Facts & Figures

ENERGY AND CARBON FOR GREEN CHEMISTRY

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ENEA Consulting provides **energy transition and sustainable development consulting services to industry**. ENEA assists companies with strategy development, provides support to innovation and projects, and also offers training and expertise services on these topics.

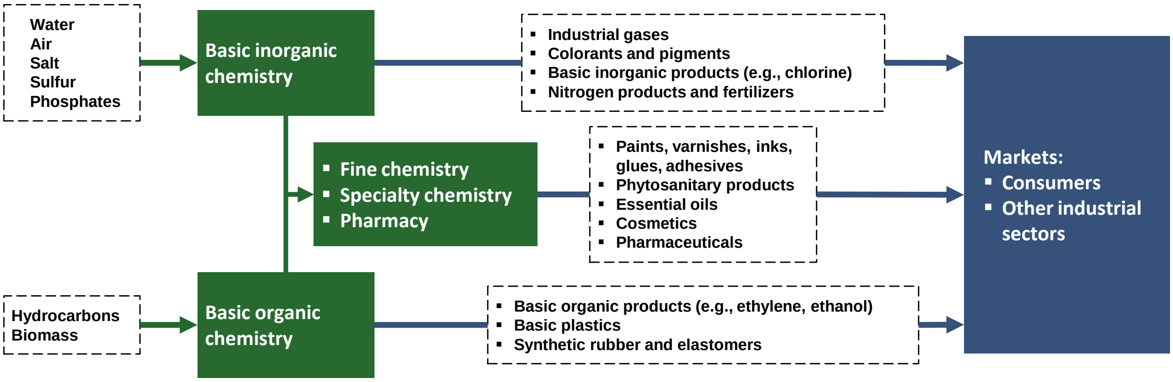
This publication is part of our policy to share ENEA's essential knowledge, with the aim to propose keys to understanding the main challenges of energy transition and sustainable development at the global scale.

It is the result of the experience of ENEA experts on the topic of green chemistry, which has been acquired in the course of our support and consultancy services to industrial companies, and from specific research work done in-house.

THE CHEMICAL SECTOR

Chemistry: a vast and diversified industrial sector

Chemistry is the basis for the synthesis of most of the intermediate and end products that ensure our survival and comfort. It's a key sector of the economy as it supplies most other sectors with inputs (plastics, composite materials, industrial gases, fertilizers, etc.). From agriculture to medicine, through fuels, plastics and synthetic textiles, chemistry is involved in most matter transformation chains.

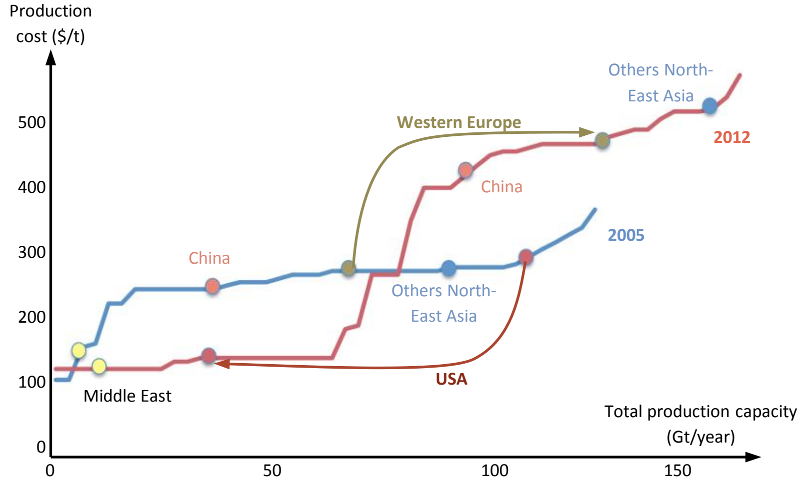


Main branches of the chemical industry

The chemical sector today: global competition, value creation and competitiveness

The chemical industry's global landscape has changed dramatically over recent years, with growing risks for the industry in Europe. Asian chemical companies have been experiencing very strong growth since the 1980's, driven by their domestic markets, which now represent half the global market. A wave of investment then took place in the Middle East in the early 2000's to take advantage of the region's natural resources.

Since 2006, large-scale shale gas exploration and development in the United States has given the American chemical industry a strong competitive advantage. The price of gas, which can impact the competitiveness of a large part of the chemical industry (gas feedstock and fuel), was halved. Companies from across the world are positioning themselves in the U.S. to take advantage of this boon: the American Chemistry Council announced in February 2014 that more than 100 billion dollars of investments had been announced for a total of 148 projects (new sites, production capacity increases, retrofitting, etc.). The graph opposite illustrates the upheaval in competitiveness experienced in the industry in under 10 years for the case of ethylene.



Breakdown by global production costs for ethylene, evolution between 2005 and 2012 (according to the American Chemistry Council)

THE CHEMICAL SECTOR

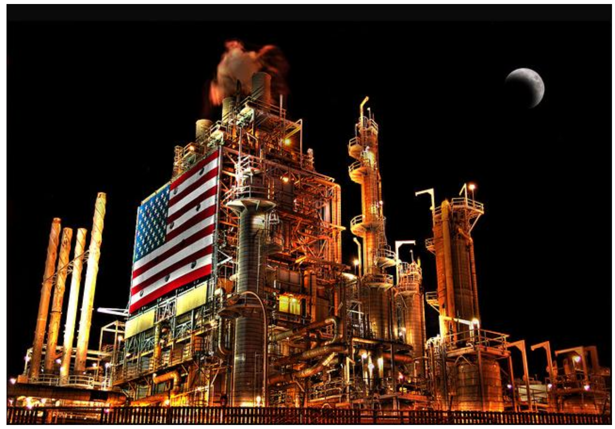
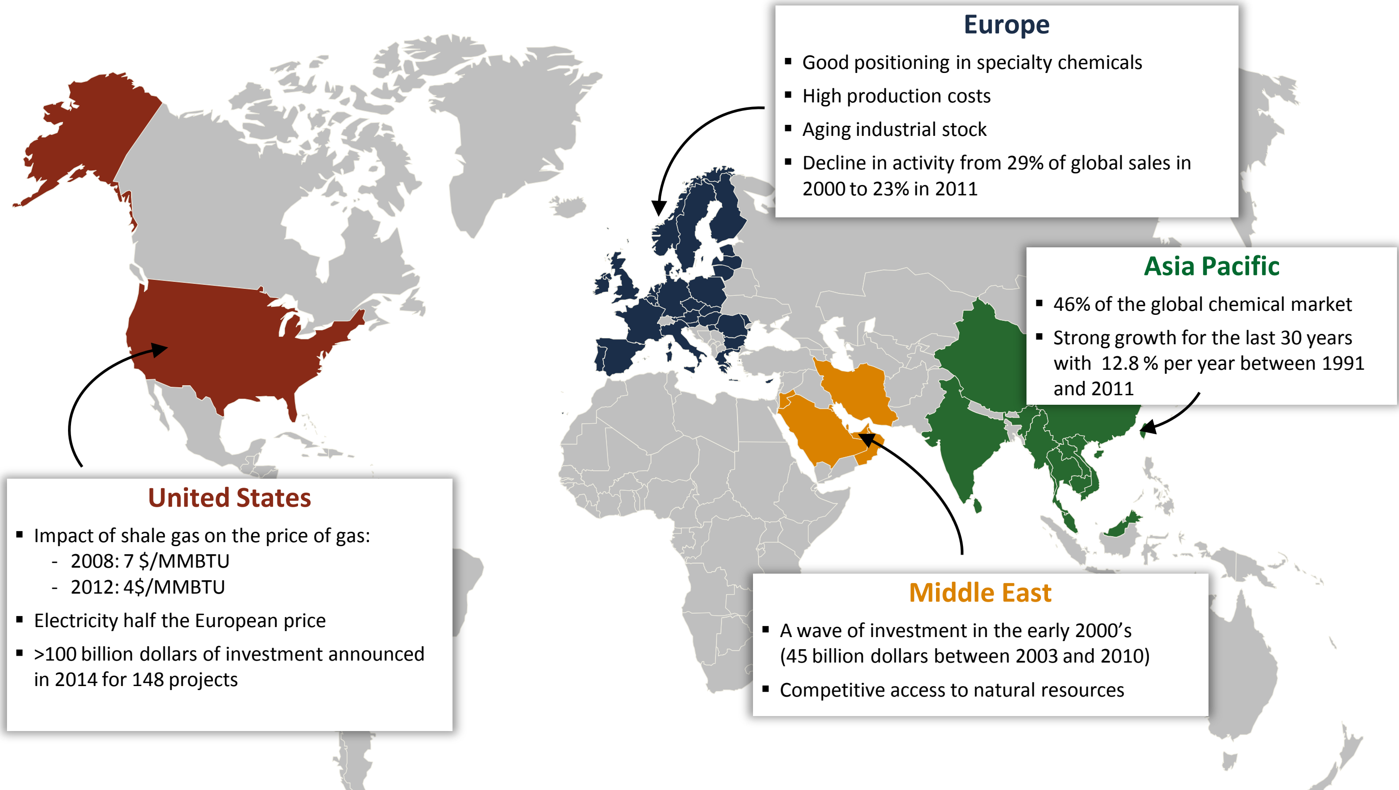


Photo credit: Canon in 2D

The first investments ($15 billion) will enable the United States to increase their ethylene and polyethylene production capacity by 40% by 2017, and then new capacities will progressively come on line for the rest of the chain, with repercussions on downstream chemical companies and then on other industrial sectors that will experience a drop in input prices. In addition to the gas price differential, American companies are currently benefitting from electricity prices that are half those in Europe and from very competitive labor costs (source: IFRI with IEA statistics).

While cost reduction is vital for industries located in Europe, it's also crucial to establish new strategies to move away from a price war that would be fatal for them. In parallel to production site closures that started in 2012, we've observed a refocusing on specialty chemicals, with a race to innovate in order to differentiate through functionality.

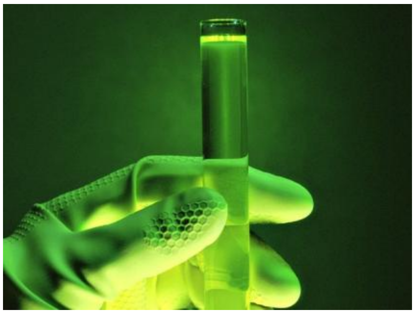
Environmental differentiation, made possible with the principles of green chemistry, also opens up new opportunities for value creation. Today, it is one of the routes being explored to give new impetus to the European chemical industry, which is leading in developments in this field.



Current state of the chemical industry in the main global regions

CHEMISTRY: IMPACTING ALL INDUSTRIES

The basis of sustainable industry: green chemistry



Maintaining a positive image for products of chemical origin in the eyes of end users is strategic for the chemical industry. This is particularly true for plastics that are ever more criticized. The environmental concerns of consumers are growing as are the political commitments of many countries , including emerging ones.

Beyond the chemical industry, many industrial sectors are currently trying to reduce the impact of their activities on human health (toxicity) and the environment (global warming, destruction of ecosystems). However, the impact of a product also stems from that of the raw materials used to make it. The weight of chemistry can therefore be important in life-cycle analyses (see box below), environmental and carbon assessments, and when evaluating the impact on the raw material resources used by products in other sectors. For example, to help their customers optimize their impacts, BASF has developed the Eco-Efficiency Label for products enabling their customers to reduce their energy consumption and greenhouse gas emissions.

Meeting these new expectations will require a comprehensive commitment from chemical companies, from the divisions working closely with customers to refine their understanding of future expectations (marketing, communication…) to the divisions involved in identifying priority development areas (Strategy, Innovation, R&D…). For chemical companies not directly in contact with end product users, more B2B2C approaches are being developed, mostly driven by other sectors that are working with their suppliers to improve the overall impact of their products: luxury goods, food products, health, cosmetics, etc.

Focus: LCA, to quantify the impact of chemistry on the environmental assessment of other sectors

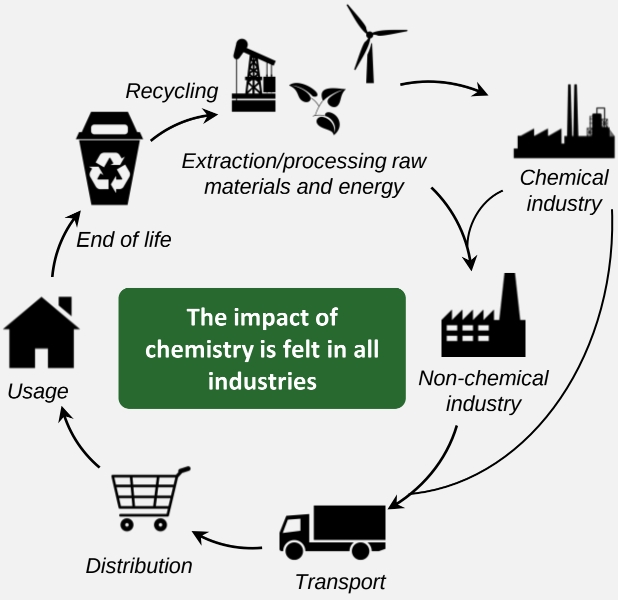
Life cycle analysis (LCA) is a method used to quantify the potential effects on the environment of a service or a product, from the extraction of the raw materials required to produce it to its end-of-life channels.

Carrying out an LCA on a product comes down to establishing an environmental profile that takes into account all of the inputs (raw materials, energy, etc.) and outputs (discharge, waste, etc.) associated with its life.

The impact of a product thus takes into account the impacts associated with its manufacturing and its usage but also that of the elements and materials that make it up, their origin and impacts linked to their production.

For a company to improve the environmental impact of their products, it's necessary to improve the impact of all of the upstream circuits, in particular by involving suppliers in the environmental improvement process.

It's an opportunity for chemical companies to differentiate themselves by proactively proposing sustainable inputs to their customers.

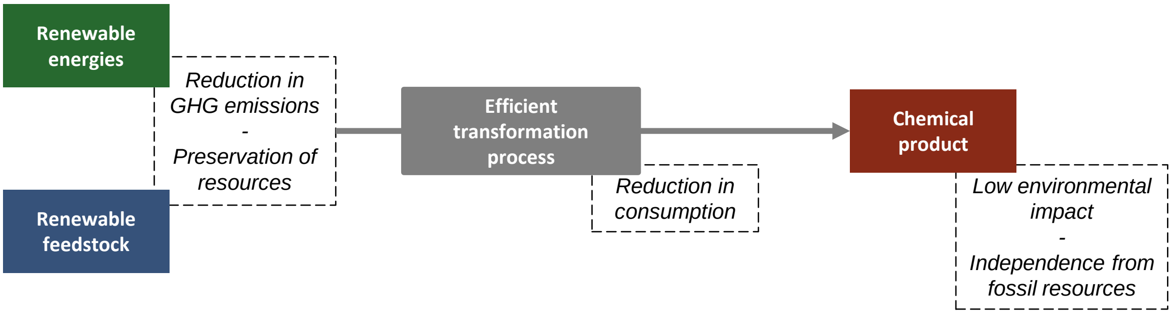


Pictogram credits: the Noun Project

GREEN CHEMISTRY

Green chemistry concepts

The concept of "green chemistry", created in the United States in the early 1990's, puts forward a new paradigm to meet the growing demand for products of chemical origin while preserving essential raw material resources and minimizing their negative impacts on people and their environment. In 1991, the EPA (Environmental Protection Agency) defined green chemistry, whose 12 principles are listed opposite, as "*the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances.*"



Eco-design of a chemical product

Energy and carbon for green chemistry

The greatest progress made on the different green chemistry principles has been on the reduction in product toxicity and danger, due in particular to recent changes in the regulations (for example, REACH in Europe or TSCA in the US). Incremental progress was also made on energy and carbon aspects but with substantial residual improvement potential.

In recent years, the inclusion of energy and carbon aspects into research and development work done by chemical producers and OEMs has become a strategic challenge and an opportunity for Europe to capitalize on its lead in the field of green chemistry.

Two topics, developed in this publication, are of particular interest to the actors in this sector:

- Designing chemical processes to reduce the costs associated with the consumption of fossil fuels:
    - ✓ Energy sobriety
    - ✓ Modification of processes
- Using renewable inputs containing non-depletable molecules and atoms, to improve the carbon impact of the end products, provide new functionalities and open up new markets:
    - ✓ Biobased chemistry
    - ✓ CO_2 as feedstock
    - ✓ Use of microalgae
    - ✓ Recycling

GREEN CHEMISTRY

The 12 principles of green chemistry

All of the sustainability challenges for chemistry were outlined by Paul Anastas and John Warner in 12 principles, which aim to reduce in as much as possible the toxicity and danger of products and their environmental impact.

1. **Waste prevention:** It is better to prevent waste than to treat or clean up waste after it has been created, *e.g., greenhouse gases, formation of tropospheric ozone and acid rain.*

2. **Atom economy:** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product, *e.g., ibuprofen. The original 6-stage Boots synthesis (1960) incorporates only 40% of input atoms (mass) into the ibuprofen (60% waste). In 1992, BHC commercialized a new 3-stage process with 77% efficiency (not including the recovery of the co-produced acetic acid).*

3. **Less hazardous chemical syntheses:** Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment, *e.g., alternative reagents to replace phosgene in urethane synthesis.*

4. **Designing safer chemicals:** Chemical products should be designed to effect their desired function while minimizing their toxicity, *e.g., alternatives to bisphenol A.*

5. **Safer solvents and auxiliaries:** The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary when possible and innocuous when used, *e.g., use of supercritical* CO_2 *as an innocuous solvent.*

6. **Design for energy efficiency:** Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. *If possible, synthetic methods should be conducted at ambient temperature and pressure.*

7. **Use of renewable feedstocks:** A raw material or feedstock should be renewable rather than depleting wherever technically and economically practicable, *e.g., use of biomass in bio-refineries.*

8. **Reduce derivatives:** Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided, because such steps require additional reagents and can generate waste, *e.g., direct enzymatic synthesis of penicillin instead of the indirect chemical route.*

9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents, *e.g., reduction in solvent consumption and in organic waste production from fine chemistry.*

10. **Design for degradation:** Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment, *e.g., use of linear alkyl sulfonate for biodegradable detergents.*

11. **Real-time analysis for pollution prevention:** Analytical methodologies need to be further developed to enable real-time in-process monitoring and control prior to the formation of hazardous substances.

12. **Inherently safer chemistry for accident prevention:** substances and forms of substances used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions and fires, *e.g., the use of ammonia at low temperature reduces its volatility and risks linked to its toxicity.*

IMPROVING PROCESSES

Energy sobriety

A key condition for the competitiveness of the European chemical industry for some years now has been to bring down production costs. From among the different ways of doing this, improving energy efficiency has been on the roadmap of most industrial companies in the sector. The growing severity of international competition is currently pushing companies to find new ways of economizing.

Specifically investing to reduce energy consumption remains tricky, however, considerable improvements can be made by integrating energy and environmental performance criteria very early on in investment decisions concerning new production capacity or upgrading operations. In addition to energy savings, reductions in greenhouse gas emissions can alone, in some cases, justify the additional cost of responsible investing.

Reduce consumption
- **Facilities:** Investments in the best available technologies
- **Sites:** "Sober plants", exergy analyses
- **Auxiliaries:** optimization of utilities
- **Operations:** metrology, sequencing, behavioral

Recover lost energy flows
- **Facilities:** heat recovery (retrofit)
- **Sites:** process integration (new)
- **Waste:** incineration, methanization, etc.
- **Industrial ecology:** integrations covering entire industrial parks

Optimize feedstock sources
- **Thermal autoproduction:** cogeneration, biomass, solar thermal, geothermal, etc.
- **Electrical autoproduction:** PV, wind power, cogeneration, etc.

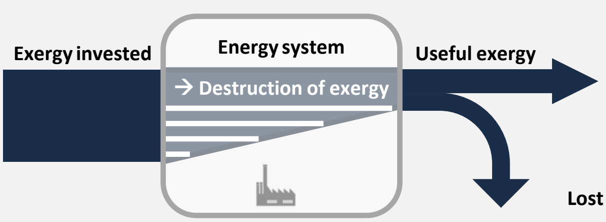
Optimize procurement, identify sources of profit
- **Procurement:** Reduction in number of contracts
- **Energy storage and flexibility:** Synchronization of consumption with energy prices
- Load shedding, network services contracts, etc.

The System / Sector approach to boost energy efficiency

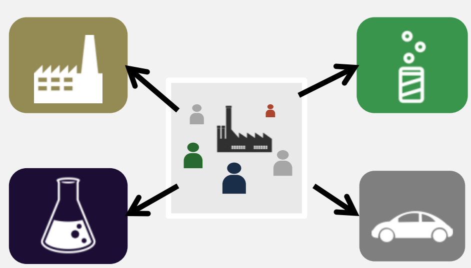
To create a new breakthrough when most sectors have reached a threshold in the race for energy savings, ENEA has developed a dual system/sector approach:

Systemic approach
Breakdown then systemic integration of process chains through the study of exergy loss

(See ENEA publication on exergy)



Trans-sector approach
Dissemination of information on cross-cutting technologies between sectors



Pictogram credits: the Noun Project

IMPROVING PROCESSES

Improving transformation routes: feasibility, competitiveness & sustainability

Chemical processes must become more sober, flexible and modular and must function in a more intense manner in order to cope with changing constraints. The challenges when designing factories of the future capable of meeting increasingly variable demands (volume and product types) while tolerating a wider diversity of inputs (including biomass and recyclables) are technical (feasibility) but also economic (competitiveness) and environmental (clean process). The example of the development of biofuels illustrates this threefold requirement:

1. The 1st generation of biofuels was technically feasible but barely economically viable and turned out to have a controversial environmental balance sheet.
2. The 2nd generation were rightly designed to obtain an improved environmental balance sheet but resulted in additional costs.
3. The development of 3rd generation biofuels aims at optimizing all of the requirements, with improved productivity and a reduced impact on resources (including food resources).

This need for improvement is particularly true for biochemistry, whose costs must be decreased to be able to compete with traditional routes on the most important markets. There are currently several lines of research, including:

- Lignin recovery (30% of the mass of biomass and 40% of its calorific value) beyond the generation of energy via combustion, particularly through the development of multi-product processes. Its molecular structure is compatible with a conversion into carbon fibers, adhesives, resins, aromatics and other chemical products whose aggregate added value is crucial for the profitability of biorefineries.
- The development of more efficient and robust enzymes allowing the recovery of a wider spectrum of molecules present in the biomass.
- The structuring of the sector to reduce transport costs associated with the delivery of inputs.

In the chemical sector, projects to develop modular and flexible plants, such as CoPIRIDE or F^3 Factory, financed at the European level, are trying to find ways of filling these requirements.

Focus: Biogas for green chemistry

By analogy with fossil materials in traditional chemistry, biomass represents a source of energy and a molecular resource for product synthesis in green chemistry. Biogas producers, by feeding the network with green gas, would be supplying consumers to cover their energy needs and also chemical companies to cover their feedstock needs with an input of renewable origin.

Biogas is developing quickly in Europe, and not only in Germany where there are already more than 7000 methanization units, but also in France: the French Ministry of Ecology (MEDDE) launched a call for projects in June 2014 for the development of 1500 methanizers over a 3-year period.

Biogas production and network injection site in Falkenberg in operation since 2009 (ENEA Consulting)

Biogas-based chemistry could become a sustainable alternative to gas-based chemistry that is favored by the use of shale gas. The main obstacle to its development is linked to the low reactivity of the methane molecule, while shale gases make it possible to use ethane and other longer carbon chain gas fractions. Processes are currently being developed to overcome this obstacle, such as favoring methane activation to produce ethylene (example of the Californian start-up Siluria) or blocking the methanization reaction to obtain a mix of carbon chains.

BIOBASED CHEMISTRY

Biofeedstocks – an opportunity to differentiate through functionality

The environmental benefits of biobased chemistry are first derived by replacing feedstocks with a high ecological footprint (particularly fossil feedstocks) with renewable inputs. In addition to products as conventional as bioethanol, many bio-sourced products are now commonly used – algae are used in the cosmetic industry, starch and oils are transformed to make detergents, bioplastics are synthesized for packaging, cars, sports gear, etc.

In 2010, 8% of raw materials in France were plant based (ADEME, 2011), i.e. 50 Mt excluding biofuels (IEA). The French chemical industry has pledged to increase the share of renewable raw materials to 15% by 2017.

In the short term, the cost of biofeedstocks makes it tricky to simply replace products derived from traditional chemistry at iso-functionality, even if a premium can sometimes reward the ecological added value on certain sensitive markets (agri-food, infants, etc.). The characteristics of certain materials or molecules derived from biobased chemistry can however have differentiating properties, thus providing opportunities to develop new products.

Among the most widely-used biopolymers today there is PLA (polylactic acid), a biodegradable thermoplastic polymer that companies such as TOTAL are using to develop business activities. PLA is made from the polymerization of sugars and fats and has the biodegradability and biocompatibility properties that are sought out in the packaging and health sectors: its degradation into lactic acid allows it to used in both intracorporeal medical applications (temporary implants) and agricultural applications (agricultural film, compost bags). PHA (polyhydroxyalacanoate) is another biopolymer that is also under development, notably to propose a heat-resistant alternative to PLA.

Focus: biobased chemistry in application today – the example of succinic acid

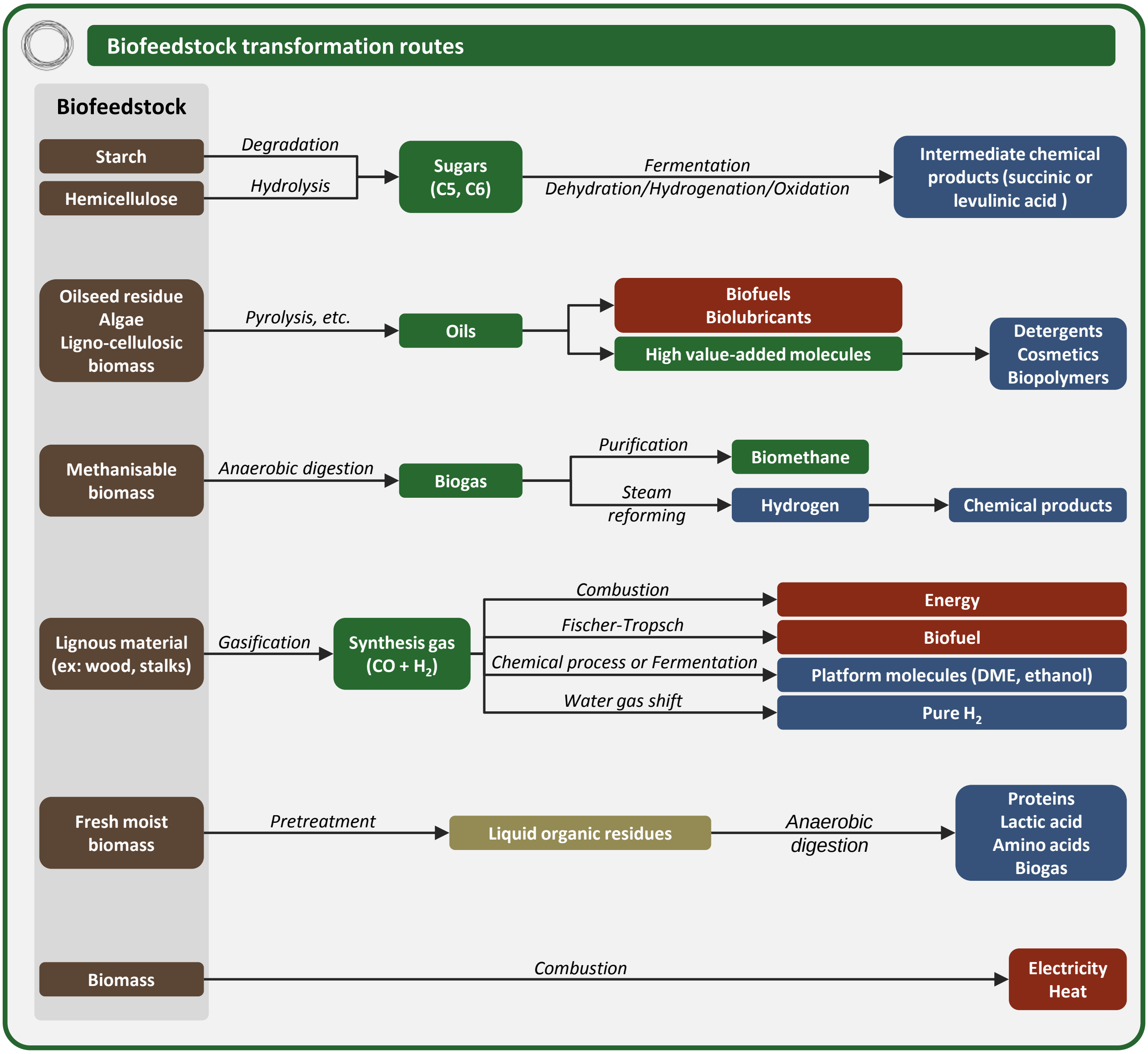
Succinic acid is a platform molecule used in the synthesis of a wide variety of chemical products, in particular detergents and biodegradable plastics. It's also used as an additive to control acidity in certain foods and drugs, as well as in wine, where it is already naturally present. Its synthesis is traditionally based on the use of oil and natural gas.

Succinic acid was identified by the Department of Energy (USA) as one of the ten most promising platform molecules produced from carbohydrates.

Photo credit: Uncalno Tekno

Roquette, in partnership with DSM, has developed a bioprocess to synthesize succinic acid via the fermentation of glucose derived from starch in the presence of CO_2 and yeast. In 2013, Reverdia, the joint venture created through this partnership, commissioned the world's biggest bio-sourced succinic acid factory (10,000 tpa) to meet the very high growth on this market expected between 2010 and 2020 (ADEME, 2011).

BIOBASED CHEMISTRY



BIOBASED CHEMISTRY

Biorefineries

The biorefinery concept adopts the refining philosophy used for petroleum products: extract all of the usable molecules from a raw product and minimize residue. It is theoretically possible to use a biomass source to simultaneously produce high value-added chemical products (HVA), fuels and energy, heat or electricity.

The first generation of biorefineries was designed to use sugar (cane sugar), starch (corn) or oilseed (vegetable oil) biomass and represents almost 95% of the stock of biorefineries with roughly 1400 installations. However, their ecological balance sheet is under criticism today due to the competition that has arisen for land use, with food farming particularly.

Pomacle-Bazancourt Biorefinery (source: IAR Pole)

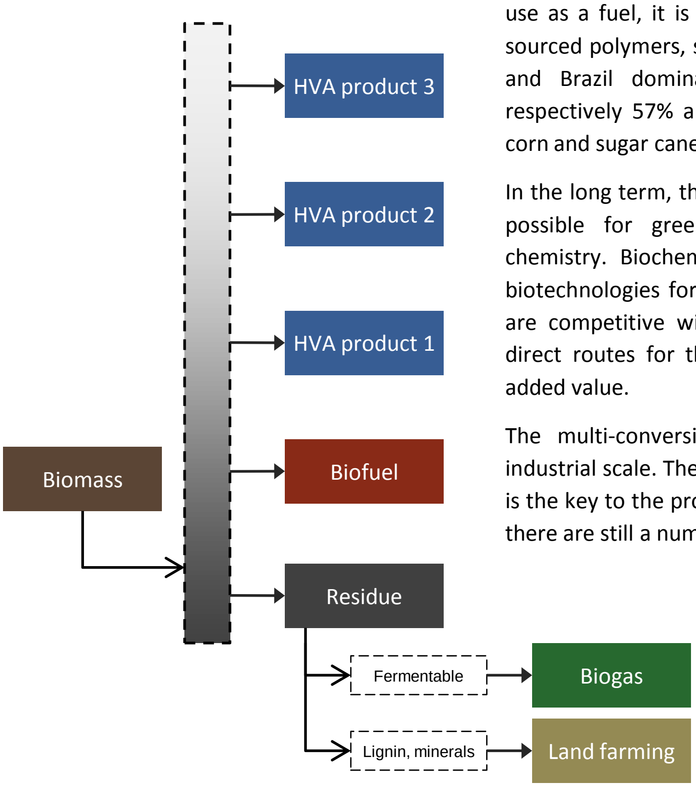
The 2nd generation allows the use of lignocellulose residue in the biomass (fibrous polymer molecules from wood and plant stems) which will improve the ecological balance sheet. The conversion routes used (gasification, enzyme reactions, etc.) are more complex to implement and this sector is still under development.

The current stock of biorefineries is essentially dedicated to the production of platform molecules capable of leading to the same chemical products and fuels as those made in petro-sourced refineries. This approach has the advantage of producing bio-sourced chemicals that are identical to petro-sourced ones and thus able to replace them.

Bioethanol, a platform molecule for the chemical sector or a final molecule for fuel synthesis, is the most widely produced molecule by biorefineries (867 kt in 2012 in France and almost 100 Mt worldwide). In addition to extensive use as a fuel, it is also at the basis of the synthesis of many bio-sourced polymers, such as PVC and polyethylene. The United States and Brazil dominate the bioethanol production market with respectively 57% and 27% of global production in 2013; both use corn and sugar cane crops as feedstock.

In the long term, the optimized conversion of inputs should make it possible for green chemistry to compete with conventional chemistry. Biochemical synthesis routes, and in particular white biotechnologies for industry, can implement reaction patterns that are competitive with petro-sourced routes, since they use more direct routes for the production of complex molecules with high added value.

The multi-conversion of biomass is not yet attainable on an industrial scale. The ability to extract several product simultaneously is the key to the profitable use of numerous sources of biomass, but there are still a number of technical challenges that remain.

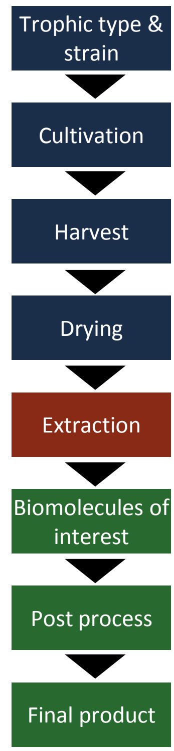


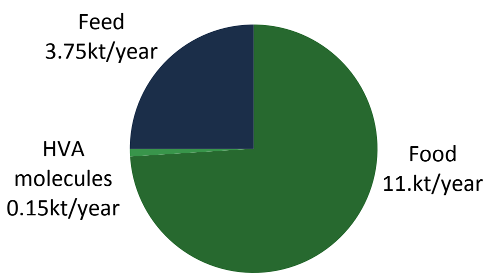
Principle of multi-conversion in a biorefinery

BIOBASED CHEMISTRY

microalgae

The ability of microalgae to produce complex molecules via biological mechanisms offers growing opportunities for the production of molecules appropriate for chemical applications. Their cultivation is one the main routes for the conversion of CO_2 (which they need to develop) leading to an improvement in the environmental balance sheet of the molecules produced compared with those produced in conventional processes. Major R&D efforts are being made today to develop the production of new molecules but there are already existing industrial usages in the fields of food and feed (15 kt/year).

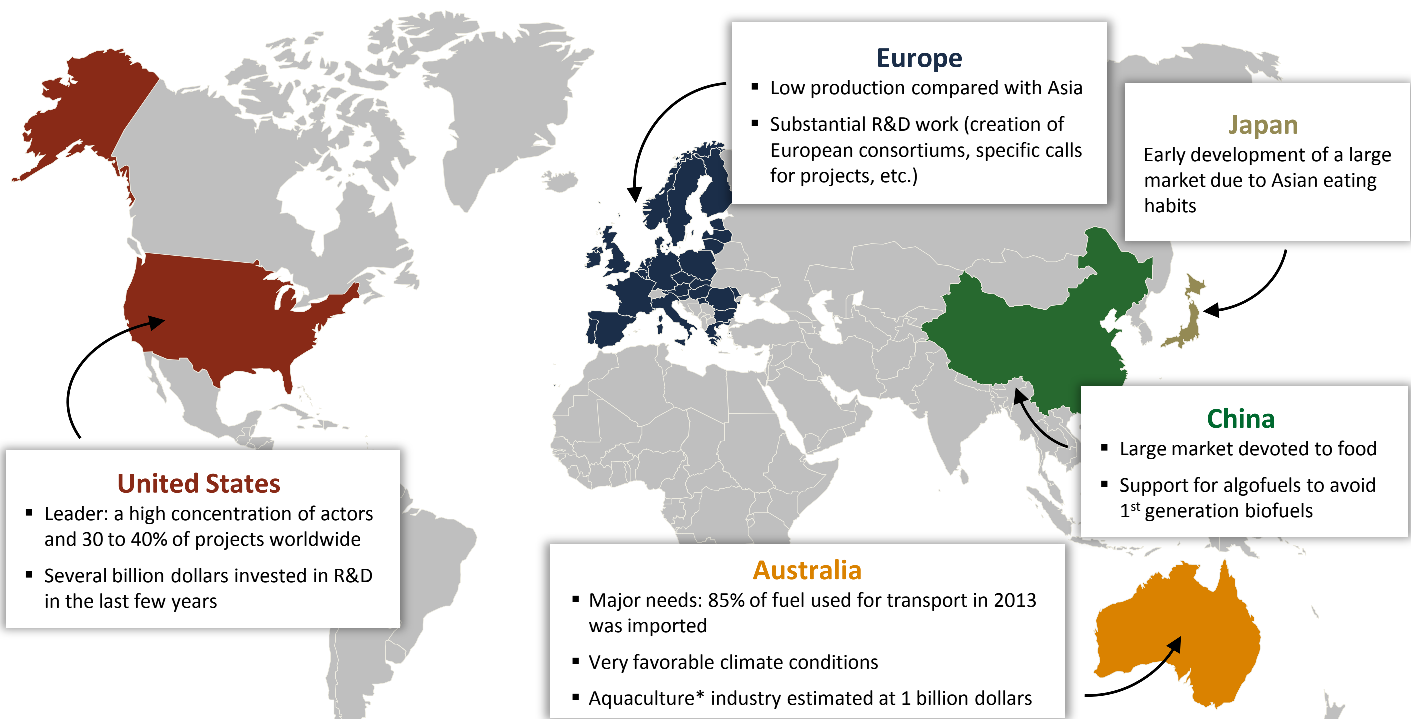




microalgae markets worldwide (Total volume: 15 kt/year - 2010)

After the initial developments made back in the 1970's, new efforts were started in the early 2000's to produce biofuels from microalgae, as they represent a biomass source with higher productivity levels than those of terrestrial plants (for the same surface area). Very high production costs and important water requirements however remain major drawbacks to their industrial development. Many actors have decided to reorient their efforts towards the production of higher value-added (HVA) products or a biofuel / HVA co-conversion to improve profitability.

The cumulative effect of the complexities of agronomy (for cultivation) and chemistry (for molecule extraction) make developments all that much more complicated (see opposite). Joint work done by actors from these two worlds is currently underway, although chemical companies don't necessarily want to integrate the upstream competencies of biomass cultivation, harvesting and pre-processing.



* The aquaculture industry is a possible market for microalgae (feed)

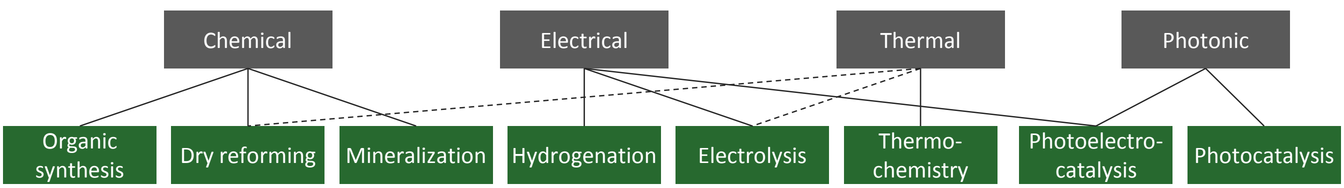
Microalgae across the world

CO_2 AS A FEEDSTOCK FOR THE CHEMICAL INDUSTRY

The use of CO_2, an alternative to geological storage

The reduction of CO_2 emissions into the atmosphere is one of the key elements in the fight against global warming. CO_2 capture on industrial processes was developed with this in mind and was driven by the promise of an attractive price per ton of CO_2 on the markets (EU-ETS in Europe). Only geological storage has storage levels that are compatible with anthropogenic CO_2 volumes but the promise of a growing availability of this gas has led to a new interest in conversion opportunities. With the constraints linked to the societal acceptance of CCS (Carbon Capture and Storage) projects, a weakening in political will with regard to carbon, followed by a collapse of the EU-ETS carbon market in 2012, a shift took place from CCS towards CCU (Carbon Capture and Use).

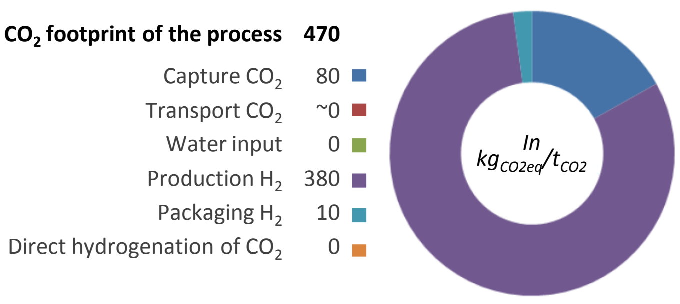
From among the CO_2 usage routes currently under development, both chemical conversion and algae usage are generating substantial interest. For the chemical industry, the use of CO_2 as an input for the production of carbon-based molecules or polymers could make it possible to improve the carbon impact of products, reduce dependency on fossil resources and even develop new products for new uses.



Different processes for the chemical conversion of CO_2 and sources of energy used

The chemical conversion of CO_2, an environmental benefit?

The carbon footprint of CO_2 converted in a process is rarely zero – using CO_2 means emitting CO_2. Upstream of its use, the capture and transport stages themselves emit CO_2. Moreover, CO_2 is a particularly stable molecule, its energy level and reactivity are very low. The transformation of CO_2 into a useful product requires energy that does not systematically come from renewable sources and thus contributes to the process' carbon footprint. During the synthesis of methanol by hydrogenation for example, while the CO_2 balance remains positive, only 53% of the CO_2 converted would really be avoided, leaving 470 kg of CO_2 being emitted into the atmosphere (ADEME study, modelling by ENEA, nominal scenario). Beyond this intrinsic balance, the comprehensive environmental assessment of the development of a CO_2 process is indicated by the difference with the CO_2 balance of the product made in a conventional process. As the conventional production of methanol emits on average 650 kg_{CO2}/t_{CH3OH}, the overall positive impact of the CO_2 process would thus be 1180 kg_{CO2}/t_{CH3OH}.



CO_2 footprint of the hydrogenation of CO_2
(source: ADEME study, nominal scenario, modelling by ENEA)

The carbon footprint of the reagent replaced by CO_2 can weigh heavily on the final impact of the process. For example, the organic synthesis of polycarbonate polyols from CO_2 makes it possible to reduce the consumption of epoxide, a reagent of the process with a high carbon footprint.

A more global approach like the "life cycle analysis" is therefore vital to perceive the true impact of the use of CO_2 in chemistry on climate change.

CO_2 AS A FEEDSTOCK FOR THE CHEMICAL INDUSTRY

The chemical industry, a prime CO_2 conversion market

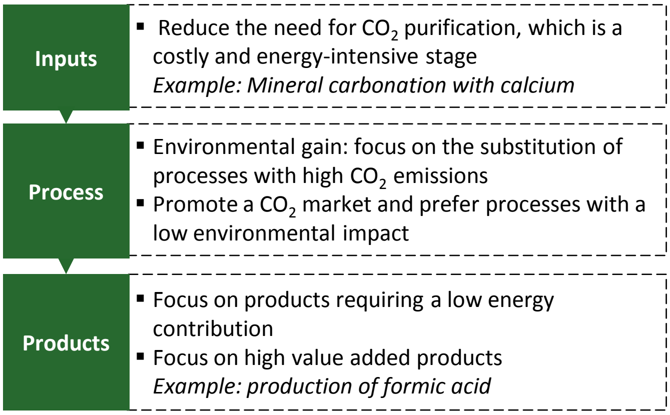
Energy and fuel could represent a mass market for the conversion of CO_2 (in the order of a $GtCO_2$/year). However, the low added value of the final product and the high cost of its production from CO_2 (in particular for energy) do not make it possible to reach economic viability with the technologies currently available.

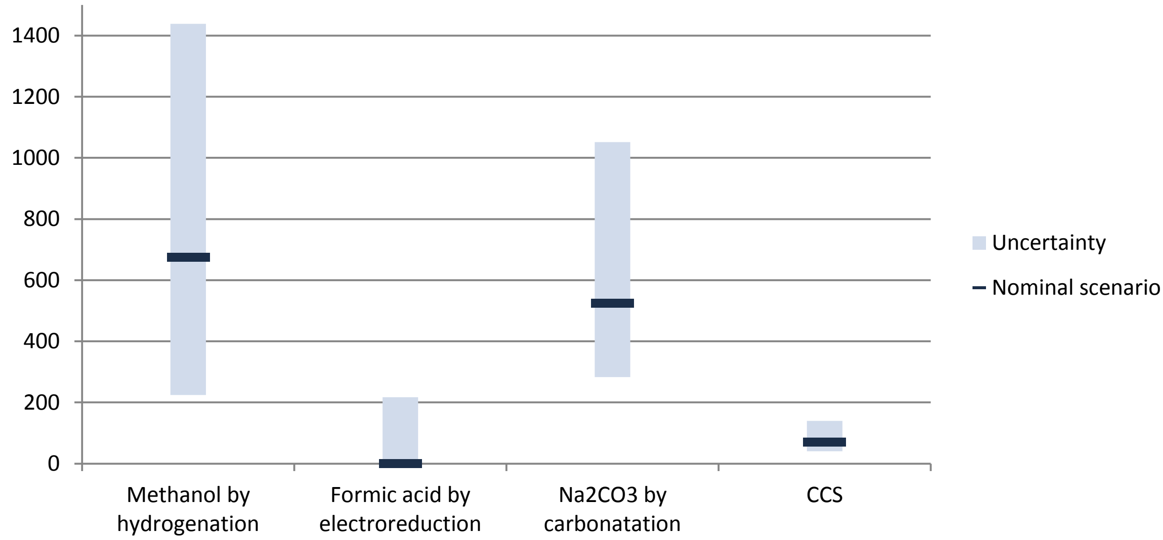
To this end, it appears relevant to favor CO_2 conversion routes to make products with a low "energy level" and with a high market price, while being aware that these choices are generally made to the detriment of the CO_2 impact, given the more limited size of the markets concerned. It's nevertheless a significant contribution that chemistry can provide the overall efforts of industry.

Modelling carried out by ENEA for the ADEME shows that the technical and economic conditions are still rarely sufficient to chemically convert CO_2. Balancing production costs using CO_2 an input with the market price would require a valuation level of avoided CO_2 hard to foresee in the medium term (see figure below).

The production of formic acid using the CO_2 derived from biogas purification stands out as a potentially profitable option today.

Improving the economic viability of CO_2 based chemistry





Value of CO_2 required to balance production costs and market price for 3 CCU processes and comparison with CCS, in €/t_{CO2} (source: ADEME study, modelling by ENEA)

RECYCLING

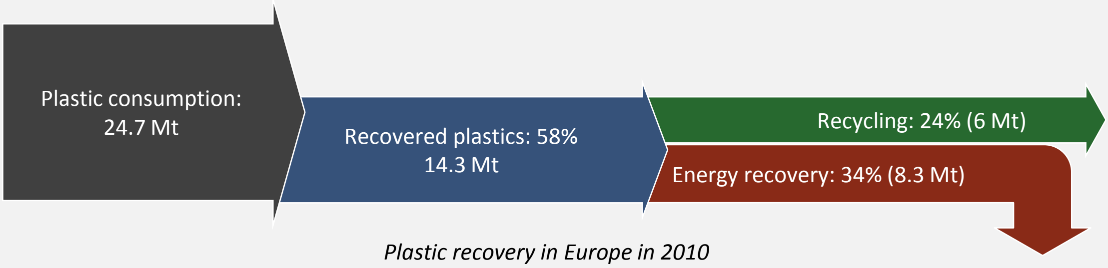
The issue of recyclability

The ability to maintain a high level of quality throughout successive recycling cycles is one of the functionalities increasingly sought out in the development of new materials. The idea is to design from the outset a material intended to be recycled at iso-functionality, which is not the case at the moment.

The entire production chain must be taken into account to optimize the value and the costs of recycling: the identification, sorting and purity of plastic waste coming into recycling processes play a major role in determining the purity of output products.

Focus: recovery and recycling routes for plastics

Recycling is also a possible route to reduce the environmental impact of products made by the chemical industry, particularly plastics, be they bio-sourced or petro-sourced. Only roughly one quarter of plastic products are recycled today in Europe.



Plastic recovery in Europe in 2010

Mechanical recycling is today the most widely used recycling method. Property degradation is inevitable, in particular in the processing of thermofusible plastics, but the affordable cost of the processes concerned have enabled the development of economic solutions for material recovery. We can mention the examples of polyethylene terephtalate (PET), used to make plastic bottles and then transformed into synthetic fibers (used to make fleece mainly) or polyethylene (PE) that can be recycled for degraded applications (garbage bags mainly).

Chemical recycling, which consists in depolymerizing plastics to reform monomers, could be used to produce recycled plastics with properties equivalent to the virgin materials, but does require often complex and costly processes.

These two recycling methods require waste sorting, a very costly and energy-intensive stage. At-source sorting systems would bring down associated costs early on and thus remove one of the main economic obstacles to recycling.

When recycling is not possible (too complex or expensive), the most commonly used route today is energy recovery (combustion). Better recovery alternatives for these materials are being developed, such as the production of synthetic oil (syncrude) based on plastics and pushed by start-ups such as Cynar (UK), Envion (USA) and JBI (USA). These thermal cracking processes will make it possible to deal with the growing complexification of plastics (blends, composites…) by requiring less upstream sorting.

THE CURRENT SITUATION

Key lessons

The European chemical industry is undergoing tremendous change due to the rapidly growing competition from the United States and Asia on commodities. The use of shale gas offers companies based in the United States particularly low energy costs, which is bolstering their competitiveness in a very energy-intensive sector.

Green chemistry, and more specifically the consideration of energy and carbon issues, is opening up many opportunities to stimulate competitiveness and differentiation. Significant efforts will still be required to technically develop the corresponding solutions, as well as to build the required relationships with partners and customers for these new solutions in order to make them economically viable. Today, these efforts are driven by a global situation that is pushing European actors to find disruptive solutions.

Reduce costs

The first lever is to reduce energy consumption. Most chemical companies have already implemented energy efficiency measures but it is possible to find new sources via:

- the reworking of processes, or entire industrial sites, via systemic and exergy analyses;
- technology transfer from the energy-intensive sectors the most advanced in terms of energy efficiency, in particular with regard to utilities and cross-cutting technologies.

Improve the environmental footprint

Environmental added value is one of the possibilities being explored to differentiate products and maintain positions on sensitive markets where additional costs can be passed on in the final prices. A reduction in energy consumption leads to a *de facto* improvement in the chemical sector’s carbon balance. Hydrocarbons, largely of fossil origin, are one of the main sources of raw materials, therefore the biosourcing of inputs could offer new opportunities to further improve the environmental impact of chemical products and to propose to end customers solutions in line with their increasingly high expectations in this field. The use of microalgae and CO_2 conversion are also among the development routes being explored today.

Boost value creation through functionalities

Biosourcing still presents some real economic challenges, in particular compared with conventional inputs. Head-on competition with conventional products is therefore rarely possible today. Having said that, the specific properties of bio-sourced molecules make it possible to develop products with new functionalities that are difficult or even impossible to produce in an economically viable way with traditional methods – these are the first markets that are opening the way for biobased chemistry.

Beyond the chemical industry, a challenge for industry as a whole

Products made by the chemical industry are vital inputs for many industrial sectors and represent an integral part of the environmental impact of the final products. For these industrial sectors, the evolution of their carbon footprint is at least partly dependent on that of their suppliers in the chemical sector, so their goal to improve, driven by the expectations of end users and regulatory constraints, is a key factor to encourage the chemical industry to also move in this direction. Moreover, like for many innovations in the materials sectors, partnerships between chemical companies and potential users of their products will doubtless be a decisive factor.

For more information:

ENEA Consulting: ADEME study on the chemical conversion of CO_2

ENEA Consulting: ADEME study of the potential of algal resources for energy and chemistry in France by 2030

Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998, p.30. By permission of Oxford University Press

Suschem France: Roadmap with DGCIS and UIC

IEA: Biobased chemicals, value added products from biorefineries

IFRI: Impact of the development of shale gas in the United States on the European petrochemical industry, 2013

Authors: Louis-Marie Jacquelin, Jacques de Bucy, Alexis Caujolle

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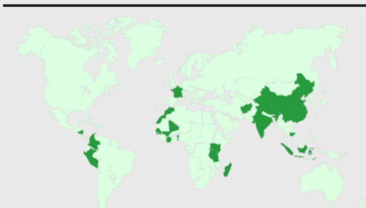

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