield powerful tools which make it possible to define an active site, quantify the surface chemistry, and determine the step rate through a rationally based rate equation. Only by linking all the modelling scales is it possible to achieve optimum process and plant configuration.

In particular, the theoretical modelling of complex homogeneous and heterogeneous systems must be significantly improved by including detailed molecular approaches. The models will have to become much more sophisticated and include such things as solvation effects and transition state calculations, etc. It will be necessary to study chemical reactions in a much more rigorous way than they are today, in order to carefully establish reaction cycles and kinetic models.

Therefore, more suitable simulation programs must be developed. The automation of all the regulation and control systems must be strongly improved following the progress in computer hardware and software and the miniaturization of sensors, actuators and electronic devices, with the aim of achieving a more efficient and safer plant operation. All these aspects are of paramount importance for scaling up the processes; therefore, the necessary theory, modelling, simulation and automation improvements must be studied using a multi-disciplinary team approach.



Universities, Research centers and Companies Acknowledged for Their Participation in the Reaction and Process Design National Survey

University	Other Institution	Industrial Company
Polytechnics of Milan	CNR- ICCOM-Florence	FEDERCHIMICA (representing more than 1500 enterprises)
Polytechnics of Turin	Istituto Superiore di Sanità	ENDURA SpA
University of Bari	ENEA – Rome	CIBA Italia
University of Bologna	CNR-Istituto di Ricerche sulla Combustione- Naples	ENI - Milan
University of Camerino	GRICU	ENEA - Rome
University of Florence	AIDIC	DOW ITALIA SpA
University of Genua	SCI - Società Chimica Italiana	Solvay Solexis SpA
University of L'Aquila	CIRCC - Consorzio Interuniversitario Reattività Chimica e Catalisi	Radici SpA
University of Messina	INSTM	Mossi & Ghisolfi SpA
University of Milan	CIRCMSB - Consorzio Interuniversitario di Ricerca in Chimica dei Metalli nei sitemi biologici	
University of Naples "Federico II" (Science Faculty)	CINMPIS - Consorzio Interuniversitario Nazionale "Metodologie e Processi Innovativi di Sintesi"	
University of Naplles "Federico II" (Engineering Faculty)		
University of Padua		
University of Palermo		
University of Pavia		
University of Pisa		
University of Rome "La Sapienza"		
University of Roma "Tor Vergata"		
University of Turin		
University of Tuscia		
University of Urbino		

4.4 Horizontal Issues

This section deals with some actions which should be promoted to create a cultural and operative environment where the main topics in the previous sections can find a more general consensus and therefore an easier path to their implementation.

What follows focuses on sustainability, which is definitely one of the main drivers of the SusChem Platform as well as of the related Italian SusChem Platform (IT-SusChem). The ultimate goal of all the research actions proposed within the thematic sections of this vision document is progress towards a more sustainable society.

Today “Sustainability” and “Sustainable Development” are very common and often abused words, but their use in the context of chemical activities is appropriate since chemistry and chemical productions play an unquestionable and essential role in meeting an impressive variety of needs in our everyday life. Nevertheless, the crucial contribution of chemistry and chemistry-related activities to a good quality of life is not generally recognized. Conversely, a sort of distrust towards anything to which the label chemistry can be attached is the prevailing current attitude with public opinion. This trend must be reversed and, at the same time, a more concerned attention to the social and environmental implications of their productions have to be reinforced among chemical operators.

Therefore, it is necessary to promote actions aimed at developing a widespread culture of sustainability. Sustainability means a process of continuous evolution and innovation for meeting shared needs of welfare, equity and environmental protection in a financially satisfactory way. This culture must be promoted among both chemical insiders and laymen with the final aim of establishing a positive interaction between these two worlds.

The implementation of actions aiming for the promotion of a new positive and motivated attitude towards chemistry is definitely the main goal of this section of the document. In order to make concern for sustainability customary and to avoid the risk of self-reference, the following actions will be carried out:

a) finding criteria for a quantitative evaluation of progress towards sustainability which can be associated with any given initiative;
b) developing an attitude towards focusing attention on societal needs for orienting activities and products;
c) increasing attention to proper communication, where benefits and risks are clearly presented in such a way as to provide the chemical community with accreditation as a reliable entity.

These points may be better detailed as follows:

1) Processes and products must be considered within the framework of their life cycle through a Life Cycle Assessment (LCA) procedure or a lifecycle thinking approach.

   These procedures are becoming quite common but are currently limited to considering environmental impact only; therefore, they must be modified to include societal and economic impact as well. Furthermore, in order to guarantee reliable inputs to the Life Cycle Inventory (LCI) phase, a database focused specifically on particular Italian and European situations should also be prepared. A close connection with the activities developed within the European Platform on Life Cycle Assessment is recommended.

2) Support must be given to SMEs through the development of simplified tools for sustainability assessment and the implementation of systems for environmental and risk assessment and management

   The upcoming enforcement of REACH regulations will provide a unique opportunity to guarantee the reliability of both risk assessment and safety information, thus contributing to improving public confidence in chemical productions.

3) The enforcement of new and stricter environmental regulations must be seen as an opportunity for promoting innovation, and not as a heavy constraint. National and local institutions and agencies (APAT, ARPA, ISS,..) must be involved in promoting a management of authorization and control procedures focusing on substantial technical aspects rather than formal ones.

4) Due to the “pervasive” role of chemistry, some attention has to be paid to the activities of other platforms which are active in the framework of EU 7th WP, in order to integrate research efforts and maximize technological opportunities.

A crucial point is the establishment, with public opinion and the authorities, of a shared perception that chemistry is a vital element of our lives and that chemical productions play a propulsive role in guaranteeing and innovating products and services of current use.

The creation of a mutual trust among citizens, decision-makers/competent authorities, and industry is essential not only for the development of new productions, but also for maintaining ongoing activities. This entails due attention to an effective communication characterized by completeness, reliability and attention to the needs and concerns of the those concerned. This, in turn, requires the improvement of the public’s basic chemical culture in order to make its role effective, in compliance with the Arhus convention.

Particular attention must be paid especially to communication with decision-makers, in order to make them aware of the central role of chemistry and its great innovation capacity. They must become actively involved in promoting actions of support to all the components of this sector (research, industry, education) with a vision not limited to local situations but comprising broader scenarios, at least at the EU level, in order to avoid drawbacks to the national industrial system .

It should be noted that, even if all the above-mentioned actions are successfully performed, the practical exploitation of the huge innovative potential of chemistry cannot be made real if there are not enough skilled people working on it. Attention to education is therefore crucial, due to its fundamental role in the early stages of the formation of concerned citizens, as well as in the preparation of technical experts and the upgrading of their skills throughout their whole professional life.

As a matter of fact, all European universities are now experiencing a decline in enrollment in the scientific/technical areas in general, and in chemistry and chemistry-related subjects in particular.

This trend must be reversed and appropriate actions must be promoted by the different players who are aware that chemistry is an essential component of the European knowledge-based society envisaged by the EU Lisbon process. At universities the specific curricula must be promoted by emphasizing the role of chemistry and chemical technologies as prime drivers for innovation and progress towards a more sustainable society.

The role of research institutions must be reinforced through a concrete recognition of their mission, on the basis of a reliable allocation of human and financial resources.

Companies, too, are expected to improve their employees' education through an extensive use of life-long learning; once again, a specific organization must be devised for SMEs in order to keep them on or close to the leading edge of innovation.

A sound system of relations must be promoted among these actors to link scientific approaches with technological ones and, lastly, with production, as well as to identify strategic themes where research efforts should be concentrated.

As previously stressed, the main activity within this Platform should be focused on value creation, while taking care of environmental performance. Additionally, all factors that will strongly affect any successful innovation, such as economic barriers and social acceptances, should be better defined.

Several scientific and technical organizations within the chemistry, chemical engineering and biotechnology communities are engaged in activities aiming to achieve these goals.

Among these organizations, the Italian Chemical Society (SCI) definitely occupies a leading position and can play an important role in this regard. It currently has approximately 5,000 members, most of whom from academia, but with a growing proportion coming from industry as well as from high school, and with an important part played by young people. It should be remembered that the fundamental objective of the SCI is the spreading of chemical science and its applications in order to stress its importance in the modern society. Within the SCI it is possible to find many kinds of expertise that will improve partners' cooperation, technology transfer from academia to industry, societal consensus and well-focused communications, optimization of regulatory issues and, most important, strong support for chemical education and recognition of world-class skills within the new generations. In other words, SCI can be the landmark for any interactivity between the production-linked issues of the IT-SusChem, namely Materials, Reaction Processes and Biotechnology, while dealing with specific problems such as the connection between different complementary expertises, the setting up of a proper campaign to improve the image of Chemistry, and the stimulation of a correct teaching-to-learning relationship to aid the recruiting of future chemists.

In conclusion, this horizontal issue of the IT SusChem Platform must achieve specific results in:

- Identifying an effective coordination structure
- Agreeing on common objective, results and strategies
- Measuring results to track performances
- Using information to improve performances
- Reporting performances effectively

Additionally, there are two emerging themes within the horizontal area that need to be specifically developed: i) the proper social concerns and stimulation for the proper support for innovation, with special attention to a fruitful development of the appropriate skill set, and ii) the enhancement of the skills that will underpin these goals.

5. Structure and Governance of IT- SusChem

PROMOTER COMMITTEE

Coordinator *at interim*: Luigi Busetto (University of Bologna): luigi.busetto@unibo.it

- Nicola Barbini (Board of the European Technology Platform SusChem)
- Fabrizio Cavani (University of Bologna)
- Gabriele Centi (University of Messina and INSTM)
- Fabio Fava (University of Bologna)
- Giovanni Pieri (Delegate of the Ministry of Research and University in the ETP SusChem Mirror Group)
- Vito Pignatelli (ENEA Casaccia, Rome)
- Pietro Tundo (University of Venice)
- Sesto Viticoli (National Research Council, CNR, Rome)

SCIENTIFIC COMMITTEE

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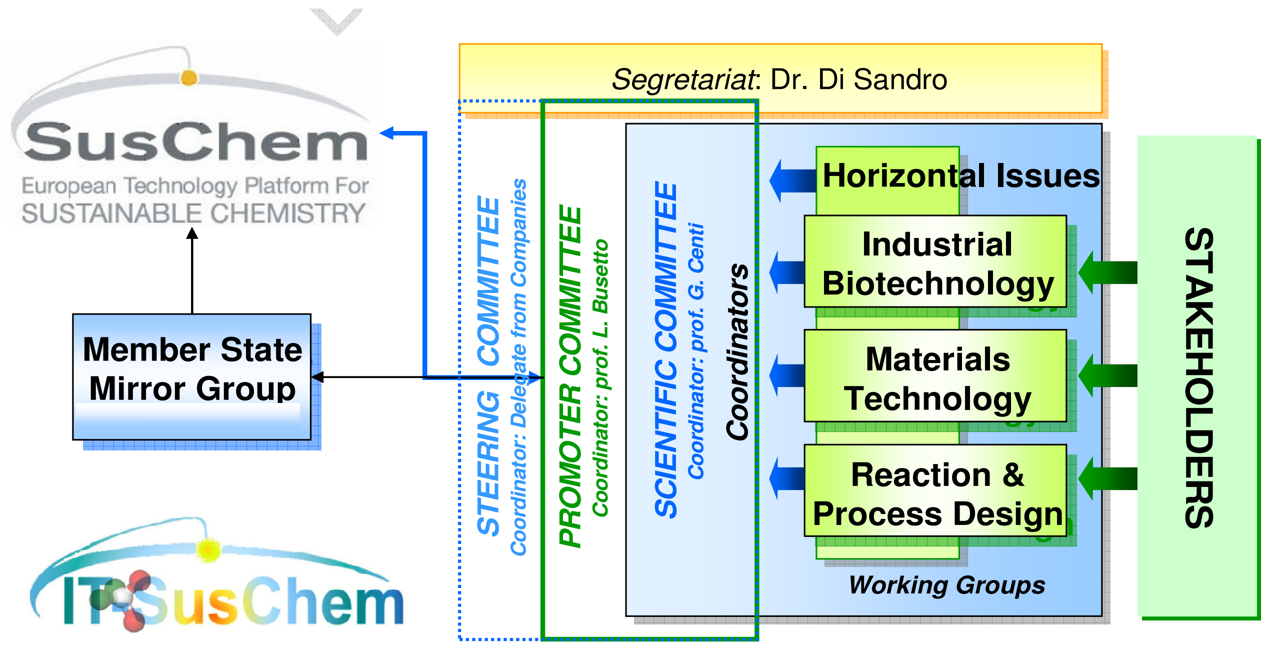

Technology Section: "**INDUSTRIAL BIOTECHNOLOGY**"

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- Gianluca Cencia (Federambiente)
- Enrica Galli (University of Milan)
- Lucia Gardossi (University of Trieste & Biocatalysis & Bioseparation Association)
- Marco Gobbetti (University of Bari)
- Gabriele Iorio (University of Calabria & GRICU)
- Mauro Majone (University of Rome "La Sapienza")
- Giuseppe Martini (CNR – Rome)
- Roberto Morabito (ENEA Casaccia, Rome)
- Patrizia Perego (University of Genua)
- Danilo Porro (Univ. of Milan Bicocca & Ind. Biotech. Minist. Committee)
- Enrico Rizzarelli (University of Catania)
- Giovanni Sannia (University of Naples "Federico II")
- Leonardo Vingiani (Assobiotec)

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- Piero Cavigliasso (PROPLAST)
- Emo Chiellini (University di Pisa)
- Alberto Cigada (Politecnico of Milan)
- Enrico Costantini (BASELLPolyolefins – Ferrara)
- Saverio Russo (University of Genua and INSTM)
- Gianfranco Scorrano (University of Padua)
- Francesco La Mantia (University of Palermo)
- Claudio Migliaresi (University of Trento)
- Carlo Taliani (National Research Council - CNR of Bologna)
- Teodoro Valente (University of Rome "La Sapienza" & AIMAT)
- Claudio Zannoni (University of Bologna and INSTM)

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- Michele Aresta (University of Bari & CIRCC)
- Alberto Bertucco (University of Padua & GRICU)
- Claudio Bianchini (National Research Council – CNR, Florence)
- Renato Bozio (University of Padua and INSTM)
- Marta Catellani (University of Parma & CIRCC)
- Angelo Chianese (University of Rome "La Sapienza" & AIDIC)
- Attilio Citterio (Politecnico of Milan)
- Salvatore Coluccia (University of Turin)
- Giuseppe Filardo (University of Palermo & CIRCC)
- Cosimo Franco (Endura S.p.A - Bologna)
- Dario Lazzari (CIBA – Sasso Marconi, Bologna)
- Luigi Messori (University of Firenze & CIRCMSB)
- Francesco Naso (University of Bari)
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- Luciano Morselli (Chairman of *Ecomondo*, the International Traid Fair on Material and Energy Recovery and Sustainable Development, University of Bologna)
- Ermete Realacci (Honorary President of Legambiente)
- Ferruccio Trifirò (Director of *La Chimica e l'Industria* - Milan; journal of the Italian Chemical Society, University of Bologna)

IT-SusChem Web Site

- *http://www.unibo.it/Portale/Ricerca/Servizi+Docenti+Ricercatori/finanzeuropei/ITSuschemPlatform.htm*
  (available on the web site the list of activities, documents available for download, list of endorsement, press release, contacts)
- *http://www.unibo.it/Portale/Ricerca/suschem.htm*
  (information on the launch of the platform, press release, contacts)

6. Stakeholders participating in IT- SusChem

Industrial Companies and Private Research Laboratories

1. FEDERCHIMICA
2. Assobiotec - Associazione Nazionale per lo Sviluppo delle Biotecnologie
3. UNIPRO - Associazione Italiana delle Imprese Cosmetiche
4. FEDERAMBIENTE
5. Agri 2000 Soc. Coop.
6. INTESA SANPAOLO - International Affairs
7. BioDec SRL
8. Biodiversity SpA
9. BIOSEARCH AMBIENTE SRL
10. Biosensor Srl
11. Biosphere S.p.A.
12. Biosynthex srl
13. BioTecnologie BT S.r.l.
14. Consorzio Stabile COSINT s.c.r.l.
15. Contento Trade
16. DETECH srl
17. Dipietro Automazione Srl
18. ESI Italia srl
19. GECOsistema srl
20. GUABER S.p.A.
21. Hexion Specialty Chemicals S.r.l.
22. ITEA SPA
23. ITER srl
24. LABOR S.r.l.
25. Laboratori ARCHA SRL.
26. LENVIROS srl
27. Ma.Tec. Materials Technologies
28. Marcopolo Engineering Spa
29. MAVI SUD S.R.L.
30. Micromeritics Srl
31. Migi srl
32. Naxospharma srl
33. Novamont SpA
34. P GROUP s.r.l
35. Plasma Solution S.r.l., spin off of theUniversity ofi Bari
36. POLYNT S.p.A.
37. Process Service s.r.l.
38. Radicipartecipazioni spa
39. Riservice srl
40. S.T.A. SRL
41. Sacmi Imola S.C.
42. Scriba Nanotecnologie Srl
43. Sea Marconi Technologies di V. Tumiatti s.a.s.
44. Serichim Srl
45. Sincrotrone Trieste S.C.p.A.
46. SO.F.TER. SPA
47. SOGRAF CHEMICAL srl
48. SPES s.c.p.a
49. Sud Chemie Catalysts italia S.r.L
50. Sviluppo Chimica spa
51. Sviluppumbria spa
52. T.S.A. spa
53. Vulcaflex Spa
54. E.Ge.Co. Soluzioni Ambientali srl

Italian Universities and Inter-university Consortia

Industrial Biotechnology

55. Centro di Eccellenza per la Biosensoristica Vegetale e Microbica of the University of Turin (CEBIOVEM)
56. Consorzio Interuniversitario Biotecnologie (C.I.B.)(25 Universities)
57. Consorzio Interuniversitario "Istituto Nazionale Biostrutture e Biosistemi" (INBB)(25 Universities)
58. Consorzio Interuniversitario di Ricerca in chimica dei Metalli nei sistemi Biologici (CIRCMSB) (21 Universities)
59. Consorzio Interuniversitario di Ricerca in Economia e Marketing dei Prodotti Agro-alimentari
60. HeteroBioLab - Laboratorio di progettazione, sintesi e studio di eterocicl biologicamente attivi– (HBL)
61. Mycotheca Universitatis Taurinensis (MUT)
62. Consorzio di Ricerche Applicate alla Biotecnologia (CRAB)(Several Universities and Companies)

Materials Technology

63. Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali (INSTM)(44 Universities)
64. Centro di Riferimento INSTM: NIPLAB
65. Centro di Eccellenza Materiali Innovativi Nanostrutturati per applicazione chimiche fisiche e biomediche (CEMIN)
66. Centro di Eccellenza Superfici ed Interfasi Nanostrutturate (NIS)

Reaction and Process Design

67. Centro interuniversitario per lo Sviluppo della Sostenibilità dei Prodotti (CE.SI.S.P.)
68. Consorzio Nazionale Interuniversitario per le scienze fisiche della materia (CNISM) (37 Universities)
69. Consorzio Interuniversitario Reattività Chimica e Catalisi (CIRCC) (18 Universities)
70. Consorzio Interuniversitario di Ricerca in chimica dei Metalli nei sistemi Biologici (CIRCMSB)(21 Universities)
71. Consorzio Interuniversitario Nazionale "Metodologie e Processi Innovativi di Sintesi" (C.I.N.M.P.I.S.)(16 Universities)
72. HeteroBioLab – Laboratorio di progettazione, sintesi e studio di eterocicli biologicamente attivi (HBL)

Others:

73. Accademia Nazionale delle Scienze detta dei Lincei
74. Centro di eccellenza of the University of Milan

75. Laboratorio A Rete Regionale per le Acque – FE 120 Obiettivo 2
76. Dipartimento di Biologia Vegetale of the University of Turin

Universities:

(Universities which adhered individually to the platform independently from their participation in the Interuniversity consortia – listed above - supporting IT SusChem)

77. Politecnico of Milan
78. Politecnico di Turin
79. University La Sapienza - Rome
80. University of Bari
81. University of Insubria
82. University of Tuscia
83. University of L'Aquila
84. University of Brescia
85. University of Cagliari
86. University of Camerino
87. University of Catania
88. University of Ferrara
89. University of Genua
90. University of Messina
91. University of Milan
92. University of Milan - Bicocca
93. University of Palermo
94. University of Parma
95. University of Perugia
96. University of Rome "Tor Vergata"
97. University of Rome "La Sapienza"
98. University of Salerno
99. University of Siena
100. University of Turin
101. University of Trieste
102. University of Udine
103. University of Urbino
104. University of Basilicata
105. University of Calabria
106. University of Cagliari
107. University of Florence
108. University of Lecce
109. University of Modena e Reggio Emilia
110. University of Naples "Parthenope"
111. University of Naples Federico II
112. University of Pisa
113. Università Politecnica delle Marche – Dipartment of Food Science

Associations

114. Associazione Italiana Chimica per l'Ingegneria (AIC Ing)
115. Associazione Italiana di Ingegneria Chimica (AIDIC)
116. Associazione Italiana di Scienza e Tecnologia delle Macromolecole (AIM)
117. Associazione Italiana di Ingegneria dei Materiali (AIMAT onlus)
118. Associazione Industriale per la Ricerca Italiana (AIRI/ Nanotec IT)
119. Associazione Italiana Zeoliti onlus
120. Associazione Nazionale dei Biotecnologi Italiani (ANBI)
121. Confindustria
122. Consiglio Nazionale dei Chimici (CNC)
123. Associazione Italiana Chimica e Tecnologia delle Ciclodestrine

124. EGOCREANET / ON_NS
125. Gruppo di Ingegneria Chimica dell'Università (GRICU)
126. KYOTO CLUB
127. Ricerche e tecnologie cosmetologiche (RTC)
128. TECNOALIMENTI S.C.p.A

Other Research Centers

129. Consiglio per la Ricerca e la Sperimentazione in Agricoltura – (C.R.A.)
130. Istituto Sperimentale per la Nutrizione delle Piante, SOP di Turin
131. Centro Ceramico - Bologna - Centro di Ricerca e Sperimentazione per l'Industria Ceramica
132. Centro per l'Istruzione Professionale e l'Assistenza Tecnica- (CIPAT)
133. Centro Regionale di Competenza Analisi e Monitoraggio del Rischio Ambientale (AMRA)
134. Consiglio Nazionale delle Ricerche (CNR)
135. CNR - Istituto Fotonica e Nanotecnologie – Sezione Trento
136. Consiglio Nazionale delle Ricerche – Istituto di Biostrutture e Bioimmagini Catania
137. CNR Bari
138. CNR Istituto di Chimica Biomolecolare, Catania
139. CNR Istituto di Chimica Biomolecolare, Napoli
140. CNR Sesto Fiorentino (FI)
141. CNR, Istituto di Chimica del Riconoscimento Molecolare, Milan
142. ENEA
143. ENEA C. R. Casaccia (Rome)
146. ENEA C. R. Trisaia (MT)
147. ENEA Bologna, Bologna
148. Gruppo di ricerca "Interferenti Endocrini", Dip. Sanità Alimentare ed Animale – Istituto Superiore di Sanità (ISS)
149. ISTEC C.N.R.
150. Istituto di Chimica e Tecnologia dei Polimeri del Consiglio Nazionale delle Ricerche
151. Istituto di ricerche sulla combustione -CNR
152. Istituto per lo Studio delle Macromolecole (ISMAC) del CNR
153. Stazione Sperimentale per le industrie degli oli e grassi

Source:

http://www.unibo.it/Portale/Ricerca/Servizi+Docenti+Ricercatori/finanzeuropei/ITSuschemPlatform.htm