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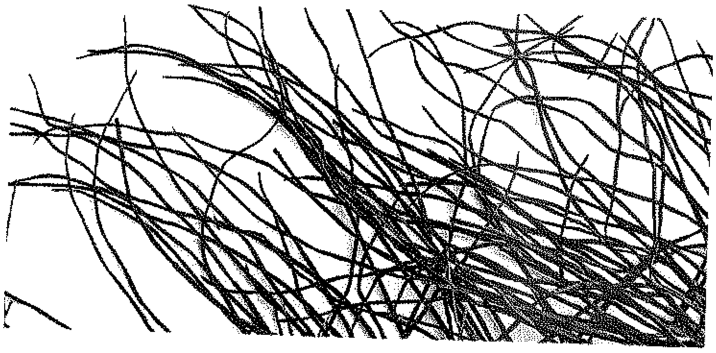

# The technological revolution of the process industry

*"Imagination is more important than knowledge"*
*(Albert Einstein)*

*Additional efforts are needed in spite of the present financial and economic crisis. Conventional ways are no longer sufficient. A thorough innovation of industry is needed and has indeed already started. Some call it the 3rd Industrial Revolution. An important feature of it is interdisciplinarity of science, technology and enterprise.*

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SINCE THE TIME OF A PREVIOUS ARTICLE, "Facing sustainable development in the processing industries" [1], published six years ago in this magazine in occasion of ACHEMA 03, the social and economic environments have changed dramatically, immersing the world in a deep crisis. During past years very populous countries such as China and India have shown a spectacular growth, bringing about an important increase of global energy consumption. According to the US Department of Energy (DOE), between 2002 and 2007 35% of the increase of the world crude oil consumption was due to China. Industrialized countries have made significant progress in developing and applying alternative energies, but these efforts are not sufficient to guarantee sustainability. At only three years to the deadline of the Kyoto Protocol in 2012, several countries are not satisfying their compromises to reduce their emissions of greenhouse gases (GHG), and will not be able to go down to the fixed limits. Even leading countries in developing renewable energies, like Spain, have increased their GHG's emissions far above their compromise with the Kyoto Protocol. Spain increased its emissions in 2007 to about 53% above the 1990 level, when it should have been only 15%. Until now the USA, the biggest energy consumer of the world, has not been coordinating its policy within the UN framework. Hopefully the new government of the USA will coordinate its climate change issues with the rest of the world.

At the beginning of this year, the United Nations Environmental Program (UNEP) stated "In the last twelve months, the climate change debate has taken a dramatic turn. The release of the IPCC Fourth Assessment Report and the Stern Review report on The Economics of Climate Change, the movie "An Inconvenient Truth", and the Nobel Peace prize awarded to the IPCC and Al Gore have galvanized public opinion and created a new momentum to address what many world leaders describe as the most serious challenge ever faced by human societies. At the same time, it is now less than just 18 months before nations must agree on a new and fully formed climate treaty under the UN Framework Convention on Climate Change (UNFCCC) in Copenhagen in late 2009."

## 1

## CALLS FOR A "THIRD INDUSTRIAL REVOLUTION"

In the new deteriorated economic and social scenario, originated by financial disasters, innovation is a must in business and industry. Today innovation has to do with interdisciplinarity. For example, oil companies now are becoming "energy companies", and are yet important players in alternative energies (wind, solar, biofuels, etc.). This is why ACHEMA 2009 claims to be the summit of the process industry in a broad sense, enclosing the chemical industry, biotechnology, the pharmaceutical and food industries, environmental technology, materials technology and energy production. Because, as stated in the ACHEMA 2009 brochure, "The process industry constantly faces new challenges; they can only be overcome by focussed interaction between the various disciplines." In his introduction to the 29th International Exhibition-Congress on Chemical Engineering, Environmental Protection and Biotechnology, Professor Gerhard Kreysa, Chief Executive of ACHEMA, warns that "It is not banks and services, but steel, cement, chemistry and engineering that constitute the pillars of any affluent society." He refers to the Potsdam Memorandum (October 2007) whereby 15 Nobel laureates demand a "great transformation" (that they see as "a thorough re-invention of our industrial metabolism"), and to the International Energy Agency who calls for "a global technological revolution". He asserts that this does not mean "a quantitative growth based on available technology, but will require a similarly unprecedented innovation drive... The key challenge for this innovation drive is to solve the energy problem". In the Potsdam Memorandum emphasis is also put on interdisciplinarity: "The best young minds, especially those of women, need to be motivated to engage in interdisciplinary problem-solving, based on ever enhanced disciplinary excellence."

Now that we are celebrating the 200th anniversary of the birth of Charles Darwin, "the survival of the fittest" is also applicable to industry. In a report [2] on the US chemical industry, at the Nanowerk website, this is made clear:" The strength and vitality of the U.S. chemical industry relies on innovation. Every year, U.S. chemical companies invest over $26 billion dollars in R&D in order to create new products and processes to solve performance, safety, environmental, and efficiency problems in diverse industries. One clear indicator of this commitment is that the chemical industry accounts for one out of every four U.S. patents. Growing global competition has heightened the need to accelerate the development of new products for continued economic growth. New opportunities created through R&D are essential to helping the United States maintain and strengthen its position in world markets."

In the report to the European Commission "Leading the Way to the Third Industrial Revolution: A New Energy Agenda for the European Union in the 21st Century"[3], Jeremy Rifkin, president of The Foundation on Economic Trends in Washington, DC, and senior advisor to the European Parliament Leadership group on advancing the Third Industrial Revolution and the shift to a Hydrogen Economy, writes: "The EU has begun the journey toward a Third Industrial Revolution by mandating that 20 percent of all EU energy be generated by renewable sources of energy by 2020. By committing itself to a renewable energy future, the EU has laid the foundation pillar for a zero emission, sustainable economic era." The paper describes, in detail, the pillars that will need to be put in place to establish the foundation for the Third Industrial Revolution and a new energy era for the European Union and concludes with key recommendations for implementing it across the EU. Remember that 2009 has been designated the European Year of Creativity and Innovation as proposed by the European Comission and ammended by the European Parliament. While the Commission highlights the Lifelong Learning Programme, the European Parliament stresses the importance of all EU programmes that promote creativity and innovation.

Satoshi Kawachi, chairman of the International Council of Chemical Associations (ICCA), delivers the following message in the ICCA Review 2007-08 [4]: "Addressing climate change requires a global, long-term approach, including a focused, multi-faceted effort by the chemical industry in conjunction with other industrial sectors and segments of society. For its part, the chemical industry will make a contribution to climate change solutions by:

- Developing the innovative products and technologies that enable society to meet greenhouse gas (GHG) reduction goals.
- Improving the energy efficiency of its production processes.
- Promoting the adoption of the industry's best practices and technologies worldwide.
- Promoting solutions and outcomes that support both GHG reduction and economic growth."

Already 5 years ago, at the outcome of a study of March 2004 called 'Horizon 2015: Is the European chemical industry losing its global leadership?'[5], conducted by 150 experts, the European Chemical Industry Council (CEFIC) launched its SUSTECH-Innovation Programme with two-fold objectives:

- To facilitate the establishment of European industry-academia collaborative research consortia and networks aimed at chemistry research.

- Advocating chemistry innovation priorities, including R&D priorities, based on industry innovation needs regarding R&D, as well as managing initiatives addressing innovation barriers and constraints in Europe.

As a result a "European Technology Platform for Sustainable Chemistry" [6] was created as a base of SUSTECH's efforts to stimulate innovation and aiming to engage with a wide cross-section of stakeholders to achieve wide-scale buy-in to the Platform and its research priorities.

The second edition of OECD's "Energy Technology Perspectives 2008: Scenarios and Strategies to 2050" [7], which is the result of an International Energy Agency (IEA) analysis, demonstrates that a more sustainable energy future is within our reach, and that technology is the key. Considering different global scenarios to 2050, the study contains technology road maps for all key energy sectors, including electricity generation, buildings, industry and transport. It emphasises that increased energy efficiency, $CO_2$ capture and storage, renewables, and nuclear power will all be important.

## 2
## IMPERATIVE ENERGY EFFICIENCY

Energy efficiency is widely recognised as the most effective solution for addressing both energy security and GHG emissions reduction. This is why the European Commission has placed energy efficiency at the top of its list of energy priorities, claiming that the EU could reduce energy consumption by 20% by 2020, representing a saving of 60 billion Euros per annum.

**THE EUROPEAN COMMISSION HAS PLACED ENERGY EFFICIENCY AT THE TOP OF ITS LIST OF ENERGY PRIORITIES**

According to EUROPIA [8], the European Petroleum Industry Association, the oil refining industry supports the objective of using energy efficiently and has made already significant progress by updating and upgrading its facilities. But although energy efficiency in refining has improved by 13% over the past 15 years, the strong growth of diesel demand, and the request for significantly cleaner fuels, has resulted in higher total energy consumption in refining. The energy consumption of the refining industry is directly dependant on the energy demand of road transport, more than on its own energy efficiency improvements. Therefore, in 2008, EUROPIA launched a pan-European consumer-awareness campaign [9] on energy efficient car driving entitled "Save more than fuel", giving 10 tips to car drivers. This is the first time the Industry has united to engage in such a public initiative, and is a first contribution to demonstrate the importance placed on the most efficient use of transport fuel products and the contribution this can make towards energy security and emissions reduction.

A paper prepared for the IEA Standing Group on Long-Term Cooperation in 2008 explores different "Measures of Energy Efficiency Performance" (MEEP) [10]: absolute energy consumption, energy intensity, diffusion of specific energy-saving technology and thermal efficiency. It discusses their advantages and disadvantages and their roles within policy frameworks. The author, Tanako Kanaka of the Energy Efficiency and Environment Division of the IEA, advises that policy makers should consider the suitability of MEEP based on criteria such as reliability, feasibility and verifiability. The paper considers the importance of so-called boundary definitions when measuring energy performance, and how these affect the appropriateness of country comparisons to guide policy decisions. The use of energy data without detailed documentation of assumption and boundary definitions should be limited to the analysis of individual production units, and not for comparison beyond its boundary. The link between MEEP and policy design is essential, yet sometimes overlooked. First, policies need to recognize which entities are likely to implement energy efficiency improvements. These may be multi-national, multi-activity companies that have to face different country-level policies. Second, efficiency policy and analysis should be considered from the broader perspective of economy-wide energy efficiency improvement. Since industrial products are used all across society, energy efficiency should be measured, to the extent possible, in broader boundary terms, to decrease energy consumption from society as a whole.

A positive voluntary global initiative of the International Council of Chemical Associations (ICCA) is "Responsible Care" [11]. One of its aims is to improve the environmental performance of products and processes by the companies who adhere to the initiative. It is currently active in 53 countries around the world and is considered as a major contribution by the industry in achieving sustainable development. For example, the Federation of the Spanish Chemical Industry (FEIQUE) presented its Report of Responsible Care 2008 [12] about the evolution of the performance of the chemical industry in Spain. It shows that the adhering companies have reduced GHG emissions per ton of product produced by 24% since 1999. Table 1 shows how the Spanish chemical industry has been leading environmental efforts of the industry. The report estimates that by 2012 total GHG emissions will be reduced by 24%. These reductions are the result of the own emissions reductions and of new products produced which enable other users to reduce their emissions. For example, the companies reduced their energy consumption per ton of product by 21% by increasing thermal efficiency and installing cogeneration systems. Also, they collaborated indirectly, by producing new light polymers used in the automotive industry, thermal insulation materials used in buildings, etc.

An interesting example of R&D cooperation on energy efficiency is NODESZELOSS [13], a Cooperative Research Project under the Sixth Framework Programme of the European Commission, carried out by a multinational consortium formed by 8 small and medium-

**TABLE 1**

**ENVIRONMENTAL INVESTMENTS AND EXPENSES OF THE SPANISH INDUSTRY**

| ACTIVITY SECTOR | Capital Investments and Expenses (millions of Euros) | % of total |
|---|---|---|
| Chemical Industry | 411.1 | 16 % |
| Food, Beverages and Tobacco | 408.0 | 16 % |
| Metallurgy and Metallic Products | 379.4 | 14 % |
| Energy | 333.8 | 13 % |
| Non Metallic Minerals | 232.7 | 9 % |
| Extractive Industries and Refining | 200.8 | 8 % |
| Transportation Materials | 194.1 | 7 % |
| Paper and Graphic Arts | 153.1 | 6 % |
| Transformation Industry | 86.3 | 3 % |
| Other Industries | 218.2 | 8 % |
| Total | 2,617.5 | 100% |

(Source: Instituto Nacional de Estadística, published October 2008)

sized enterprises (SME's) and 3 research and technological development centres (RTD), making a total of 11 multinational partners. The SME's not having facilities to undertake the research project by themselves, decided to ask the Universidad Complutense de Madrid to coordinate the project. This project addresses the specific problem of cost saving of a group of SME's paper mills, specially related to energy and maintenance costs and chemical program evaluation, to optimize the wet end of the paper machine. One of the key factors to improve competitiveness in papermaking industry is to get more knowledge of pulp suspension flows, which is needed in order to improve the design of equipment, pipes and pumps to save energy and operations maintenance cost and to reach a better pulp processing with the consequence improvement in product quality. The viscosity of the pulp (and so the energy needed to pump it around the system) varies from one paper type to another, yet before the NODESZELOSS project came along, there were no devices that were able to accurately measure pulp viscosity. The project partners developed such a device, effectively fuelling our understanding of how paper pulp flows and how adding different substances to the pulp affects the flow. This knowledge will help the paper industry improve the design of its pipes and pumps, and so drastically reduce its energy use. Meanwhile, the project partners are improving the device with the aim of commercialising it.

## 3

### THE NEED FOR NEW GENERATIONS OF BIOFUELS

Under biofuels are generally understood bioethanol, used in spark ignition engines, and biodiesel, used in compression ignition engines. At present, bioethanol is produced by enzymatic fermentation of first generation feedstocks, i.e. crops such as sugarcane, sugarbeet, corn, wheat, barley, rye, sorghum, and cassava [14]. Biodiesel is usually produced by the transesterification of vegetable oil or animal fat feedstocks using methanol to form methyl esters. First generation vegetable feedstocks for biodiesel are mostly rapeseed, soybean, sunflower, maize and palm oil. Several projects exist to recycle used vegetable oils. If their collection is efficiently organised it is a sustainable solution, but their market is limited and they cannot be considered as new generation feedstocks. An analytical study of waste oil collection networks has been made by PROBIO in Spain and Italy within the Intelligent Energy framework of the EU [15].

## 3.1

### Constraints of first generation biofuels

The exclusive use of first generation feedstocks is not sustainable at the medium and long term. In November 2008, the International Energy Agency (IEA), published a report titled: "From 1st- to 2nd-Generation Biofuel Technologies - An Overview of Current Industry and RD&D Activities" [16]. The report has been produced as a joint effort between the IEA Secretariat and IEA Bioenergy, and has been funded by the Italian Ministry for the Environment, Land and Sea. In the introduction it is stated: "It is increasingly understood that 1st generation biofuels, produced primarily from food crops, are limited in their ability to achieve targets for oil-product substitution, climate change mitigation, and economic growth. Their sustainable production is under review, as is the possibility of creating undue competition for land and water used for food and fibre production. A possible exception that appears to meet many of the acceptable criteria is ethanol produced from sugar cane." The report cites following current constraints and concerns for many of the 1st generation biofuels:

- They contribution to higher food prices due to competition with food crops.
- They are an expensive option for energy security without government grants and subsidies.
- They provide only limited green house gases (GHG) reduction benefits, at relatively high costs per ton of $CO_2$ emission avoided. (mostly exceeds USD 250/200 € per ton of $CO_2$).
- In general they do not meet their claimed environmental benefits because the biomass feedstock may not always be produced sustainable.
- They accelerate deforestation.
- They have potentially a negative impact on biodiversity.
- They compete for scarce water resources in some regions.

Likewise the US National Biofuels Action Plan (Oct. 2008) states [17] that "Environmental implications, such as the effect of feedstock production on soil, water and air quality need to be considered. As well as market implications caused by imbalance between feedstocks used for biofuels, for food, feed, and fiber, when the use of first generation feedstocks increases".

The European Parliament too expresses its doubts regarding the medium- and long-term suitability of first-generation biofuels as a substitute for oil and calls for increased efforts in researching synthetic fuels in its report on possible solutions to the challenges in relation to oil supply [18].

Version 3 of a Well-to-Wheels (WTW) impact analysis [19] of different bio-products and other alternatives has been prepared jointly by the Institute for Environment and Sustainability (IES), the European Council on Automotive R&D (EUCAR), and the EU Commission's Joint Research Centre (JRC), with the objective to estimate greenhouse gas emissions, energy efficiency and industrial costs of all significant automotive fuels and power-trains for the European Union after 2010. With respect to biofuels, the study concludes that the EU production of biodiesel and bio-ethanol from arable crops offers well-to-wheels greenhouse gas savings, but at much higher cost than many other forms of greenhouse gas mitigation. Making fuels from straw and forest residuals seems more attractive, but the processes are not yet demonstrated.

## 3.2.

### Second generation biofuels

- Biofuels from lignocellulosic feedstocks

Because of the constraints on first generation biofuels, a new generation of feedstocks is needed. The most at hand are lignocellulosic feedstocks. These second generation feedstocks include low-cost crop and forest residues, wood process wastes, and the organic fraction of municipal solid wastes. The biofuel produced from these feedstocks is ethanol, using the biochemical process in which enzymes and other micro-organisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol. The residue of the enzyme hydrolysis can be used for heat and power generation. Yield of ethanol produced by enzyme hydrolysis could be up to 300 liter per dry ton of biomass, higher than by Biomass to Liquid (BTL) [16] (Table 2).

According to the already mentioned IEA report [16], 2$^{nd}$ generation biofuels technologies are still relatively immature and are likely to become a solution in the medium term and the commercial application will probably not be deployed before 2015-2020. Also it is considered that 2$^{nd}$ generation biofuels technologies will not be commercially competitive in the near future unless the oil price remain well over USD 100/Bbl. Major technical and economic hurdles are still to be faced before they can be widely deployed, although significant investing in R&D and in pilot and demonstration plants is being made. Among the technology improvements required, the report cites:

- Improvements of physical and chemical feedstock pretreatments and of combinations of both pretreatments.
- Development of new and/or improved enzymes (*). The production costs of present cellulases are still high.
- A key goal for the commercialisation of bioethanol is that all sugars released during the pretreatment and hydrolysis steps are fermented into ethanol. Inhibitory substances of the hydrolysis reaction must be eliminated.
- There is much room for improvement of process integration of the large number of process steps involved.

(*)As an example, extensive research is being made at different locations on improvements and optimization of the production process of the cellulase enzymes from fungi, in particular *Trichoderma reesei*, and their use for the enzymatic hydrolysis of pretreated cellulose into ethanol.

The IEA report further suggests that a broad collaborative approach should be taken in order to complement the various R&D efforts in different countries, to reduce the risks to investors and to create a positive environment for the participation of financial institutions. Funding for demonstration and deployment of 2nd generation biofuels is needed from both the public and private sectors. Developing links between industry, universities, research organisations and governments has proven to be a successful approach in some instances. The IEA suggests to use mechanisms similar to the US "Program for Construction of Demonstration Technologies" funded by the US Department of Energy.

But innovating process technology is not sufficient. Adapted distribution logistics are also required. As Steen Riisgaard, President of Novozymes and Chairman of EuropaBio, the EU association for bioindustries, says [20] "We are all excited about getting to the second generation biofuels, but I would like to underline that in order to facilitate the transition towards second generation biofuels, a market for first generation biofuels is needed, with an appropriate infrastructure and distribution"

- Algae for biofuels

Algae are a very promising prime material for biofuels. They grow about 20 to 30 times faster than food crops and it has been demonstrated that algae are capable of producing at least 30 times more oil per hectare than corn and soybean crops. Up to 60% of its biomass can be converted into oil or carbohydrates. Several companies and research centres, especially in the USA, have R&D projects going on to produce and convert algae into biofuel, mostly as biodiesel.

**TABLE 2**

**INDICATIVE BIOFUEL YIELD RANGES PER DRY TONNE OF FEEDSTOCK FROM BIOCHEMICAL AND THERMO-CHEMICAL PROCESSES**

| Process | Biofuel | Biofuel yield l/dry t | LHV, MJ/l | Energy yield, GJ/t |
|---|---|---|---|---|
| **Biochemical:** | | | | |
| **Enzymatic hydrolysis** | Ethanol | 110 to 300 | 21.1° | 2.3 to 6.3 |
| **Thermo-chemical:** | | | | |
| **Syngas-to-Fischer Tropsch** | Diesel | 75 to 200 | 34.4 | 2.6 to 6.9 |
| **Syngas to ethanol** | Ethanol | 120 to 160 | 21.1 | 2.5 |

(Source: IEA & Bioenergy, Ref. 16)