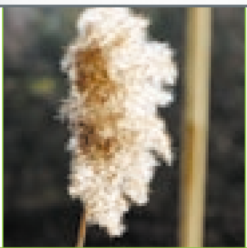
A European Technology Platform For SUSTAINABLE CHEMISTRY



cefic

EuropaBio

The European Association for Bioindustries

Contents

The establishment of a European Technology Platform for Sustainable Chemistry aims to boost chemical research, development and innovation in Europe. The Technology Platform for Sustainable Chemistry is a joint initiative of Cefic, EuropaBio and the European Commission's DG Research.

This document expresses the chemical industry's views on the rationale, scope and organisation of the Technology Platform. It is intended to act as a thought starter, and an invitation to additional stakeholders to participate in the Platform's future activities that will ultimately result in a Strategic Research Agenda and action plan.

"We are responsible not only for what we do, but also for what we do not do."

Molière.

Executive summary

Chemistry is ubiquitous and is vital for the quality of modern life. More and better use of chemistry will enable our European society to become more sustainable. This requires major chemical innovations and thus a successful and healthy EU chemical industry to capture their value and spread their use.

The EU is world-leading in chemicals production. Its chemical industry supplies products to virtually all downstream industry sectors. More than just a supplier of chemicals, the industry - with its continuous supply of product and process innovations - is also an engine for innovation for downstream sectors.

Whilst the EU chemical industry today appears strong and healthy, the competitiveness of the sector in Europe is at risk. This is due mainly to relatively high cost of production, low market growth, and delocalisation of customer industries. In all but the most optimistic future scenarios, the net trade balance falls and Europe could well become a net importer of chemicals by 2015! The sector's role as an enabler of innovation to the downstream industry is therefore also in danger. The difference between the most optimistic scenario and all other scenarios lies in a European chemical industry driven by innovation.

Innovation is a key driver for future competitiveness, to enable design and manufacturing of higher added value products and more eco-efficient chemicals manufacturing in Europe that should also result in restored public confidence in the industry's (new) products and technologies. Research and Development is a major source of innovation in this 'knowledge-intensive' industry. However, EU chemical R&D expenditures are decreasing and are structurally lower than in competing regions, which are also better organised to capitalise on new areas of chemistry research.

There is an urgent need to boost chemical research and innovation in Europe. It is recommended to establish a European Technology Platform on Sustainable Chemistry to galvanise and focus collaborative research, development and innovation activities relating to the European chemicals industry.

Ambition

To sustain a successful, competitive, EU chemical industry with global business leadership

Strategic Objectives

- To maintain and strengthen the competitiveness and sustainability of the chemical industry in Europe based on technology leadership.
- To help meet society's needs in terms of food, health, energy and materials in close cooperation with all stakeholders.
- To boost and sustain chemistry research in Europe.
- To improve EU framework conditions conducive to chemical innovation.

The Technology Platform should provide:

- A management process to integrate multiple stakeholder perspectives into a shared vision of 'a more sustainable future EU chemical industry'.
- A European strategy for research and innovation in key chemical technology areas, i.e. industrial (or 'white') biotechnology, materials technology and reaction & process design.
- An action plan to implement this strategy, including mobilisation of resources for collaborative R&D to sustain a strong European chemical science base, alignment of relevant EU policies and initiatives, and recommendations on EU innovation framework improvements.

Introduction

Chemistry is ubiquitous and vital for Europe …

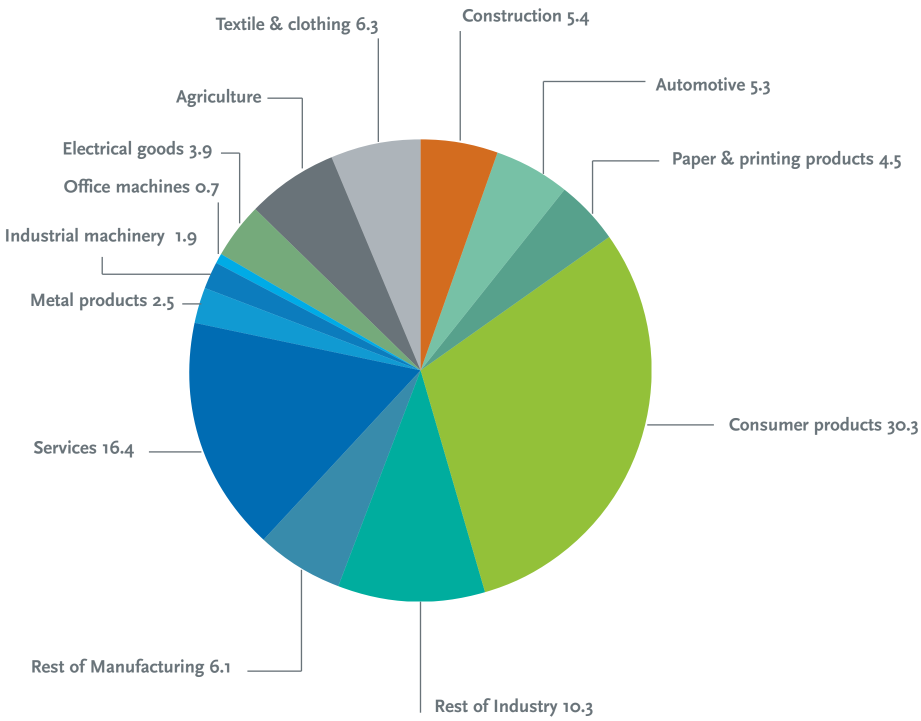
Chemistry deals with the manipulation of molecules, its essence lying in the design, production and transformation of materials. These materials provide useful functionalities, and their very usefulness means they are found everywhere. Chemicals are found in buildings and houses, in appliances and electronic devices, in paper and textiles. Chemicals are essential components of power-generating and storage systems. They enable important new environmental technologies such as wind-power and fuel cells. Chemicals are required in our transport infrastructure in cars, ships and airplanes. Chemistry is the core science for all new drugs and diagnostic technologies. Chemicals protect and promote our crops, provide solutions in the areas of hygiene, for example in disinfectants and detergents, in food and cosmetics including flavours and fragrances. They are an essential part of modern textiles, colours, print and painting, computers and mobile phones. Chemicals are also essential for fun in fashion, leisure and sporting goods.

The last decade has witnessed a dramatic progress in chemical knowledge. The promise of Chemistry could bring great positive changes in our society, but this will only become a reality if the Chemical Industry succeeds in advancing breakthrough inventions from the lab into new products and services in the marketplace. As far as Chemistry is concerned, we are convinced that the best is yet to come: novel anti-cancer, anti-aging and disease prevention therapeutics based on exploiting the 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 arable land; functional materials that make our vehicles lighter and stronger, hence more energy efficient; and safer buildings with lower energy consumption.

Chemicals are produced by the EU chemical industry, which in turn supplies virtually all downstream sectors …

The chemicals sector produces thousands of different products, and supplies them to almost all other sectors of the economy. A major share (27 %) of chemical products is further

Figure 1. The share of chemical domestic consumption, including pharmaceuticals.



processed within the industry itself. In many instances, it is only after several processing stages that products are delivered to customers[1].

The products range from basic chemicals (37.7%), via specialty and fine chemicals (28.8%) and pharmaceuticals (23.3%) to consumer chemicals (10.2%). The biggest industrial customers of chemicals are the metals, mechanical, electrical and electronics industries, textiles and clothing, the automotive industry and paper and printing products (Figure 1).

The value-added downstream may be several orders of magnitude larger than the chemicals sector itself. For example Organic Light-Emitting Diodes (OLED's) represent a relatively modest market of € 350 million, but generate a market in display technology 10 times larger, which in turn are important components in consumer products (mobile phones, flat screens, etc.) with a retail value of nearly € 50 billion!

... and the chemical industry is a catalyst for innovation in downstream sectors.

More than just a supplier of raw materials, the chemical industry is a major source of innovation to downstream sectors.

There are countless examples of chemical inventions that have enabled innovations in other industries, such as polycarbonate as a base for optical storage media, liquid crystals for displays and aliphatic polyurethane for use in water-based coating systems. Various mechanisms exist by which chemical innovations stimulate others: new materials for improved products, process innovations, and price reduction, enabling use of chemicals in more and larger volume applications.

A recent German study underlined the disproportionate impact of chemicals innovation as a driver of innovation in other sectors[2], accounting for well over 50% of innovation in pharmaceuticals, textile and clothing, metal and petroleum processing industries.

The EU is a world leader in chemicals production, a major employer and a major contributor to the EU's GDP and trade balance.

World chemicals production in 2002 was estimated at € 1300 billion excluding pharmaceuticals. The EU is a leading global chemicals producing area, with € 360 billion or 28 % of world chemicals production. The sector's contribution to the EU GDP (€ 22 trillion) amounts to 2.4%.
In addition world pharmaceutical production was € 541 billion with a European share of € 167 billion in 2002.

The chemicals sector comprises some 25,000 enterprises in Europe. Ninety-eight percent of these have less than 500 employees and may be considered as SMEs, accounting for 45% of the sector's added value. The EU chemical industry currently employs 1.7 million people directly, of which 46% are in SMEs.

In 2002, the EU chemical industry sold 71% of its output within the European internal market, 46% of which was intra-EU exports. The chemical trade balance has grown from € 14 billion in 1990 to € 42 billion in 2002. The chemical industry is therefore a major net contributor to the manufacturing trade balance of the European Union, representing over 40% of that trade balance today.

The EU chemical industry's future competitiveness is at risk ...

Whilst industry today appears strong and healthy, a recent study by Cefic[3] concluded that the sector's future competitiveness is in danger.
The industry is under great pressure, in particular on environmental and health aspects. The regulatory framework raises indirect costs while placing high expectations for innovation in products and processes. There is now significant stress on the industry to improve its poor economic performance.

... leading to potentially less positive future prospects for the sector ...

The leading position of the EU in chemicals manufacturing is already slowly eroding: the EU's share of global output has declined from 32 % a decade ago to 28 % today. This is reflected within the European economy as well: output growth in the chemical industry (2.8%) was slightly lower than that of the overall manufacturing industry (2.9%) during the years 1996- 2001.

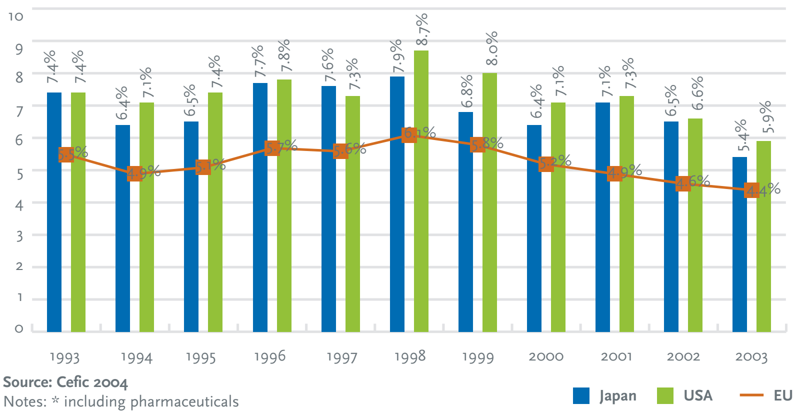
While labour productivity has steadily increased over the last ten years, employment in the EU chemical industry has decreased by 16% to 1.7 million, and by 40% in Central and Eastern Europe to 1 million.

The current climate for chemical investment is not particularly favourable in Europe because of low return on investment due to a combination of relatively high production costs, changing regional balance in manufacturing in customer sectors, and absence of advantaged feed stocks. While investments in the EU have followed the general trend for industrialised regions, investments have been structurally lower in Europe (Figure 2).

The Cefic competitiveness study developed four future scenarios with a 2015 time horizon. In all of them the EU production share rises slightly, but transiently, as a result of the EU enlargement process, before decreasing subsequently by 16 to 23%, depending on the particular scenario.

In all but the most optimistic scenarios, the net trade balance falls and Europe could well become a net importer of chemicals by 2015! This will also have a serious 'knock-on' effect on the future viability of customer businesses in Europe, such as pharmaceuticals.

Figure 2: Chemical industry capital spending in the EU, the SA and Japan* : 1993-2003



Source: Cefic 2004
Notes: * including pharmaceuticals

... and in addition, there are environmental concerns ...

The usefulness of chemicals derives from their reactivity and industry's skill in harnessing this. With this goes the responsibility for effective management of risk to both health and the environment. In common with many areas of technology there is real public concern about the effectiveness of risk management and the extent of our knowledge of the risks. This is founded on a combination of such factors as major plant incidents (*e.g.* Toulouse, Seveso), the detection of trace quantities of potentially hazardous chemicals in body tissue using biomonitoring, and evidence of endocrine disrupting effects linked to certain chemicals in nature.

In terms of the broader ecological load, the industry has made good progress in decoupling production growth from its emissions, *e.g.* CO_2 and NO_x, and energy usage. By 2001, the Chemical industry had increased production by 38% since 1990, but its energy consumption had increased by only 5% and CO_2 emissions had fallen by 6%. These are important developments in eco-efficiency consistent with the Commission's call for more sustainable technologies contained in the Environmental Technologies Action Plan[4]. The aspiration should be for evermore sustainable production and consumption of chemicals in the future, increasing eco-efficiency (therefore less waste) and restored confidence in the industry's (new) products and technologies.

... this leads to a pressing need for boosting chemical innovation in Europe

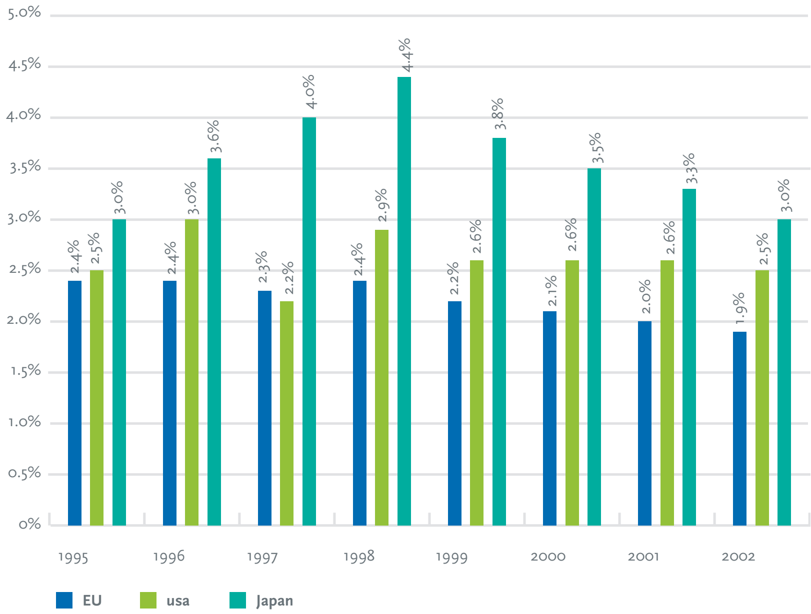
There is an urgent need to boost research, development and innovation in sustainable chemical technologies in Europe if the economic and strategic contribution of the industry is to be sustained. The enhancement of innovation efforts are to provide the technology base for more sustainable chemicals production, products and services, thereby increasing eco-efficiency and value added, and to boost investments in Europe by improving innovation framework conditions. Innovation will be a major determining factor to secure the sector's competitiveness and consequently the competitiveness of its vast downstream customer base.

Chemistry Research

Research is a major source of innovation ...

The chemical industry is particularly "knowledge-intensive", and Europe's research is competitive in the global context: Europe is a leader in many key technology areas, as demonstrated by the very high share of European scientific publications in the main refereed journals of this field of science, and by the large number of patents deposited by European companies and researchers, *e.g.* in the US (23%). The European Chemical Industry has an impressive track-record of turning chemistry inventions into products and process innovations, *e.g.* the ongoing development of metallocene-based applications in catalysis and, more recently, bio-sensors. R&D is recognized by most chemical companies and downstream users of chemicals as the single most important element of innovation.

Figure 3: R&D Expenditure in the Chemical Industry in the EU, the USA and Japan



... but R&D expenditures are decreasing and are structurally lower than in competing regions ...

However, the current focus on financial performance, frequent restructuring programmes and increasing regulatory costs are limiting R&D spending in industry, which structurally underperforms in comparison to the USA and Japan (Figure 3). Moreover, since chemistry offers the base for many innovations in other sectors, these repercussions are much wider for European manufacturing.

... which are better organized to capitalize on the new areas of chemicals research

Unlike Europe, both the USA and Japan have national strategies and roadmaps for key chemical technology areas to guide their public-private research expenditures. In comparison, European efforts are relatively fragmented, *i.e.* chemistry research is spread over multiple thematic areas, and public-private partnerships are as yet underdeveloped. All of this places Europe at a competitive disadvantage compared to regions which are generally recognised for providing more supportive environments for innovation.

Industry-academia research collaboration is increasingly important ...

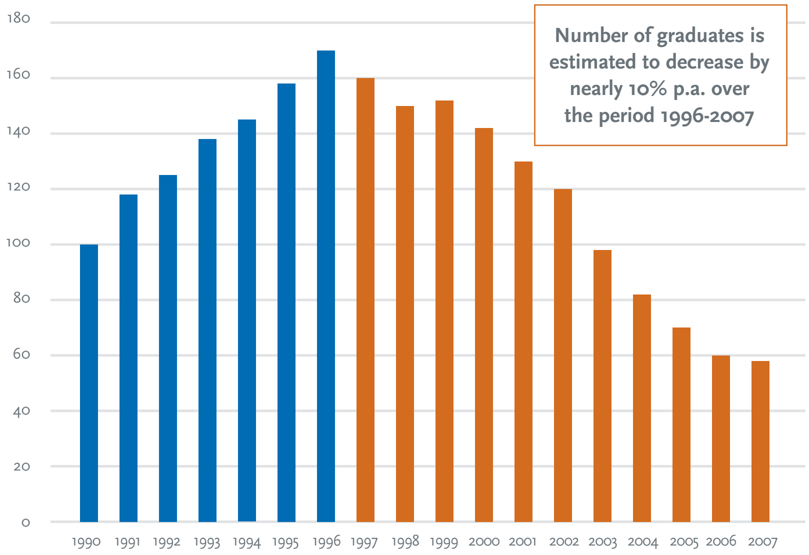
Traditionally, there is a high degree of industry-academia chemistry research. For example, 22% of German chemical companies are engaged with universities compared to less than 7% in the overall German industry.[2]

Two major incentives for collaboration are: improved access to remote expertise, and shorter time-to-market. Collaboration is increasingly important, driven by the trends towards lean organisations and outsourcing of "non-core" activities. Collaboration is particularly crucial to SMEs, however larger companies tend to benefit most from this trend.[5] In today's fast-paced marketplace, collaboration should ultimately save time for all companies.[6] Public funding is an important incentive and facilitating element to get access to academic partners.

... but there is a worrying decline in chemistry graduates

Unfortunately we are also witnessing a sharp decline in the number of students graduating in chemistry and this trend is expected to continue in the foreseeable future. The decline reflects the greater attraction of areas such as services and IT (Figure 4). If the sector is to remain innovative and growing, this trend must be reversed.

Figure 4: Chemical and industrial chemicals* graduates in major EU countries



Notes: * including pharmaceuticals
Cefic 2004

A platform for chemistry

There is clearly a pressing need for a mechanism to galvanise and focus research and innovation activities relating to the Chemical Industry and its partner industries in the value chain.

The proposed approach is to create a European Technology Platform to achieve this.

The vision

Our vision is that enhanced chemistry research and innovation, in particular in the areas of industrial (or 'white') biotechnology, materials technology and reaction & process design, will lead to breakthrough chemical product and process innovations and support an increasingly sustainable, eco-efficient and competitive EU Chemicals industry in the next 10-15 years. Creativity in science will be replicated in marketing and stakeholder relationships, featuring open communication, and result in enhanced appreciation of the industry by society at large. Harnessing chemical technologies effectively will be a key element in achieving the EU's Lisbon objectives and the Community's desire to realise Sustainable Development.

Technology Platform scope and objectives

The main goal of the Technology Platform will be to support the long-term success of the European Chemistry supply chain as a whole, by providing a major incentive for boosting chemical innovation in Europe both across the supply chain and across disciplines.

Platform deliverables

- A long term vision for sustainable chemical technologies in Europe
- A vision for a competitive and sustainable chemical industry
- Strategic Research Agendas (SRAs) and respective implementation plans for key technology areas identified that can catalyse the alignment of EU and national initiatives and boost research excellence
- Mobilisation of financial support for R&D from public EU and national funds and from private sources, thus providing a European dimension to research in chemical sciences in order to focus and avoid duplication of activities
- Identification and elimination of barriers and addressing constraints to chemical innovation, including skills, innovation transfer, regulation and societal acceptance
- Consensus among stakeholders on methods for and interpretation of chemical risk assessments
- Determination of the socio-economic impacts of SRAs and proposed related actions, including establishing a balance between expected benefits and potentially undesirable consequences of the prioritised new technologies.

The Technology Platform will be instrumental in stimulating both public and private sectors in Europe to commit more dedicated funds to chemical R&D, and in addressing major chemistry-specific barriers and constraints in order to meet the required pace of innovation. This is fully in line with the EU Lisbon strategy and related EU actions defined, for example, in the 3% Action Plan[7] and in the Innovation Action Plan (in preparation)[8], and fits the perspectives of the future of EU Research as recently communicated by the Commission.[9]

Scope: Three technology sub-platforms and horizontal issues

The outputs from the chemical sciences have such a broad impact, including in life sciences, computational sciences, and advanced methods of process engineering and control, that research requires discovery activities and invention across the entire spectrum of the chemical sciences: from fundamental, molecular-level chemistry to large-scale chemical processing technology and cross-disciplinary collaborations with biology and physics, as well as with underpinning chemical technologies such as catalysis and emerging technologies like nanotechnology. [10]

Three key technology areas for the Chemical Industry and its partners have been identified, which are critical and open for further innovation, and together they will provide a balanced approach towards improved eco-efficiency. Furthermore, horizontal issues, including the financial, regulatory and societal dimensions, should also be addressed to boost investment. These are the four challenges facing the Technology Platform. Rationales and perspectives for each sub-platform and horizontal issues are briefly depicted below; more details are listed in the annexes.

Each technology sub-platform will develop its own detailed vision and action plan, based on the views of the respective stakeholder communities involved, and will include relevant existing and future European networks, such as ERAnets (*e.g.* ERA Chemistry) and Networks-of-Excellence. The platform as a whole aims to facilitate breakthrough developments at disciplinary and sectorial interfaces based on the interdisciplinary approaches of the individual sub-platforms.

Industrial Biotechnology

Industrial biotechnology is an emerging technology area entering its 'growth' stage. It is increasingly impacting the chemical sector, enabling both the conversion of (renewable) resources, such as sugars or vegetable oils, and the more efficient conversion of conventional raw materials using biotechnological processes (including biocatalysis) into a wide variety of chemical substances, many of which cannot be made directly by synthetic routes.[11] These include fine and bulk chemicals, pharmaceuticals, bio-colorants, solvents, bio-plastics, vitamins, food additives, bio-pesticides and liquid bio-fuels such as bio-ethanol and bio-diesel.

Biotechnology is proving its worth as a technology that can contribute to sustainable industrial development delivering eco-efficiency through:

- Reduced usage of water and traditional chemicals.
- Reduced use of energy, and thus lower levels of fossil fuel CO_2 emissions. Substitution of a number of chemical processes could make a significant contribution towards meeting the targets set by the Kyoto treaty.
- Increased use of renewable resources, whether as chemical feedstock or fuels. Growing rather than extracting will reduce the use of fossil fuels and is carbon-neutral.
- Production of new materials. Cell cultures are unique in their capacity to make new pharmaceuticals and vaccines which could not otherwise be made.
- Processing of biomass for bulk chemical applications including thermochemical and (catalytic) hydrothermal biomass conversion processes.

Industrial biotechnology needs to be nurtured to overcome a number of barriers before its full potential can be realised. Challenges include the integration of disciplines such as biochemistry, microbiology, molecular genetics and process technology to develop useful processes and products, based on microbial, animal or plant cells, their organelles or enzymes as biocatalysts. Europe is facing fierce competition from the USA and Japan which have long term plans and large R&D commitments in place in this area. There are additional problems blocking industrial biotechnology's

Industrial biotechnology has been in use now for two decades as laundry detergent enzymes; it has also been used to make penicillin and an alternative to animal-derived insulin, as well as to produce many vaccines and medicines. Last year, a number of recent cases of industrial use of biotechnology were described,[11] ranging from relatively small-scale production of vitamins to large-scale bio-based plastics production, including the use of enzymes in textile applications, exemplifying the area's potential to increase materials and energy efficiency while reducing emissions.

development. The raw materials or feedstock like vegetable oils and glucose needed for bioprocesses are expensive and the enzymes used to convert the material require a high investment in research and long development times. An increased level of research and investment in developing cheap feedstock and powerful enzymes is crucial.

The Industrial Biotechnology initiative has already identified and engaged with its key stakeholders and is progressing its vision activities.

Materials Technology

Discovery of new materials with tailored properties and the ability to process them are rate-limiting to new business development in many industries. 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, and their recyclability.

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.

Application areas of interest include:

- Functional Materials and bio-(compatible) materials with tailored properties which include thin films and surface coatings, drug implant technologies and medical prosthetics using nanotechnological and bio-mimetic materials concepts.
- Intelligent Materials with tailored electrical (*e.g.* superconducting), optical and magnetic properties for applications in electronic devices such as displays or sensors, and for the support of quantum computing.
- New sustainable technologies in the areas of both energy and environment, which include catalysis and renewable energy sources such as solar and fuel cell technologies.
- New methods of polymerization, including catalysis.

There is a need for enhanced identification of opportunities, in close cooperation with partner industries down the value chain, and to coordinate and enhance public-private research to move beyond the limited nature of industrial research programmes and avoid fragmentation and duplication of efforts.

Areas of research interest include:

- Computer simulation of materials properties and processes including advanced processing, manufacturing systems, high throughput experimentation, and prediction of product properties.
- Developing spontaneous **self-assembly** techniques as a useful tool for the synthesis and manufacture of complex systems and materials. Mixtures of chemical components could organise themselves into complex structures spanning the nano scale to the macro scale.

The confluence of market demand and innovative technology development will create many opportunities for new enterprises in the materials sector, amongst which will be new high technology leaders. Moreover, innovation in this area will drive many innovative, high-value applications in the downstream industries.

> Nanotechnology is an emerging technology that allows the exact design of material properties by controlling parameters such as domain properties at the molecular level. The new technology has the potential to make a significant impact on our world. Like chemistry it has an enabling character – it underpins technology clusters of importance to the EU such as materials and manufacturing. Application areas include construction, cosmetics, polymer additives, functional surfaces, sensors and biosensors, molecular electronics, targeted drug release and manufacturing. Design approaches are miniaturisation and molecular assembly.
> Although there is nothing like a single "discipline" called "nanotechnology", the ability to design the properties of many materials on molecular scale will be crucial for most high-value applications. The technology development will go hand-in-hand with assessing and managing the balance between benefits and risks.

Reaction and process design

Reaction and process design is of vital importance for the chemical industry. Product life cycles are becoming shorter and specialty chemicals evermore rapidly become higher volume commodity products.
The only way to remain profitable under these high cost pressure conditions is to keep a high level of excellence in the area of *process intensification*. It is of paramount importance to have the best, i.e. the fastest, cheapest and cleanest production processes.

Reaction and process design is an overarching technology that can be applied to all areas of chemistry. The importance of technology leadership in this area is even more important due to the commercial threat from Asia where chemical products are produced at lower costs than in Europe. In many cases, the focus of chemical research, as opposed to pharmaceutical and agrochemical research, does not lie in the search for novel structures, but in the optimization of production processes for basic chemicals, intermediates and fine chemicals known to society for many years.

Catalysis is the chemical and molecular science that focuses on accelerating and increasing the material and energy efficiency of chemical reactions. More than 80% of the processes in the chemical industry (including pharmaceuticals), worth approximately €1500 billion, depend on catalytic technologies (Source: VCI). Catalysis directly contributes 2 to 3% of the EU's GDP, and an order of magnitude larger when taking into account industries that depend on chemical raw materials (source: OECD). There is constant need for improved conversion technologies and new catalysts including enzymes, coupled with novel reactor and process technologies.

In reaction process and design, two complementary, yet distinct, approaches have to be aligned:
- A Process Science and Engineering approach dealing with (reactive) distillation, crystallization techniques, reactor design, drying methods and separation and purification techniques that will include process analysis, modelling and control.
- A Chemical approach, dealing with the development of products such as catalysts, novel synthetic routes, new reactions and novel solvents.

The Technology Platform will reflect the way this field enhances the synergy at universities between research and education in chemistry and chemical engineering, and will promote the necessary interactions between these disciplines. This sub-platform aims to bring chemical sciences, chemical technology and engineering sciences closer together to result in innovations in reaction and process design.

Chemical innovation: Horizontal issues and constraints

A strategic approach to innovation is required to achieve focus on value creation from a sustainability perspective rather than cost reduction or environmental performance only. This is a key advantage of the Technology Platform as it can more effectively address the integration of all the factors underpinning eco-efficient innovation.
This is particularly true as the industry seeks to control the health and environmental impacts of new technology developments within supportive and effective regulatory frameworks.
Successful innovation is never defined

by scientific and technological aspects alone, but equally by other factors that need to be addressed to enhance investments in new industrial applications.

There are many cross-cutting factors that need to be addressed including:

- Education and skills.
- Knowledge and technology transfer mechanisms.
- Research on health, safety and environment-related issues, such as the reduction of risk assessment costs and animal testing through improved methods.
- Research infrastructures and engagement in EU research funding programmes including researchers' mobility.
- Engagement and alignment with relevant other (EU) initiatives, for example the European Research Council (in preparation); related European action plans and initiatives such as the "3%",[7] Environmental Technologies,[4] Innovation[8] and Manufacturing Technologies[12] action plans, and other European Technology Platforms for which chemistry is an essential enabling technology.
- Access to venture capital.
- Congruence between effective regulation and stimulation of innovation; for example the eventual need for regulation impact assessment.
- Building confidence in new technologies by raising awareness of the general public.

A number of general innovation issues, which are beyond the specific remit of this Platform have also been identified. These issues will be monitored and contributions made to policy discussions as appropriate. The issues include:

- Intellectual Property Rights exploitation and protection
- State-aid for R&D
- Technology Transfer Block Exemption regulation

There is a need for a number of other political and fiscal measures, as well as efforts to increase the public's awareness about new chemical technologies, for which this Platform can serve as an interface with the European Institutions.

Partnership and organisation of the Technology Platform

Partnership

The Technology Platform will consist of a network of strategic and intellectual alliances that bridge academia, industry and relevant additional partners, to foster the whole innovation process from idea to product launch.

While the Platform will be industry-led, it is imperative that this is a real partnership with other key stakeholders to enable a shared vision to be developed.

Technical solutions to unsolved problems can only be achieved by close collaboration between academic and industrial research, therefore first rate academic partners as well as research councils, in particular through relevant ERAnets such as ERA Chemistry, will play a pivotal role in the proposed research activities. Industrial partners from across the value chain will have a key role in relaying their demands for new chemistry. To enable smooth transition of an invention into the market, financial institutions, for example the European Investment Bank and venture capitalists, also need to be in close contact. Innovation framework matters can only be effectively addressed by close engagement with policy makers and regulatory bodies.

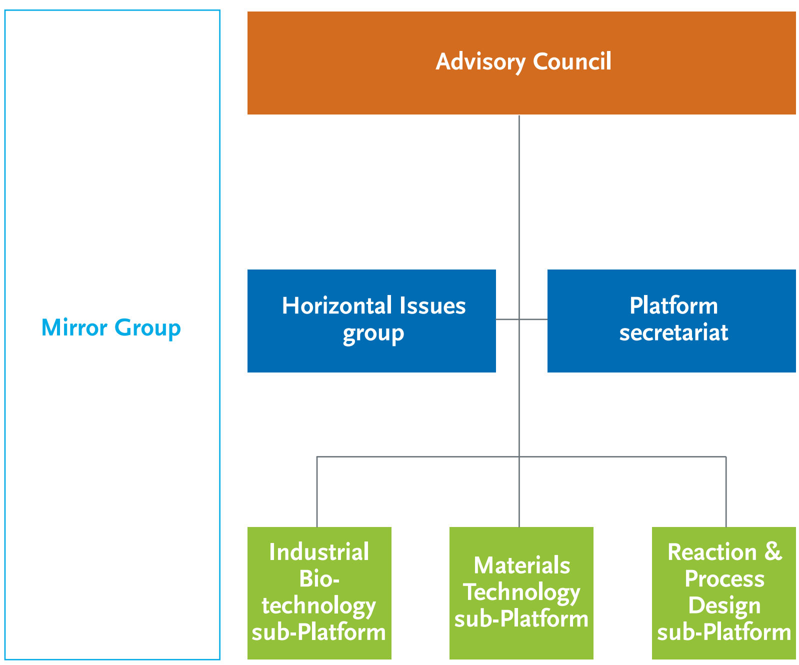
The Technology Platform should have a transparent structure and this openness will be key to achieving public trust. The composition of the partnership may grow or change as the priorities evolve.

The combination of skills and infrastructure to support this initiative is already considerable in Europe, in particular among the members of the AllChemE alliance[13]. We now need to put it to work in a concerted manner.

Platform organisation

A high-level 'Advisory Council' (AC), consisting of balanced delegations of various constituencies, will serve as the Platform's board.

Figure 5: A possible organisation structure of the Technology Platform



The high-level Advisory Council will have the mission to:

- Develop an overall long-term vision and general innovation targets.
- Improve co-ordination and best added-value between the sub-platforms.
- Organise horizontal activities agreed by all three sub-platforms.
- Form the policy interface on issues common to the three sub-platforms.

In order to create an efficient and flexible body the Advisory Council will consist of a limited number of high-level representatives from industry, government including the European Commission, academia and other key stakeholder organisations, bringing constructive yet differing views and having a decision-making mandate. The Advisory Council members are nominated by the three sub-platforms with equal numbers of representatives per sub-platform. The Advisory Council should include the sub-group leaders who together form the board's Executive Committee.

Four sub-groups will coordinate the respective technology areas proposed

- Industrial biotechnology
- Materials technologies
- Reaction and process design
- Horizontal issues

The task of the technology sub-platforms and the horizontal issues group will be to:

- Develop a long-term vision, innovation targets and a Strategic Research Agenda.
- Form the policy interface on specific issues.
- Plan, acquire and manage specific projects and programmes.

A mirror group, consisting of representatives of Member States and eventually of additional stakeholder organizations, will allow coordination with national initiatives and projects, ensure a two-way flow of information from and towards the (sub-)platform(s), and act as a discussion forum for Member States. The mirror group may articulate its work addressing sub-sector-specific issues. A discussion with Member State representatives should lead to an appropriate organizational structure.

The Platform will be supported by a Platform Secretariat.

Annexes

Annex 1. Industrial Biotechnology.

Whereas in the past, eco-industries have mainly been associated with end-of-pipe technologies focusing on waste treatment rather than waste prevention, modern industrial biotechnologies are preventive, focusing on cleaner manufacturing processes to minimize waste in the first place. Industrial biotechnologies range from the use of enzymes or whole cell systems to catalyse chemical conversions of conventional or renewable resources, to thermo chemical and (catalytic) hydrothermal (sub- and supercritical water) biomass conversion processes for bulk chemical industry. Some examples are:

1. Vitamin B2 through Bio synthesis resulted in 95% less waste and 40% costs reduction
2. Antibiotic production was simplified from a 10 step procedure to 1 step, achieving 65% less waste, 50% less energy consumption and 50% cost reduction
3. The application of enzymes in the textile industry resulted in 25% lower energy consumption and 60% lower emissions
4. Use of Bio-polymers derived from corn (renewable) requires 17-55% less fossil fuel input (not renewable)
5. Fuel and bulk chemistry benefit greatly from production biomass with total elimination of net CO_2 emissions.

The prospects

Further development of industrial biotechnology will thus enable improvement of current chemical processes as well as allow for the use of unconventional renewable raw materials including low value biomass.

Although a small number of biotechnology industries are involved in industrial biotechnology today, its contribution will be most keenly felt in the EU's heavy industries that will increasingly depend on it to remain competitive. Chemicals, textiles and leather, food, animal feed, paper and pulp, energy, metals and minerals and waste processing are industries already using biotechnology processes today.

The development of industrial biotechnology is of great interest to the European chemical industry and agro-industry. Out of the collaboration of these two industries, entirely new chemical activities can be created, as has already been demonstrated abroad. Also, industrial biotechnology may contribute significantly to the future of European agriculture, and as such is very relevant for the sustainable development of our society.

A McKinsey study has indicated that the market share of industrial biotechnology will strongly increase in all areas by 2010, but particularly in fine chemicals production. The estimated penetration degree by 2010 is estimated to lie between 30 to 60 % for fine chemicals and between 6 to 12 % for polymers and bulk chemicals. Taken over the whole of the chemical industry, the penetration of biotechnology is presently estimated at 5 % and this is expected to increase by 10 to 20 % by 2010, and strongly increase further afterwards. The penetration rate will depend mainly on a number of factors such as the future technology development, the overall demand, the feedstock (sugar and derivatives *e.g.* starch, molasses) prices, and the policy framework.

Mc Kinsey estimates that the chemical industry could generate additional added value of €11 to 22 billion per year by 2010, depending on whether the uptake is slow or fast.

Two sources will contribute to this: cost reductions, such as lower costs for raw materials and processing, combined with smaller scale investments for fermentation plants. The other source is additional revenues from innovative products and processes.

The US National Research Council has produced similar numbers. They estimate that 10% of liquid fuels and 25% of organic chemicals will be produced from renewable resources by the year 2020.

Possible areas for future research

The main long-term applications of industrial biotechnology within green chemistry will be the replacement of fossil fuel by renewable materials (**biomass and biomass conversion, organic waste**), the replacement of a conventional, non-biological process by one based on biological systems (**bioprocesses, metabolic engineering etc**), and the **development of new bio products, including antibiotics and drugs.** Industrial biotechnology is a multidisciplinary technology and includes the integrated application of disciplines such as biochemistry, microbiology, molecular genetics and process technology to develop useful processes and products, based on microbial, animal or plant cells, their organelles or enzymes as biocatalysts.

More interdisciplinary applied research effort is needed in this domain. To overcome fragmentation and obtain critical mass, research clusters and networks must be created that can grow into real centres of excellence.

Important research areas could be:

- The discovery, development and optimisation of powerful and efficient biocatalysts, and the design of proteins and/or enzymes which have novel functions.
- Low-cost raw materials for bioprocesses.
- Metabolic pathway engineering.
- Efficient reaction and separation technology.
- Effective expansion on bio process and expansion on recycling possible products.
- Atom-efficient biotechnological alternatives to conventional chemical technologies.

To date, most efforts to develop bio product and bio energy markets have focused on increased research. In the area of biomass, the USA is spending nearly ten times as much as the EU on research programmes.

Although research is essential to building these markets, it is not in itself sufficient. There are additional problems blocking industrial biotechnology's development.

The raw materials or feedstock like vegetable oils and glucose needed for bioprocesses are expensive and the enzymes used to convert the material require a high investment in research and long development times.
An increased level of research and investment in developing cheap feedstock and powerful enzymes is crucial.

Annex 2. Materials Technology

Discovery of new materials with tailored properties and the ability to process them are rate-limiting to new business development in many industries. The demands of tomorrow's technology translate directly into increasingly stringent demands on the chemicals and materials involved – their intrinsic properties, their costs, their processing and fabrication, and their ability to be recycled.

Materials science deals with the design and manufacture of materials, an area in which chemistry plays the central role; there is considerable overlap with the field of chemical engineering and physics. Anyone can relate to such substantial contributions as modern plastics, paints, textiles, and electronic materials, but greater opportunities and challenges for the future remain. The materials sector of the chemical sciences is vital, both fundamentally and pragmatically, for all areas of science and technology—as well as for the societal needs in energy, environmental protection, transportation, security, and medicine.

The prospect

It is beyond the scope of this document to make an exhaustive map of the future of this important area of innovation. Some examples are:

The electronics industry, which continually seeks new materials for superconductors, polymeric conductors and semiconductors, dielectrics, capacitors, photo resists, laser materials, luminescent materials for displays as well as new adhesives, solders and packaging materials.

Speciality polymer industries would benefit from 'intelligent' composite materials based on organic or inorganic materials and also bio-compatible materials to design longer lasting batteries, smaller and more stable sensors, improved fibres for clothes, prosthetics and implants, and more. Semi-conducting polymers could save our environment and our economies of the large burden due to corrosion issues.

In energy production and transportation, new materials with useful conducting and **superconducting** properties will have a significant impact on our society when they are developed into a practical system for the transmission of large electrical currents over long distances without energy losses.

New materials with lightweight construction will greatly enhance the efficiency and environmental sustainability of surface and air transport.

The most common form of surface engineering is painting. While paints prevent corrosion and water damage, they need to be renewed on a regular basis, which is costly and labour intensive. One significant contribution to modern life would be the development of **long-lasting coatings** with high scratch and weather resistance smart functional packaging materials, and even self-cleaning and self-healing properties. Such **surfaces** can easily be cleaned by rain, and have a mechanism to self-repair after any surface damage.

The path from electronics to biological function goes via Chemistry. Sensor technology provides a connection between biological function and an electrical signal. Advanced sensors and new microanalytical devices will have a substantial impact on health, environment, and individual protection strategies in the coming years. The ability to reliably link biologically active molecules to a surface will take functional integration to levels previously deemed impossible. This provides huge opportunities for improved medical devices and drug delivery strategies. Another aspiration is the design of materials that mimic the behaviour of physiological systems such as muscle. In addition, new sensor systems could help to detect chemical or biological threats and play an important role as components of security systems.

The chemical industry itself searches for new catalysts and many other product classes to meet increasing requirements on performance, cost and environmental impact of many of its products.

Possible areas for future research

The astonishing progress in chemical science and engineering during the 20th century make it possible to envision new goals that might previously have been considered impossible. This Technology Platform will identify the key opportunities and challenges for Material Sciences, from basic research to societal needs and from resource utilisation to environmental protection. It will look at ways in which chemists in industry and academia can work together to contribute to an improved future of our society. The focus of the activities goes well beyond the limited nature of industrial R&D programmes.

Nanotechnology: more than just a catchword.

Nanotechnology spans many areas, including nanoparticles, nanocomposites and custom designed nanostructures that find applications running from polymer additives to drug delivery and cosmetics. Europe has the expertise needed to develop a technologically competitive advantage in many of these applications. Although there is nothing like a single "discipline" called "Nanotechnology", nevertheless the ability to design the properties of much material by virtue of controlling domain size at the molecular level will be crucial for most high-value applications. A strong emphasis on these technologies characterises the long-term strategic direction of government supported research in both Japan and the USA. A confluence of market demand and innovative technology development will create many opportunities for new businesses in the materials sector; amongst which will be new high technology leaders. Moreover, the innovations in this area will drive many innovative, high-value applications in the downstream industries.

Annex 3. Reaction and Process Design

Reaction and process design is of vital importance for the chemical industry. The life cycles of products are becoming shorter and specialties are transformed rapidly into commodities. The only way to remain profitable under these high cost pressure conditions is to keep a high level of excellence in the area of *process intensification*. It is of paramount importance to have the best, *i.e.* the fastest, cheapest and cleanest production processes.

Process Science and Engineering, including engineering technologies, engineering science, and engineering design dates back to the 1930's and it is the foundation for the development, scale-up and design of chemical manufacturing facilities. When effectively integrated with basic science and enabling technologies, this area offers great potential for a quantitative understanding of chemical manufacturing allowing for improved yields, reduced waste and higher capital utilization.

Reaction and process design is an overarching technology that can be applied to all areas of chemistry. The importance of technology leadership in this area has gained even more importance due to the threat originating from Asia where chemical products are produced at lower costs than in Europe. In many cases, the focus of chemical research, as opposed to pharmaceutical and agrochemical research, does not lie in the search for novel structures for active ingredients, but on the optimization of production processes for basic chemicals, intermediates and fine chemicals known to society for many years.

The prospect

As a result of the long tradition in process research and engineering, a great amount of know-how is already available. The challenge today is to concentrate engineering research in non traditional reaction and separation systems: *e.g.* plasma and supercritical media; alternative activations *e.g.* microwave, photochemical, or electrochemical; reactive extraction and distillation and membrane reactors, as well as development of new concepts in flexible manufacturing process technology, *e.g.* the area of micro reactor technology, and the development of modular reaction techniques.

Possible areas for future research

Catalysis

Catalysis is implemented throughout the chemical production processes, because it is a key technology for the chemical industry, which through multidisciplinary focused collaborative research could result in major further developments. New approaches in catalysis should help us to move to more efficient, higher yielding chemical processes, to near zero-waste processes and to more energy efficient processes significantly reducing energy consumption. For example, there are still a number of current processes for the manufacture of fine chemicals where as much as 100 kg of waste is produced for every kg of product.

Areas in which catalysis research could provide a long-term solution through integrated cooperative research at the frontiers of knowledge include:

- Catalytic activation of C-H in alkanes: This could lead to a breakthrough in petrochemical production which could be based on alkanes constituting the major part of natural gas reserves, and not olefins from oil.
- Implementation of hydrogen as a source of energy: A number of challenges for catalysis in this area are present, *e.g.* the search for alternative sources of hydrogen not involving fossil fuels such as utilising hydrogenase enzymes, replacement of reformer catalysts for direct conversion in fuel cells; substitution of precious metal catalyst with a lower price CO tolerant catalyst so that the mass production of fuel cells can become feasible.
- Catalytic methods for transformation of complex molecules: this topic is of special importance in the area of fine chemicals production, the synthesis and immobilization of catalytic reactive centres in solid state surfaces; development of new materials by novel paradigms in nanotechnology to provide materials with higher specific surfaces. Also, selective hydrogenation and oxidation, bio catalysis (overlapping with industrial biotechnology initiative) as well as multi-site/multi-reaction catalysis are of great interest.
- Feedstock alternatives and new sources of energy from biomass: Utilizing catalysts for obtaining a number of products from renewable resources; *e.g.* biomass, synthesis gas, innovative developments across refinery/chemicals interface; unifying

themes (feedstock opportunities) across sectors *e.g.* bulk and fine/specialty groups.
- Process aspects of industrial catalysis, *e.g.* product-catalyst separation and (metal) catalyst recovery, multi-site catalysis, multi-phase reactors,

More fundamental understanding of catalysis mechanisms and tools for increasing R&D efficiency are essential.
- Understanding of catalysis: Most of the results in catalysis originate from empirical investigations, it would provide a breakthrough in the chemical research if the activity of catalysts could be rationally designed and, therefore, tailor-produced for a given transformation. Use of molecular and quantum mechanical modelling for rational design and understanding of catalysts.
- High Throughput Experimentation (HTE) for development of new catalysts. High Throughput Experimentation poses a great opportunity for catalysis since it would allow for rapid identification and development of novel more effective catalysts. However, many questions still remain to be answered before HTE can expand. Often we create more data than we can handle or interpret effectively. How do we transform the data input and database to provide knowledge of key process parameters such as kinetics? New data mining tools and capability development together with informatics are required; the bridging to bigger scales and eventually to manufacturing has not yet been tackled systematically.

Organic chemistry

Synthetic organic chemistry is a discipline that provides a cross-cutting technology for the production of chemical materials and a skill base with the know-how required by the industry.

Analogous to catalysis, organic synthesis, despite being an old dog, is learning some new tricks that will have great impact in the future of the chemical industry. Many key areas concerning novel solvents:
- Use of water as a solvent: Water is one of the cheapest and most environmentally friendly solvents; however, most conventional chemical transformations take place in organic solvents. By contrast, nature carries out chemical reactions with ease in water at pH close to neutral using enzymes and ribozymes. Therefore new paradigms in research have to be developed, including biochemistry-based ones which are included in the Industrial Biotechnology sub-platform in order to implement the use of water in organic synthesis, not only dealing with the stability of reagents and catalysts, but also with the solubility problems of adducts and products.
- Supercritical solvent technology: supercritical solvents, especially carbon dioxide, offer novel synthetic options due to their unusual solvating properties (low dielectric constant) coupled with ease of removal of the solvent, and options for phase transfer catalysis.
- Ionic liquids: Ionic liquids have been described as green solvents, as a result of their low vapour pressure, and some commercial processes have been developed recently, yet a lot of research has to be carried out before ionic liquids could be used widely in the chemical industry. The separation of the final product from the solvent is a problem that still remains to be solved, fundamental studies on the properties of ionic liquids and the kinetics and reaction parameters in ionic liquids are still unknown. The wide variety of ionic liquids available and the possibility of having a tailored synthesis of ionic liquid for a given applications, *e.g.* as new conducting materials, open a great deal of opportunities in this topic.
- New synthetic methodologies: a key aim for future more sustainable organic synthesis is to increase 'atom efficiency' – the minimization of reaction steps and the use of different chemical reagents. In the future, enzyme(-based) catalysis will be key here. Another aim is to enable the use of renewable resources and waste gases like CO, CO_2.

Annex 4. Horizontal Issues

Successful innovation is never defined solely by scientific and technological aspects. Many other factors need to be addressed. These include economic or financial barriers, regulation and societal acceptance. Identification and initiation of action for addressing horizontal barriers to and framework conditions for chemical innovation will therefore be an integral aspect of the European Technology Platform for Sustainable Chemistry.

The Prospect

Examples of key barriers and framework conditions that will need to be characterised and potentially addressed include:

Education, Skills and Knowledge Base: The availability and mobility of an appropriately qualified and skilled labour force is essential to the long-term viability and innovative capacity of the European Chemical Industry. The ability to attract high quality human resources and funding for chemistry education throughout an enlarged Europe is an objective to be pursued with partner organizations such as the Alliance for Chemical Sciences and Technologies in Europe (http://www.allcheme.org).

Industry-Academia Research Collaborations: Collaborative research is an important driver of innovation. Facilitation of cooperation with academic partners to access remote expertise and shorten time to market is an aim of the Technology Platform.

Regulatory Safety Assessment: Use of chemicals requires effective management of any potential risk to both health and the environment. There are societal and regulatory concerns about the effectiveness of risk management of chemicals that could effectively constitute barriers to the adoption of new chemical technologies or the continued use of existing technologies. Potential partner organisations for addressing such constraints include the Joint Research Centre (JRC) and the European Chemicals Bureau (ECB).

Access to Risk Capital: Access to venture capital is a potentially limiting factor in the successful adoption and implementation of innovation. In particular, this may be the case for SMEs. Improved knowledge of sources and enhanced availability of risk capital will therefore be a success criterion for this Technology Platform. A role for the European Investment Bank (EIB), the European Investment Funds (EIF) and private venture capital providers can be envisaged in this respect.

Possible areas for future research

Chemical Safety: The support and development of appropriate techniques, test methods, tools and models for use in effects and exposure assessment as part of the risk characterisation of chemicals is an appropriate activity for the Technology Platform. Congruence of the Commission's research policy with evolving Community regulatory policy on chemical safety is a key step in addressing potential barriers in this area. Failure to ensure congruent policy initiatives will stifle any attempts to stimulate innovation and competitiveness. A collaborative role for the JRC and the Cefic Long-Range Research Initiative (LRI) can be envisaged here.

Animal Testing: Current regulation of the chemical industry mandates the use of animal testing for existing and innovative chemicals. The chemical industry is therefore dependent on the use of animals in testing in order to substantiate human and environmental safety of products and services. However, societal and regulatory acceptance of animal testing is decreasing. In turn, this increases pressure on the need to develop alternative methods (based on Refinement, Reduction or Replacement i.e., the 3Rs) without jeopardising safety. The European chemical industry will therefore face major challenges in the near future with regards to the requirements and restrictions placed upon it vis-à-vis the use of animals in safety testing. This will constitute a barrier if left unaddressed and provides the justification to tackle these challenges in conjunction with partners such as JRC. Areas of activity may include *in silico* as well as *in vitro* approaches and other efforts focused at refinement of interpretation or reduction in animal use compared to existing test protocols.

Risk Communication: The actual risk from innovative technologies (as opposed to perceived risk) also needs to be effectively communicated to broader society to ensure societal acceptance. Historical failures in this respect have shown that societal acceptance is an effective barrier to innovative technologies. As such this aspect cannot be ignored in any European Technology Platform for Sustainable Chemistry.

References and notes:

1 Unless stated otherwise, data source is Cefic throughout the document.

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11 EuropaBio publication: *White Biotechnology, the gateway to a more sustainable future,* http://www.europabio.org/upload/documents/wb_100403/Innenseiten_final_screen.pdf

12 http://www.manufuture.org

13 AllChemE is the Alliance for Chemical sciences, technologies and engineering in Europe, joining industrial (CEFIC), academical (FECS, EFCE and COST Chemistry), governmental research funding (CERC3) and educational (ECTN) members of the European Chemistry community. www.AllChemE.org

FECS, through its member societies and their 150,000 individual chemical scientists in academia, industry and government across Europe, welcomes the initiative to establish the Technology Platform 'Sustainable Chemistry'. FECS looks forward to involvement as a major stakeholder in setting the chemistry research agenda in support of a dynamic environment for researchers and the future economic prosperity of Europe.

Professor Gábor Náray-Szabó, President, FECS.

The Royal Society of Chemistry welcomes the formation of the platform as positive support for the essential role that chemical science based technologies will play in the future success of the European economy.

Professor Sir Harry Kroto, President, RSC.

CERC3, representing the national research councils in the EU member countries which have responsibility for funding research and related postgraduate training in basic chemistry, welcomes the announcement of the European Technology Platform for Sustainable Chemistry. CERC3 looks forward to participate in setting a European chemistry research strategy.

Dr. Louis Vertegaal, chairperson-elect, CERC3.

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