INCA
Consorzio Interuniversitario Nazionale
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Excerpt from

Research plan of the INCA Consortium

Prepared by the Scientific Board in March 2010

Macro-area II - Technologies

A) Clean Technologies and Renewable Energy Sources

A sustainable industrial development must take into consideration issues such as environmental impact, energy consumption, valorisation of raw materials and the quality of end products. To this end, it is necessary to understand the molecular mechanisms which allow chemical transformations. In this way, it is possible to devise new eco-compatible and sustainable processes. Two classical examples are the decreasing use of separation processes based on state passage with heating and the increasing utilization of membrane-based molecular separation.

The use of renewable energy sources such as solar, wind, geothermal, and saline gradients is particularly relevant, along with the net energetic balance and yield of each productive phase. Such alternative energies are well coupled with non-thermal separation processes, which are conducted at room temperature or at just slightly higher ones.

Studies about the integration of new energy sources with separation processes and chemical transformation are really important. Photochemical reactors and submerged membranes reactors (already considered as the best available technologies for the treatment of civil wastewaters) are some of the interesting research fields, with notable potential for development and use in several productive cycles.

Membrane Bio-reactors (MBRs) are an emerging technology for the depuration of waters, they combine the use of suspended biomass, similar to that of activated-sludge plants, with a membrane system. MBRs display several advantages with respect to classical water treatments: wider operational range, high robustness with respect to peaks in the incoming load, smaller dimensions, possible automation for most of the operations, reduced need for manpower and maintenance, reduced sensitivity to changes in hydraulic fluxes, and easy scaling-up for treatments ranging from 1 to 100,000 cubic meters per day.

B) Process Intensification

At present, it is extremely difficult for chemical industries to satisfy the growing need for raw matters, energy, and products in a sustainable development framework, future challenges will concern: i) intensification and multi-scale control of processes, ii) devising of new operations and methodologies, iii) the identification of new procedures to guarantee the high quality standards required for end-products, iv) the implementation of computational applications fit for managing the several phases of a process, from molecular to industrial scale.

The term "Process Intensification" (PI) defines a strategy aiming at achieving tangible benefits for productive cycles, through a significant reduction of the dimensions of the machineries, possibly down to real miniaturization. The conceptual correlation between sustainability and physical dimensions of a productive plant should be the core guideline for the planning and building of new machineries and the design of operative protocols. These would provide more flexibility and safety to industrial processes, along with advanced automation, reduced energy consumption, minimization of wastes, in one word: a major eco-sustainability.

There are two fundamental research sectors on PI: i) the design of new machineries, processes, and plants (hardware) and ii) the implementation of new methods and protocols for already existing unitary operations (software). Research areas of major interest are shown in Fig. 1.

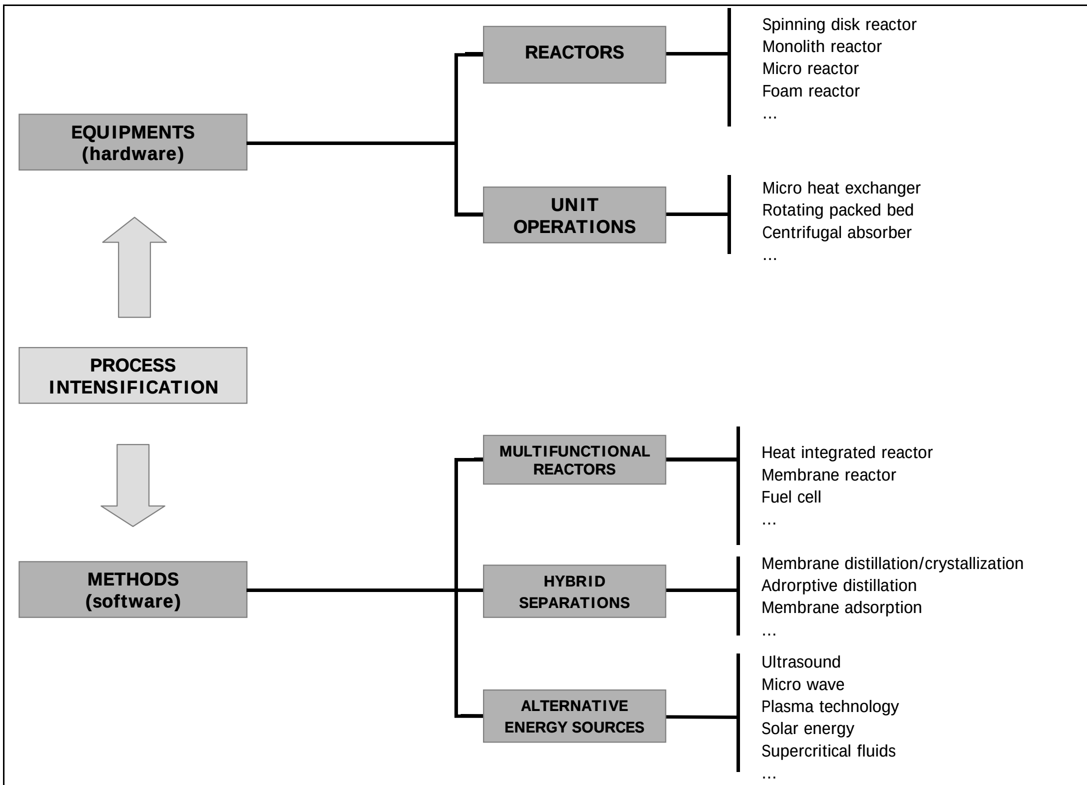

Fig. 1 Research areas related to PI

The recent European Roadmap for Process Intensification (2008) has identified potential benefits in three industrial fields of strategic importance: i) petrochemical, ii) pharmaceutical, and iii) food industry. In the petrochemical sector energy consumption is a fundamental factor for the definition of the price of end products. In this case, an increased energy efficiency would allow for economical and ecological benefits (reduced production of greenhouse gases). Commercial competitiveness is a primary objective of pharmaceutical industries. In this respect PI can provide a valid contribution through an increased reaction selectivity, better yields of the processes, and higher purity of the end products. The processes of food industry are generally characterized by high volumes of diluted spent liquids to be treated according to the low stability of raw matters. In this field, commercial viability is dependent on the costs of product transformation and of the treatment and disposal of liquid wastes. Both these aspects could be improved by the application of PI.

Process Intensification is often based on radically innovative principles ("paradigm shift"). For their application it is necessary to overcome some conceptual and practical barriers; the main ones being:

- insufficient know-how possessed by the process technicians;
- lack of pilot plants and high (technical and financial) risks connected to the implementation of PI devices at an industrial scale for existing productive processes;
- high (technical and financial) risks related to the production of prototypes at an industrial scale;
- lack of specific control systems for innovative PI devices;
- insufficient awareness about the potential benefits of PI at a managerial level.

Some combined actions are needed to overcome the abovementioned barriers, some of these actions have been already implemented:

- a specific financial support to fundamental and applied research is a prerequisite in order to reach the "proof-of-concept" on a lab scale, followed by the scaling-up to pilot plants (such research topics are specifically addressed by FP7 of the EC);
- the development of new analytical and monitoring methods (including *in-situ* ones), allowing a better comprehension of the thermodynamics and kinetics of chemical processes at a molecular level;
- the implementation of faster and more reliable non-linear models for chemical reactions;
- a wider knowledge dissemination.

C) Environmental Biotechnologies

In the future, biotechnologies will be applied more and more frequently for environment protection, since they are generally cheaper and more eco-compatible than chemical and/or physical processes.
The scaling-up from lab to on-field application requires a multi-disciplinary approach, integrating several techniques. It is fundamental to verify the economical feasibility of the process to be scaled-up. The environmental biotechnology sectors characterized by the most intense and innovative R&D activities are:

- Civil and/or industrial wastewater depuration (chemical, biological, and physical methods, bioreactors, photo-degradation, bio-photo-degradation).
- Bio-electrochemical processes: development of MFC (Microbial Fuel Cells) which couple degradation of pollutants with energy production in a very innovative fashion; they use electrodes as direct electron donors for the anaerobic microbial respiration, producing hydrogen, methane and other compounds with an high added value.

D) Industrial Biotechnologies

The state-of-the-art at a national and international level

The term White Biotechnologies collectively indicates industrial and environmental ones, which are of interest to several industrial sectors:

- Pharmaceutical companies are a classic example: (monoclonal) antibodies, vaccines, vitamins, amino acids, excipients and so on.
- Food industry is another productive sector heavily exploiting biotech: microbial starters, enzymes, proteins, organic acids, vitamins, amino acids, etc.

- Biotech is also used for innovative application of the modern chemical and textile industries: fine chemicals, building blocks, biopolymers, bio-lubricants, etc.
- Another innovative application of biotech is in the field of cosmetics: antimicrobials, antioxidants, biopolymers, etc.
- Also energy production can take advantage of biotech: bio-fuels, bio-combustibles, etc.
- Recently, biotechnologies are being used for environmental monitoring and protection: bio-sensors, bio-remediation, bio-decontamination, bio-valorisation of wastes, etc.

Due to the continuous increase in the price of oil, new white biotechnologies are being devised every day, since they are less energy consuming than chemical ones. One of fastest growing field for their application is the production of chemicals. The US market of chemicals grew from 1,200 to 1,600 billion dollars from 2001 to 2010, in the same period the sole market of biologically-produced chemicals grew from 30 to 310 billions. An identical trend is seen in Europe, where the increase over the same period is estimated between 40% and 70% (McKinskey, June 2008).

Unfortunately, the Italian biotech industry is not fully ready to take advantage of this market opportunity. It is weak and fragmented, comprising of small companies which cannot be competitive with the huge multinationals active in this field. Nonetheless, empowering research in some particular areas would allow for an increased competitiveness.

1) New and/or upgraded bio-catalytic processes for chemical synthesis

The first area is that of new and/or upgraded bio-catalytic processes for chemical synthesis, major investigations should concern:

- optimization of the activity of existing microorganisms and enzymes;
- new rapid and effective methods to identify and select new microorganisms and enzymes;
- formulation of efficient and easy-to-use enzymes;
- improvement of the engineering of the process.

2) Innovative and/or upgraded strategies for the valorisation of biomass

A second area to be investigated is that of the innovative and/or upgraded strategies for the valorisation of biomass, production surplus, by-products, residues and spent process waters (including wastewaters) of the national food industry.

Three main specific objectives are related to this area. The first is the valorisation of biomass, residues, and by-products of the Italian food industry, aiming at a more rational use, with particular attention to biomasses alternatives to carbohydrates (such as oils/lipids or oils/fats). Bio-conversion processes should be adapted to such type of biomasses, increasing and improving the activity and stability of the enzymes/microorganisms, possibly looking for synergies with the classical oil chemical processes.

The second objective is to develop the next generation of highly efficient industrial fermentations. This can be achieved by: i) increasing the process yield (metabolic engineering, genetically improved microorganisms, specialized bacteria); ii) suitable scaling-up; iii) process intensification; iv) minimization of wastes and residuals (combined techniques for recycling).

The final objective concerns the eco-efficiency of processes and their integrations through the creation of bio-refineries. In this case, an integrated approach is necessary in order to devise new processes allowing for the use of all the components of the biomass. It is fundamental to analyze the bio-refinery value chain, in order to abate costs, reduce emissions, and integrate production pathways. Critical aspects are: i) costs and eco-efficiency of production; ii) implementation of the bio-refining technologies; iii) identification of the molecules to be produced as bulk chemicals.

3) Improvement of Bioprocesses for the Production of Bio-fuels from Biomasses

a) Hydrolysis processes utilizing low-cost biomasses already available;
b) Fermentation processes for the production of ethanol;
c) Processes for the production of biogas (bio-methane and bio-hydrogen);
d) Integration of biogas processes with systems for their conversion into electric energy, e.g. fuel cells.

4) Innovative and/or Improved Strategies for the Bioremediation of Polluted Sites and Contaminated Waters

It is necessary to investigate and develop novel bioremediation techniques; particular aspects to be examined are:
a) improving knowledge on useful microorganisms (bacteria, fungi);
b) improving process engineering in specific *in situ* conditions;
c) devising and implementing new biotech tools for the characterization of sites, the planning of interventions, and the evaluation of their results.