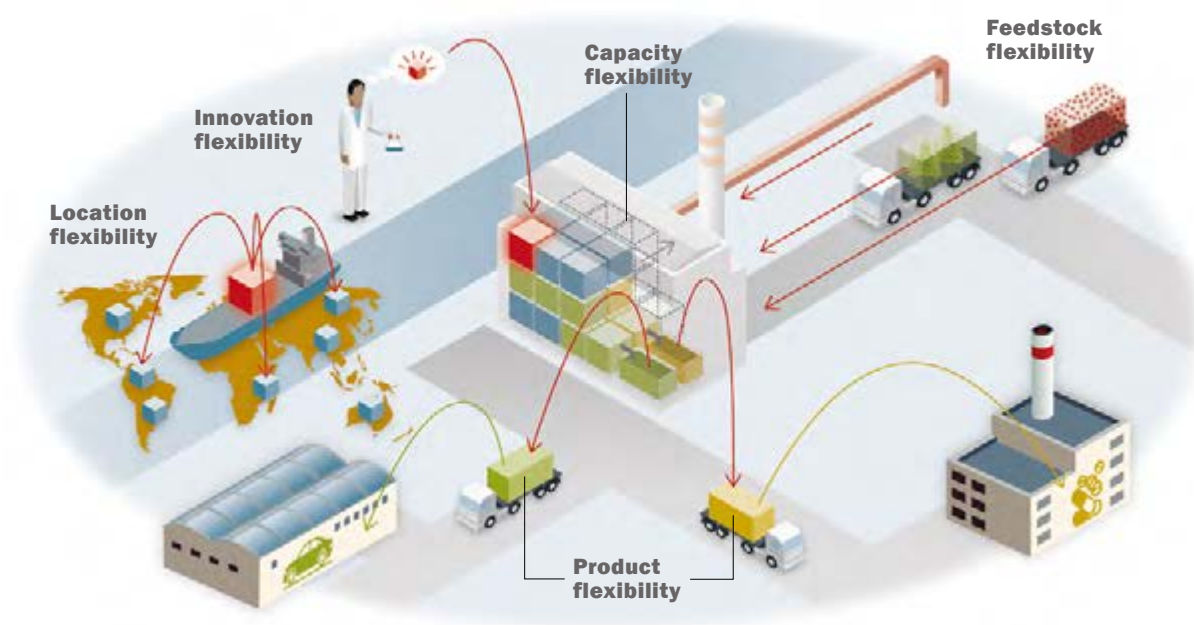


# › SMALL-SCALE FLEXIBLE PLANTS

## TOWARDS A MORE AGILE AND COMPETITIVE EU CHEMICAL INDUSTRY



**TNO** innovation  
for life

### › AUTHORS

Karin van Kranenburg  
Chrysa Sofra  
Dirk Verdoes  
Martijn de Graaff

# MANAGEMENT SUMMARY

The European chemical industry is worrying about its competitive position. In the global market it has a major disadvantage on its cost position on feedstock, energy and labour. The European industry profits from growing market demand in upcoming regions like Asia, but to a limited extent. It is looking for ways to get a significant foothold in these markets. Investment levels in Europe lag behind compared to all other regions.

The strength of the EU chemical industry lies in its knowledge position and its ability to innovate. This leading position in knowledge and innovation offers opportunities to strengthen the competitive position of the industry, not only by the innovations itself, but also by mitigating the disadvantages in other areas, e.g. by reducing costs through innovation.

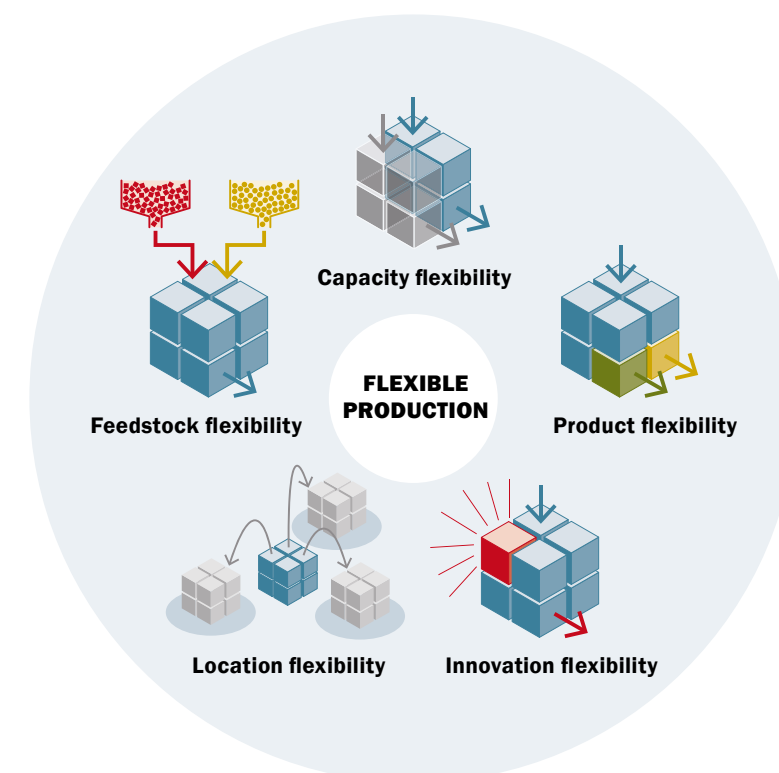
In the rapidly changing and highly volatile chemical market, flexibility is seen as a key element to strengthen the position of Europe. A way to implement this necessary flexibility is offered by the concept of flexible plants. This paper presents a vision on the opportunities that flexible plants can offer. Industry representatives from a large number of chemical companies, covering a wide range from commodities to pharma, provided valuable input for this whitepaper during interviews. Their main drivers to implement flexible plants are to:

- Shorten time to market
- Increase responsiveness to customer demand
- Enable market entry and growth in emerging markets
- Reduce CAPEX risks

In this whitepaper you can read that:

- Flexibility in production offers a route to new strategies reversing the negative trend of the moment, offering a shorter time to market, greater responsiveness to customer demand and CAPEX risk reduction. Production can be flexible in capacity, product type, innovation, location and feedstock.
- Technical developments enable the implementation of flexible plants. Modularity offers opportunities to expand and adapt a plant in a flexible manner, e.g. to enlarge capacity over time. Other relevant technical enablers are process intensification and continuous processing, novel manufacturing technologies like 3D printing, and smart industry.
- Sound business cases are within reach when supported by business models that utilise the benefits of flexibility. More emphasis should be put on value creation, while making investments and operational costs less dependent on scale.

Currently the concept of flexible production is mainly applied in R&D and pilot setting. Recently quite some examples of successful commercial implementation were reported. By joining forces in North Western Europe development and implementation in flexible production can accelerate. Therefore, it is key that companies, knowledge suppliers and governments follow the same direction together, each organisation in its own role and with its own strength. Then the way to broad adoption is open and the concept of flexible production can be implemented on a wide scale, contributing to a stronger competitive position of the EU chemical industry.





# CHANGE IS NEEDED TO STRENGTHEN THE COMPETITIVE POSITION OF THE EU CHEMICAL INDUSTRY

The EU chemical industry is worrying about its competitive position. The competitive strength of chemical companies is globally determined by the following factors:

- Cost of production
- Market demand
- Financial capability
- Knowledge and ability to innovate

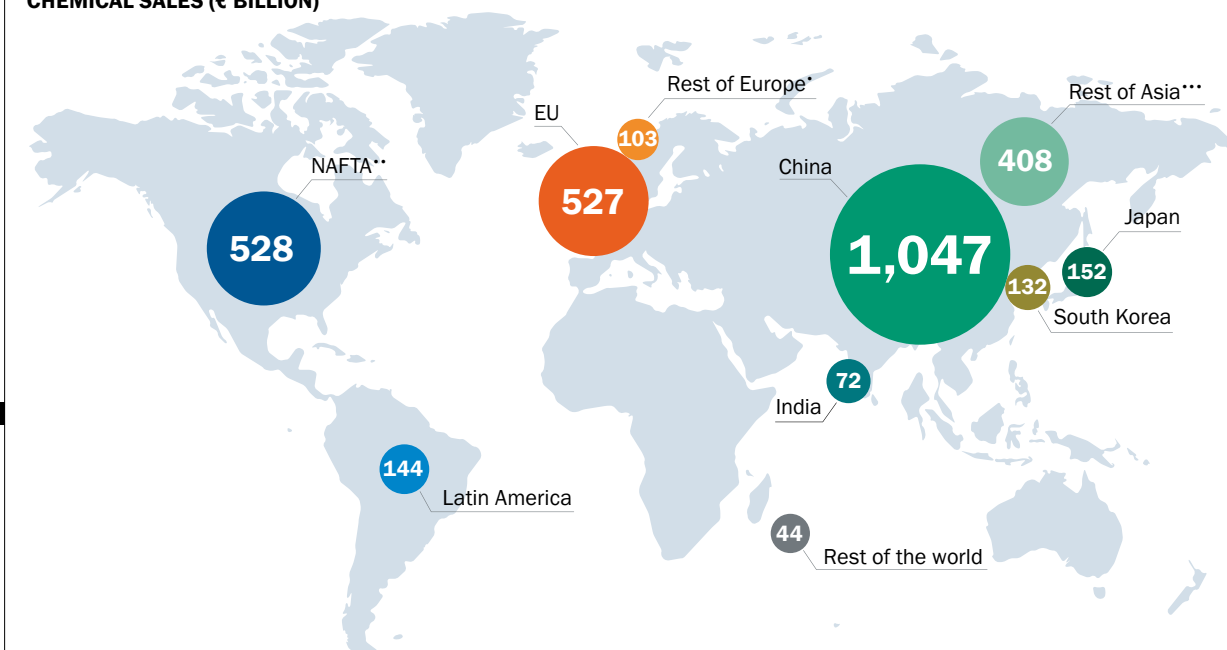
The EU chemical industry has a major disadvantage on cost of production compared to other regions. The shale gas revolution in the US has led to low energy and feedstock (specifically methane and ethane) prices. The Middle East also profits from low energy and feedstock prices, due to their oil and gas reserves. And Asia is favoured by low labour costs and, in potential, has access to large shale gas reserves.

The chemical industry is a typically global market. End markets are very broad, varying from automotive and construction to agro and food. For this reason many chemical companies are operating globally, having a foothold in different regions. Worldwide chemical sales increased with 14% in 2013. Emerging markets in Asia and Latin America contributed significantly to global growth, which makes them very attractive for chemical

## *Decreasing global competitiveness of the EU chemical industry*

companies to invest in. Though EU chemical sales have also grown and almost doubled in 20 years, the EU market share in the global chemical industry almost halved during this period. However, the European Union is still the largest trade region in the world for chemicals and the EU is still a net-exporter with a trade surplus of €49 billion in 2013. But the Trade Competitiveness Index (TCI) is declining, which means that imports are growing faster than exports. This indicates a decreasing global competitiveness of the EU chemical industry. The contribution of petrochemicals has declined significantly, where specialties, consumer chemicals and polymers realise a growing contribution to the TCI of the EU chemical industry.

### CHEMICAL SALES (€ BILLION)

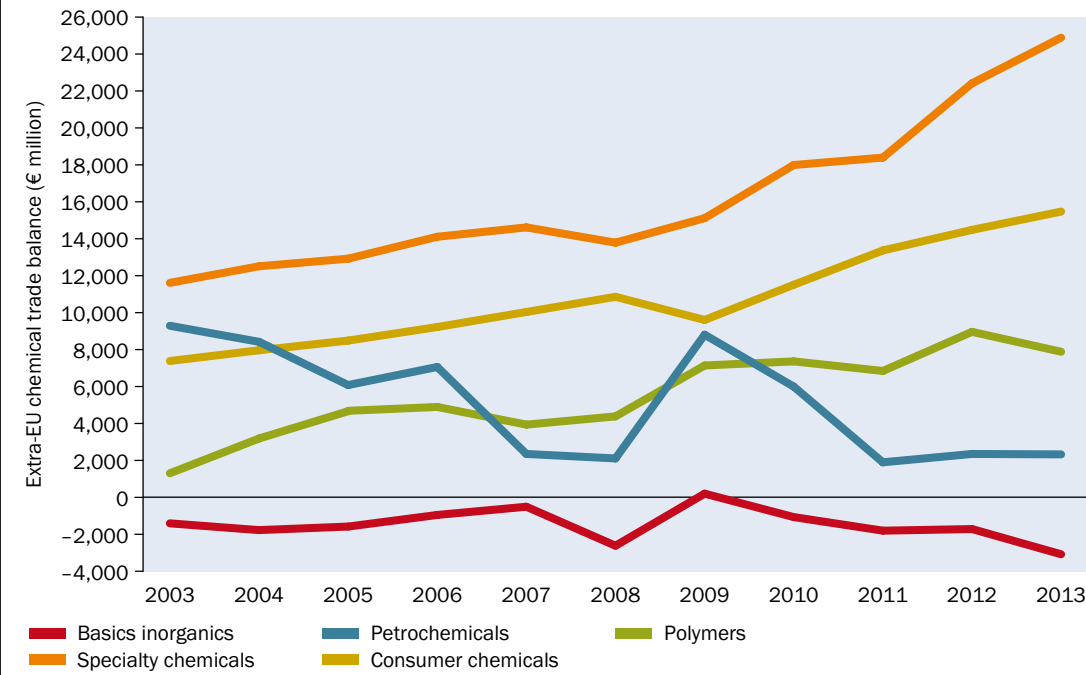


- Rest of Europe includes Switzerland, Norway, Turkey, Russia and Ukraine
- North American Free Trade Agreement
- Asia excluding China, India, Japan and South Korea

Unless specified, chemical industry excludes pharmaceuticals  
Unless specified, EU refers to EU 28

World chemicals sales in 2013 are valued at €3,156 billion. The European Union accounts for 16.7% of the total.  
Source: Cefic, The European chemical industry, Facts & Figures 2014.





Higher value products contribute most to extra-EU chemical trade surplus. Source: Cefic, *The European chemical industry, Facts & Figures 2014*.

Investments are an important factor to strengthen the competitive strength of an industry. On this point, the EU chemical industry lags behind on all other important chemical regions in the world. Although the EU realised investments of €18.6 billion in 2013, which is the highest after China (€67 billion) and the US (€24 billion), the spending intensity (capital spending as % of sales) is almost the lowest of all regions.

Another important factor for the competitive strength of an industry is its knowledge position and its ability to turn this into innovation. On this point the EU chemical industry has a very strong position: it is known for its strong knowledge position. In absolute numbers, the EU chemical industry spends more on R&D than any other region, with €8.4 billion in 2013. When looking at spending intensity on R&D as a percentage of sales, the EU spent 1.6% in 2013, significantly less than Japan (4%) but close to the USA (1.7%). China has an R&D intensity that is less than half of the EU.

Concluding we can state that the EU chemical industry has a major disadvantage on its cost position. Companies are therefore shifting their operations to low cost regions like Asia and take benefit of lower production costs. It profits from growing market demand in upcoming regions, but to a limited extent. It lags behind in investment levels. The strength of the EU chemical industry lies in its knowledge position and its ability to innovate.

### MAIN CONCERNS AND CHALLENGES

TNO performed interviews with multiple European industry representatives, covering a wide range of segments including fine chemicals, specialties, pharma and commodities. We asked them what are currently the main concerns and challenges of their company. The following items were most prominent:

- High cost of energy, feedstock and labour in Europe, which deteriorates its competitiveness
- Doing the right investments, in the right place and in technologies that will pay back
- Gain a position in emerging markets: close to customers, by applying distributed production, preferably with limited capital expenditure
- Accelerate innovation
- Stringent regulation in EU

*The EU chemical industry should build upon its strength: knowledge and innovation*

In our vision the EU chemical industry should build upon its leading position in knowledge and innovation. This offers opportunities to strengthen the competitive position of the industry, not only by the innovations itself, but also by mitigating the disadvantages in other areas, e.g. by reducing costs through innovation. By utilising this position, the EU chemical industry can stay ahead of its global competitors.

By further extending its position in specialties and fine chemicals, the EU chemical industry can mitigate its drawback on costs. In higher value products, the disadvantageous cost position on labour, energy and feedstock has lower impact than in commodities. The growing TCI of Europe for these products shows that this way is already set in. In general specialties and fine chemicals require a high level of knowledge since they are technically more complex. Innovation can ameliorate the value of these products further and makes the EU industry more attractive to invest in.

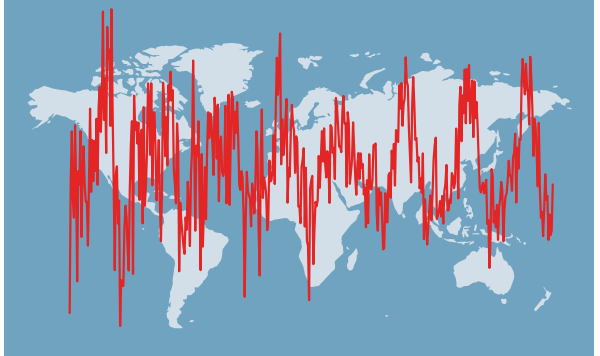
An important enabler to realise a future proof EU chemical industry lies in flexibility. A number of trends in the market have led to a growing need for instant reactions on changing market circumstances (see text box). Flexibility is key for many aspects of doing business. It covers a wide range from internal organisational aspects and flexibility in the supply chain to flexibility in technology. In this paper we will focus on small-scale flexible production.

*Flexibility is key for many aspects of doing business*

### MARKET TRENDS UNDERPIN THE NEED FOR FLEXIBILITY

Flexibility in production is key for the EU chemical industry to respond to actual changes in the global market. A number of market trends lead to an increasing need for flexibility in operations:

- Increasing volatility in demand
- High volatility in prices for feedstock and energy
- Shorter product life cycles
- Demand growth in emerging economies
- Mass customisation





# › FLEXIBLE PRODUCTION MEETS THE NEEDS OF THE INDUSTRY

The era of major new commodity chemical plants being built in Europe is over. The industry is increasingly looking for decentralised, flexible production capacity, especially for high value products. To meet the flexibility needs of the industry, an ideal plant would have the following properties:

- **Capacity flexibility:** a plant should be able to produce small volumes in a cost efficient way. When local demand grows or prices of feedstock or energy drop, it should be possible to scale the plant up or down easily.
- **Product flexibility:** a plant should be easily adaptable to switch to another product.
- **Innovation flexibility:** small-scale plants that are used in R&D and pilot setting should be very easily adaptable to try out innovative products and processes.
- **Location flexibility:** the plant should be moveable from one place to another.
- **Feedstock flexibility:** the plant should be able to handle different kinds of feedstock.

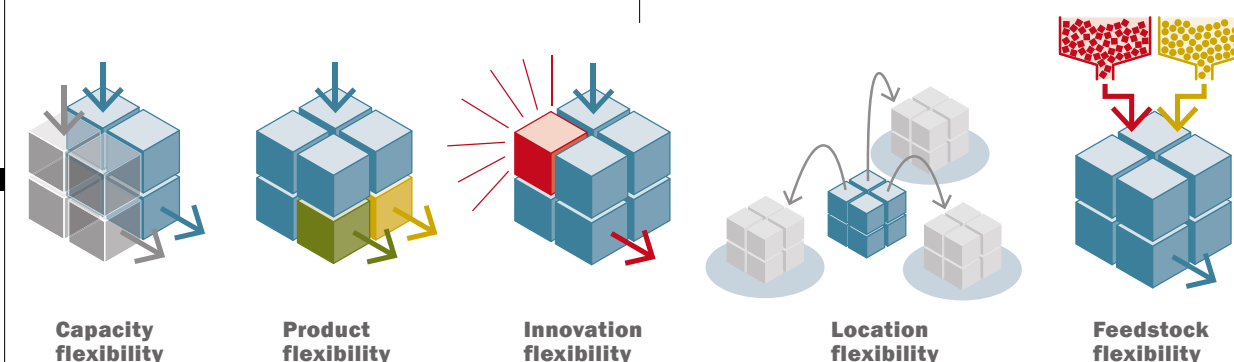
No plant exists yet that can meet all these criteria. In practice, the needs of the industry often have an emphasis on one or two types of flexibility. Also the technology is not far enough yet to combine different types of flexibility, and investments would be so high, that production would not be cost efficient. However significant steps in the right direction have been made and first implementations of the different kinds of flexibility have popped up in the market.

## CAPACITY FLEXIBILITY

Besides using its existing large-scale centralised and highly efficient plants the industry can benefit from distributed, small-scale production. This enables companies to create a foothold closer to market demand, especially in emerging economies, without the financial risk of huge investments in large-scale plants. When local demand increases, such a plant can be scaled up to produce higher volumes. Small-scale production offers the possibility to produce close to the customer, resulting in more customer intimacy and responsiveness and less transport costs. A small-scale plant can be implemented in relatively short time, especially when using modular technology. This will lead to a shorter time to market. Other benefits of small-scale production are smaller stocks and less use of working capital. Small-scale distributed and capacity flexible production may also be applied to reduce logistic costs.

Currently low capacity flexible production in some cases appears to be economically attractive already in specialties. For commodities it is generally not cost efficient yet, since economies of scale play a dominant role in commodities. However we expect it to become relevant for commodities also on longer term.

*First implementations have popped up in the market*





**PRODUCT FLEXIBILITY**

Product flexibility makes it possible to produce different products, or variations of a product, with the same equipment. This type of flexibility meets the need for greater responsiveness to customer needs and mass customisation. For example customers may need different quality plastics, that vary per week. Another trend that makes product flexibility relevant is the shortening of product life cycles. When demand for a product decreases because newer products replace it, a plant with product flexibility characteristics can be adapted to produce a new or adapted product relatively easy. This will shorten time to market significantly.

Product flexibility is mainly interesting for higher value products, e.g. specialty plastics, food ingredients or lifestyle products. Also in pharma steps towards product flexibility are visible (see the example of Pfizer below). In commodities the competition is focused on cost and less on innovation. Product flexibility is less relevant in this market segment.

**INNOVATION FLEXIBILITY**

This type of flexibility resembles product flexibility, but focusses on innovation and applies mostly in R&D and pilot setting. By making pilot plants very easily adaptable, modifications to products or new products can be tried out rapidly. The same applies to process innovation. This will accelerate product and process innovation considerably and shorten time to market.

Since this flexibility type explicitly builds on Europe's strength in knowledge and innovation, it is very important to the EU industry. Like product flexibility, it applies mostly in higher value products.

**PORTABLE PLANTS  
BY PFIZER**


Pfizer, together with partners, developed a concept for Portable Continuous Miniature and Modular Manufacturing. In the concept, formulation is done in a moveable cleanroom that can be transported to customer sites. Active ingredients will still be produced in the US, to minimise technology transfer. The concept should result in a shorter time to market, more responsiveness to customer demand (6-8 months from order), operational flexibility (multiple products and scales) and lower upfront investments and operational costs.

Source: Presentation of Michael K. O'Brien, Ph.D. at ISBioTech Flexible Facilities & Systems, Rosslyn, Virginia March 14, 2013.



**OFF-SITE BUILDING BY TEBODIN**

In 2014 Tebodin delivered a project for Huntsman Rotterdam that was built off-site in a modular way. The purpose was to minimise the necessary construction work at site and hence reduce the safety risks. Divided in 4 modules, all built outside the Huntsman site, the units were shipped, transported and safely placed within 48 hours. This meant that the time-to-production was drastically decreased.



**LOCATION FLEXIBILITY**

Location flexibility makes a plant, or parts of the plant, moveable from one place to another. Also this kind of flexibility is already applied in a commercial environment in some cases. Transportable plants can be applied in the following situations:

- Local production close to customers. Production can be synchronised to local demand: when production is enough (to meet timely demand, or enough stock is created), the plant can be moved to another region or country. In this way not only a shorter time to market is realised, but also logistic costs can be minimised.
- Production of products that are seasonal. E.g. pesticides can be produced half a year in Europe, and the rest of the year somewhere in the southern hemisphere. This principle can also be applied for bio-mass (see feedstock flexibility).
- When it is preferable not to build the plant onsite, e.g. for safety reasons: a chemical site is a risk full environment to build on and special licenses are needed which is time costly. The elements of the plants can be built in a less vulnerable environment and only need to be assembled after transport. In this way also implementation times can be reduced when building offsite.

Location flexibility is especially interesting for small-scale production, both in pharma and fine chemicals and will become viable for application in specialties within a few years. The concept is also applied for R&D purposes: a transportable pilot plant can be moved between different plants worldwide and accelerate product development locally. Building a transportable plant offsite is also interesting, and already being applied in commodities, for safety reasons.

**FEEDSTOCK FLEXIBILITY**

Feedstock flexibility enables a plant to use different kinds of feedstock. In the following situations feedstock flexibility may apply:

- Switching from one feedstock to another in the process of formulation or production of end user products. This may apply when novel materials are brought to the market. Another driver is less dependency on specific feedstock suppliers. In case of e.g. a price raise or a feedstock shortage the plant can quickly switch to another feedstock without losing quality.
- Use of different, e.g. bio-based, feedstocks. Bio-mass forms an interesting alternative to traditional feedstock to create greener products. The use of different kinds of bio-mass next to each other can be applied in the future. Think of the conversion of e.g. glucose, wood, and straw.

Location flexibility is especially interesting for small-scale production, both in pharma and fine chemicals and will become viable for application in specialties within a few years. The concept is also applied for R&D purposes: a transportable pilot plant can be moved between different plants worldwide and accelerate product development locally. Building a transportable plant offsite is also interesting, and already being applied in commodities, for safety reasons.

The table below shows the term on which we expect the different types of flexibility to become implemented in each market segment. Location and innovation flexibility are already being applied in some cases. They are currently mainly relevant for pharma and fine chemicals, and will also become for specialties. They are not relevant for commodities, except in the case where location flexibility is applied for security reasons (offsite plant building or production of hazardous materials on customer location).

*Flexibility need vs market segment.*

	Pharma	Fine chemicals	Specialties	Commodities
Location flexibility	Short-term	Short-term	Mid-term	Short-term*
Innovation flexibility	Short-term	Short-term	Mid-term	Less relevant
Product flexibility	Mid-term	Mid-term	Long-term	Less relevant
Capacity flexibility	Less relevant	Less relevant	Mid-term	Long-term
Feedstock flexibility	Less relevant	Less relevant	Mid-term	Long-term

\* Only for safety reasons, e.g. offsite plant construction or production of hazardous materials.

**BUSINESS DRIVERS FOR SMALL SCALE FLEXIBLE PRODUCTION**

During the interviews we asked companies for their main drivers to implement small scale flexible production. The main drivers that were named are the following:

- **Shorten time to market**
- **Increase responsiveness to customer demand**
- **Enable market entry and growth in emerging markets**
- **Risk reduction: financial, security of supply, reduce feedstock and energy dependence**
- **Cost reduction (mainly on logistics)**
- **Cope with decentralisation of feedstock and energy**
- **Production of hazardous materials on location**
- **Easy integration of technology**

Product flexibility is relevant for the same segments, but it will take more time before it will get adopted by the industry. Capacity and feedstock flexibility are more relevant for higher volume production and thus apply most in specialties and commodities. Since costs play an important role here the costs for implementing flexibility will have to drop significantly before the innovations will be applied. Concluding we expect expansion of flexibility to move from higher value products to specialties (mid-term) and commodities (long-term).





# TECHNOLOGICAL DEVELOPMENTS ENABLE FLEXIBLE PRODUCTION

The implementation of flexibility into chemicals production is very much dependent on technology in order to adapt to uncertainty in future demand, the increase of volatility and the need for more flexibility in innovation and processing. Common technological challenges for achieving the different types of flexibility are how to break the economy of scale and drive down capital and operational costs for smaller production units and also how to increase operational value generation to make a sound business case for flexibility.

Multiple technical developments are ongoing, both in academia and industry, that can potentially address these challenges. The most promising developments are the following:

- Modularity
- Process intensification and continuous processing
- Equipment manufacturing technologies
- ICT and smart industry

They are described below and will for sure be seen more and more in practice, by themselves and in combinations.

## MODULARITY

Modular design is an approach that subdivides processes into separate parts (modules) that can be independently created and then connected either in parallel for copying plant parts, e.g. to enable increase/decrease in capacity, or in series for connecting multiple process steps, e.g. to enable modular plant erection or change in unit operations. Modularisation could give ample opportunities for different types of flexibility, like location flexibility by moving plant parts before or after operation, capacity flexibility by using parallel units as demand increases/decreases and product flexibility by changing modules when the product profiles change.

Multiple examples on modular processing are already seen in the market ranging from R&D activities by the European F<sup>3</sup> Factory consortium, through commercial implementation of modular factory concepts by Nestlé. We expect that this is only the beginning of a movement towards the widespread use of modularity in many sub-segments of the processing industry.

## PROCESS INTENSIFICATION AND CONTINUOUS PROCESSING

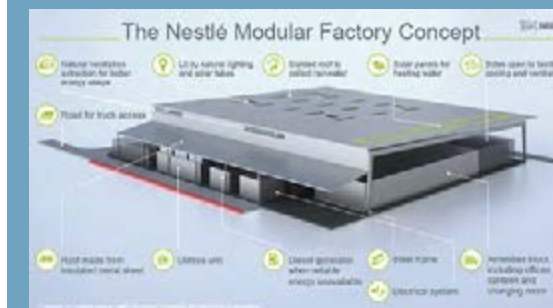
Process Intensification is an approach in chemical engineering that can be described as ‘a strategy for making dramatic reductions in the size of a chemical plant to achieve a given production objective’ (Ramshaw, 1995). This approach is enabled in the last decades by enormous scientific and technological advances in reactor engineering, separation technology and inline process analysis and control, combined with systems engineering approaches towards chemical plant design. When employed correctly, Process Intensification offers a huge increase in productivity at much lower operational and capital costs and a much

## MODULAR FACTORY CONCEPT BY NESTLÉ



A simple but nice example of modularity has been elaborated by Nestlé. The company has created a blueprint for a flexible modular factory, that can be built in half the time (<12 months) of a traditional factory, and at 50-60% of the cost. It enables Nestlé to rapidly create a foothold in countries in Africa and Asia, getting closer to their customers and raw material sources.

The factory is made of ready-to-use elements, that can be assembled on site. If needed, the factory can be moved or expanded. The factory will fulfill relatively simple processes like mixing dry goods, e.g. Maggi bouillon cubes.



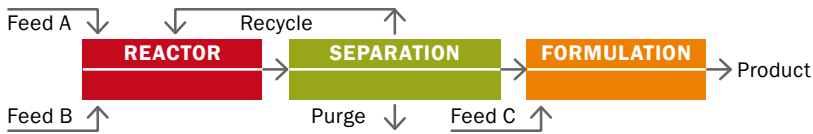
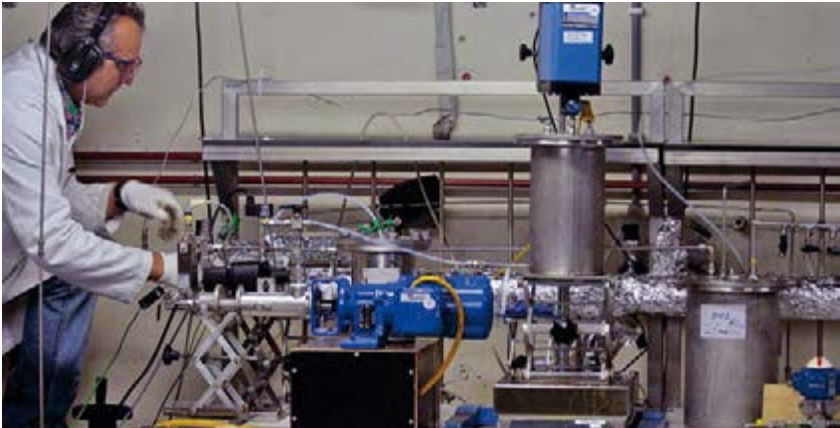
Source: [www.nestle.com/media/newsandfeatures/modular-factories](http://www.nestle.com/media/newsandfeatures/modular-factories).

smaller plant footprint compared to employing traditional methods and technologies. This addresses a number of the requirements for flexible production.

Whereas the conventional production of fine and specialty chemicals is done in batch, flexible production requires continuous processing as it offers ultimate control over heat and mass transfer and therefore gives higher product quality and lower formation of unwanted by-products and waste. Also, continuous processing enables better recycling of materials and energy integration and it enables further automation of processing. Until now continuous processing has not fully matured in the fine and specialty chemical segments due to the higher (perceived) cost of capital, the technological uncertainties and lack of knowledge concerning application in those segments. In addition batch processing has created an image of being extremely

*Technological challenges are to drive down capital and operational costs for smaller production units*





Photograph of a continuous flow chemistry research installation in the CoRIAC project at TNO and a schematic representation of full continuous processing..

**F<sup>3</sup> FACTORY PROJECT**



In the F<sup>3</sup> Factory project a standardised, modular, continuous demonstrator plant in a container has been developed. It is based on ‘plug and produce’ modular chemical production technology to deliver new manufacturing concepts that can significantly decrease process development time through the standardisation, modularisation and application of novel process intensification technologies.

The building blocks in F<sup>3</sup> Factory are called Process Equipment Assemblies (PEAs). They include intensified continuous chemical reactors, downstream equipment, storage units, pumps or combinations of these components and can be easily installed, connected or removed. PEAs can fulfill tasks like feed, reaction, separation or purification.



Bayer's Process Equipment Container Unit installed at INVITE.

Source: [www.f3factory.com](http://www.f3factory.com).

flexible. In reality the flexibility of the batch reactor is often based on accepting that it is used outside the optimal operating window with suboptimal control of function like mixing or heat exchange. During the last decade a growing amount of showcases are reported where continuous processing replaces the traditional batch processing, e.g. in pharmaceuticals and specialty plastics production.

Process Intensification and continuous processing will improve the energy and resource efficiency and thereby decrease the costs associated to raw materials, energy and waste production. In addition, the time-space yield of continuous, intensified equipment will be orders of magnitude better than for the batch reactor. This will contribute to lower the equipment costs and enable the use of novel operating conditions such as high p and/or T to further enhance the productivity rate and/or to change the yield and product purity.

**EQUIPMENT MANUFACTURING TECHNOLOGIES**

It is not difficult to find examples with impressively high volumetric productivities in continuous flow chemistry processes. However, this will only contribute to building a positive business case when the advantages of the small intensified equipment is accompanied by a cost benefit compared to the reference, which is often the batch reactor/process. So the challenge or hurdle is whether we can decrease the (investment) costs of equipment for intensified continuous production. The potential game changer on this point is the use of novel inexpensive mass production technologies. These technologies should be able to produce complex parts that can resist process environmental conditions, are relatively easy and low-cost to make and that can be changed easily in geometry.



Example of a 3D printed metal part.

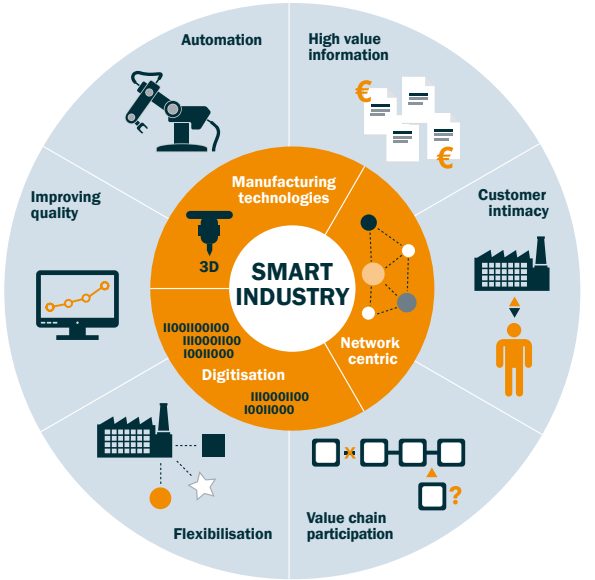
A first example of novel manufacturing technologies is *3D printing*. This technology is said to be the ‘single most disruptive phenomenon to impact global industry since mass production lines were introduced’ and enables the manufacture of any shape at any place. More and more materials can be printed using this technology. Especially, the use of 3D metal and ceramics printing is thought to change the way process technologies will be designed and manufactured and examples can already be seen in the use for rapid prototyping for R&D applications. Another interesting breakthrough manufacturing technology is *injection moulding and extrusion of ceramics*. The ceramic parts can be assembled to create almost inert reactors that can withstand high p and/or T or in membrane modules for modular separations like dewatering, microfiltration or ultrafiltration. For metals (*hydro*)forming and embossing could enable the step to create easily replicable and cost efficient metal reactor parts.

**ICT AND SMART INDUSTRY**

Smart industry, also called Industry 4.0 or Internet-of-Things, integrates ICT and internet into production. As information technologies progress, production plants will for sure be made more intelligent, more efficient and more flexible. By integrating sensors and ICT in flexible production more insight in the condition of assets is gained and this information can be used to implement condition based maintenance, preventing downtime, increasing safety and making maintenance more efficient. All these aspects contribute to increasing the robustness and the productivity, whilst decreasing maintenance costs.

ICT can also create shorter response times in the value chain. By automated monitoring and communication across the value chain responses on changes the value chain, like increases in demand, changes in customer needs, or volatility of feedstock and energy prices, will become faster and dedicated. This will for instance pay off in the reduction of the amount of products that are kept in stock.

Last but not least, ICT/Smart Industry creates the opportunity to design and operate remote controlled plants. As precursor the automation of maintenance and management of plants is already taking place. Remote controlled/operated plants will strongly reduce the amount of personnel on location which will strongly reduce the operational costs of small, flexible production plants.



Visualisation of the concept of ‘smart industry’.

Relevance of technology developments for the different types of flexibility.

	Modularity	Process intensification & continuous processing	Equipment manufacturing technologies	ICT & smart industry
Location flexibility	Relevant	Important	Relevant	Relevant
Innovation flexibility	Relevant	Not relevant	Relevant	Relevant
Product flexibility	Important	Relevant	Relevant	Not relevant
Capacity flexibility	Important	Relevant	Relevant	Important
Feedstock flexibility	Relevant	Not relevant	Relevant	Relevant



# BUSINESS MODELS SHOULD SUPPORT THE BENEFITS OF FLEXIBILITY

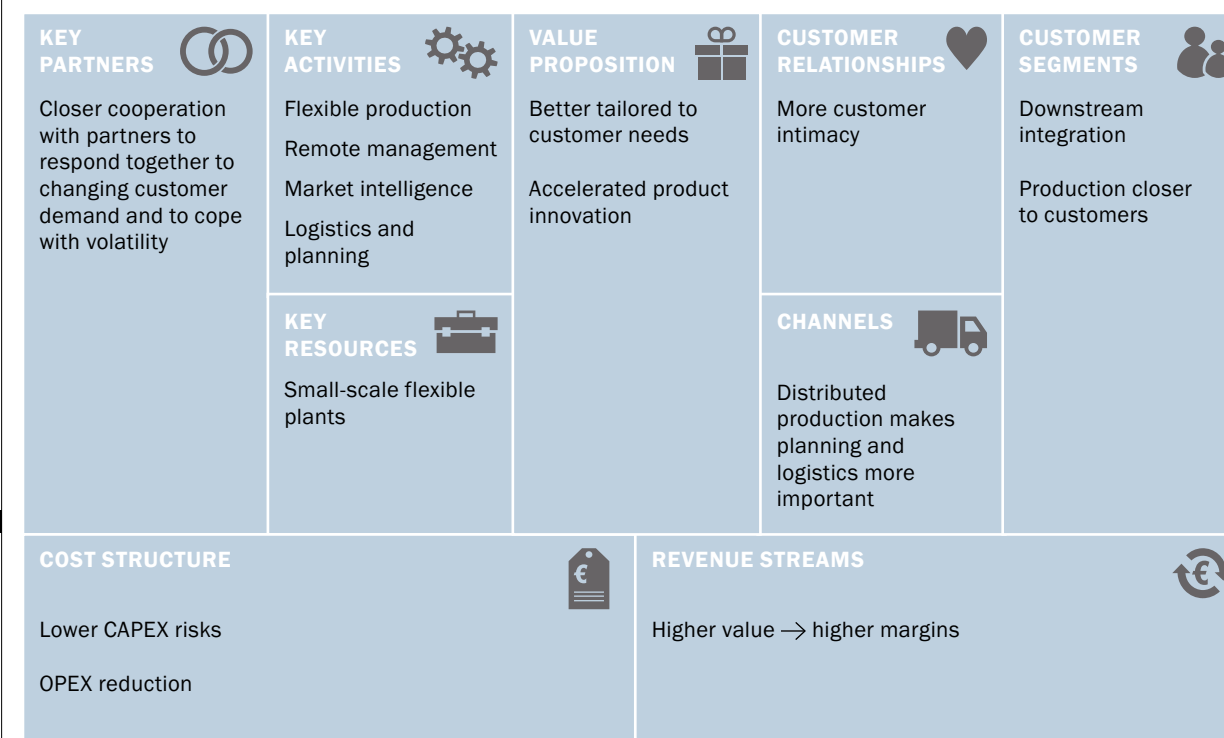
The concept of flexible modular plants will impact the way in which the industry does business. This does not only concern the technology but even more the business model of companies. Business models should support the envisaged benefits. Nowadays most business models in the chemical industry are driven by cost efficiency and large-scale production. For high value products new business models are emerging, that put more emphasis on value than on costs. To support the business benefits of small-scale flexible plants, a further adaptation of business models should take place.

Flexible production offers opportunities to create greater responsiveness to changing customer demand and accelerated product innovation. Therefore, insight in changing customer demand could be brought directly into the production process. This requires increased customer intimacy and tighter integration of the value chain on the demand side. Distributed production brings chemical customers closer to local markets and offers opportunities for downstream integration.

Also on the supply side of the value chain tighter integration is desirable. Suppliers should react fast to changing demand of chemical companies, due to changes in demand of end users, or due to changes in feedstock and energy prices. Distributed production may lead to integration of local partners into the value chain. Also in case of bio-based production new partnerships will emerge e.g. between the suppliers of bio-mass and the producers of bio-chemicals. New business models like BOOM (Build-Own-Operate-Maintain) may be applied to reduce CAPEX risks.

The shift from cost competitiveness to striving for the highest value will become more important when flexible production is implemented. This has consequences both for revenues and for costs. These consequences are elaborated in the next paragraph.

*The shift from cost competitiveness to striving for the highest value will be crucial*



Changes in business models due to flexibility, mapped on the Business Model Canvas. The Business Model Canvas method is developed by Alex Osterwalder and describes a business model by nine basic building blocks. Osterwalder defines a business model as follows: 'A business model describes the rationale of how an organisation creates, delivers and captures value'.





# SOUND BUSINESS CASES ARE A CHALLENGE, BUT WITHIN REACH

The shift towards more flexible production concepts offers opportunities to strengthen the competitive position of the chemical industry in Europe. However, for this to become reality, a sound business case needs to be realised.

This is a challenge, since the economies of scale will favour one larger-scale dedicated plant compared to multiple small scale flexible units. However, the first commercially and financially successful examples of small-scale flexible production have already been implemented. In this paragraph we will look at possible ways to realise a sound business case. One part of the answer can be found in lowering capital investment and operational costs by rethinking the way a chemical plant is set up. The other part lies in leveraging the benefits of flexibility by increasing revenues and reducing costs and investment risks in a way that they can outweigh the increased investment costs per unit of product.

**LOWERING CAPEX AND OPEX BY RETHINKING PLANT SETUP**

Up until now, plants have generally been built with a lifetime of 20-30 years in mind. Therefore, both the process design principles and the financial and decision making models assessing existing and future investments are geared towards longer evaluation periods. Anticipating on the volatility in the chemicals market, flexible plants should be designed and, therefore, evaluated based on shorter lifetime periods. This calls for a new way of thinking in terms of process design and equipment manufacturing technologies, as well as financial and decision making models that can ensure profitability.

In this paper a number of technological developments were discussed, that will have significant impact on CAPEX and OPEX, besides their benefits for e.g. product quality and time to market. They can contribute significantly to overcome economies of scale drawbacks of small-scale flexible production. In the table below their impact on CAPEX and OPEX is presented.

*The first commercially and financially successful examples of flexible production have already been implemented*

Techology	Impact on CAPEX	Impact on OPEX
Modularisation and Standardisation	<ul style="list-style-type: none"><li>– Price reduction of standard elements, when produced in larger volumes/quantities</li><li>– Easier installation and integration of elements</li><li>– Reuse of elements</li><li>– Offsite production of plants will reduce implementation times</li></ul>	<ul style="list-style-type: none"><li>– Reduced maintenance and repair costs; part of the plant can continue production during maintenance</li></ul>
Process intensification and continuous processing	<ul style="list-style-type: none"><li>– Reduction of footprint</li></ul>	<ul style="list-style-type: none"><li>– More efficient production: reduction of costs for raw materials, energy and waste</li><li>– Enables further automation of processing</li></ul>
Equipment manufacturing technologies	<ul style="list-style-type: none"><li>– Lower cost for equipment, especially for small-scale production</li><li>– Low cost rapid prototyping</li></ul>	
ICT and Smart industry	<ul style="list-style-type: none"><li>– Less spare parts and product in stock due to sensor/in formation based maintenance and production planning</li></ul>	<ul style="list-style-type: none"><li>– Less labour cost due to remote controlled plants</li><li>– More robustness and efficiency of production will reduce costs</li><li>– Condition based maintenance will prevent downtime and reduce maintenance costs</li></ul>



LEVERAGING THE BENEFITS OF SMALL-SCALE FLEXIBLE PRODUCTION

The benefits of small-scale flexible production will directly impact the competitive position of chemical companies and give them strategic advantages. They will have positive effects on revenues, but can also reduce CAPEX and OPEX in some cases. Overall, combining flexible production concepts with strategic production planning and advanced logistics can help realise the benefits of flexibility and eventually lead to improved profitability. In the table below the main benefits of flexible production, named by the interviewees, are presented. For each benefit, its impact on revenues and costs are described.

Flexible production will have positive effects on revenues

Benefit	Impact on revenues	Impact on costs
Shorten time to market	<ul style="list-style-type: none"> <li>Offers opportunities to capture market share before the competitor does</li> <li>Higher margins on innovative products</li> </ul>	<ul style="list-style-type: none"> <li>Shorter implementation times in general reduce CAPEX and OPEX needs for projects</li> </ul>
Increased responsiveness to customer demand	<ul style="list-style-type: none"> <li>Will lead to more loyal customers, that are prepare to pay a higher price, and less churn</li> <li>A better image will result in more market share</li> <li>Easy upscaling of capacity when customer demand increases</li> </ul>	<ul style="list-style-type: none"> <li>When adapting production volumes to actual demand more quickly, lower stock is needed</li> </ul>
Market entry in emerging economies	<ul style="list-style-type: none"> <li>More revenues by broadening market reach</li> </ul>	<ul style="list-style-type: none"> <li>Distributed production, close to customers, offers opportunities to reduce logistic costs</li> </ul>
Risk reduction	<ul style="list-style-type: none"> <li>Low CAPEX, small-scale production offers opportunities to create a foothold in markets where otherwise investments would be too high</li> <li>Security of supply will ensure revenues and reduce customer churn</li> </ul>	<ul style="list-style-type: none"> <li>Lower CAPEX risks in uncertain market conditions. E.g. by stepwise capacity expansion when demand increases (see graph)</li> <li>Reduced feedstock and energy dependence will lower the risk of price increases</li> </ul>



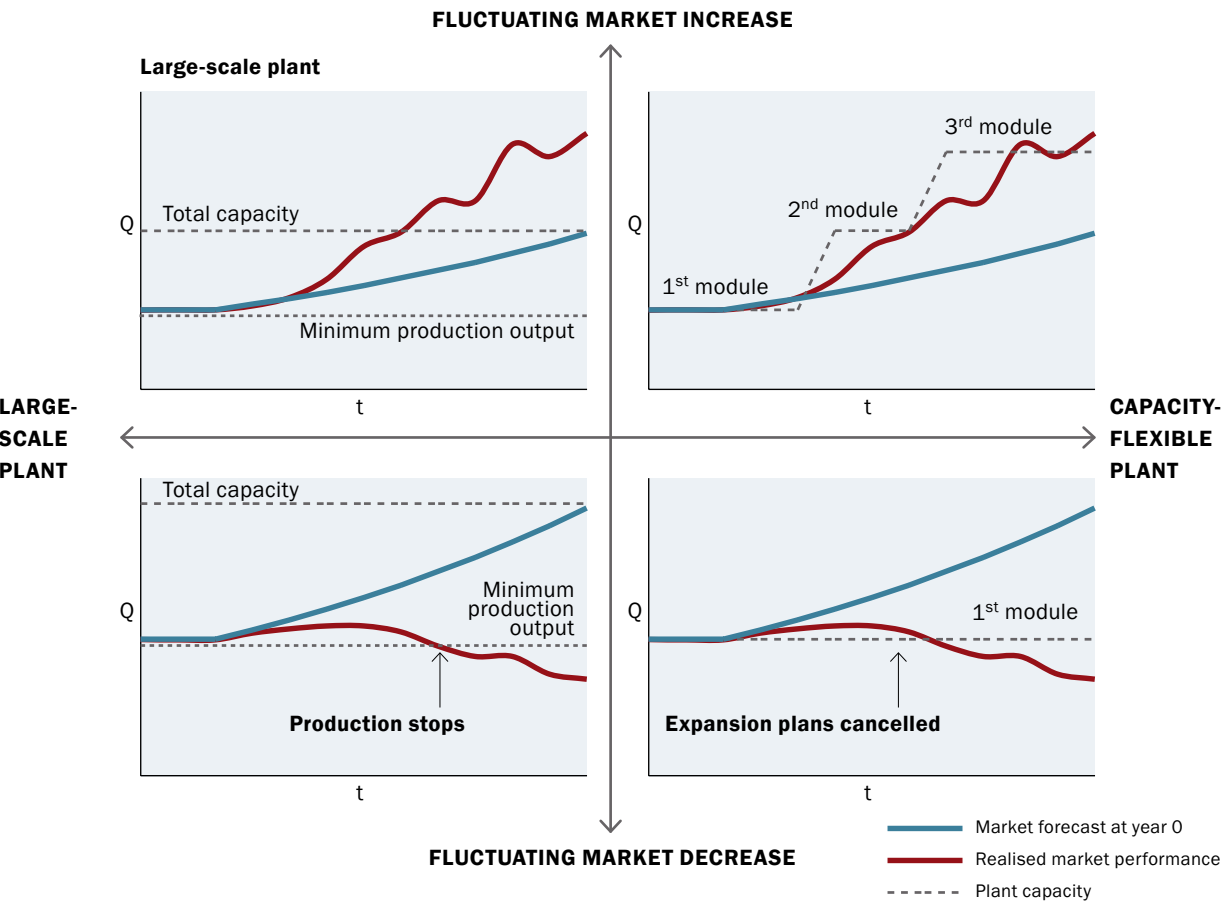
A shorter time to market offers opportunities to capture market share and realise higher margins.

EXAMPLE: RISK REDUCTION BY APPLYING CAPACITY FLEXIBILITY

Demand levels for a certain product can vary during its lifecycle, whether it is a newly launched product at its steep, yet uncertain, growth phase or an existing product in a mature market. When a new product is introduced, production output is planned based on market projections which carry a certain level of uncertainty. At first, flexibility in implementing new production technologies or adjusting existing facilities to a new process will contribute to shorter time-to-market and a stronger competitive position, and increase revenues. In addition, starting with smaller-scale production facilities will help create a foothold in the new market with reduced investment risk. If the product introduction is successful, the production capacity can be scaled up in a step-wise manner according to the market developments. In such cases, capacity flexibility can prove advantageous.

The picture below shows how capacity flexibility can reduce CAPEX risks in uncertain market circumstances. On the left the situation for a large-scale plant is depicted: total capacity of the plant is determined for a long term based on the market forecast at the investment moment. When market demand increases more than projected, capacity may get too small. When market demand appears to be disappointing, capacity is too high which leads to capital destruction, especially when production has to be stopped. In case of capacity flexibility, the plant can be expanded when market demand increases. Investments are limited when market demand decreases.

By combining the chances for reducing the cost of flexible plants and the opportunities for increased revenues and margins, positive business cases for flexible production will become within reach in many cases and will result in increased return on investment.







# TO ACCELERATE INNOVATION, A COLLABORATIVE EFFORT OF THE EU INDUSTRY IS NEEDED

Concluding we can state that the concept of small-scale flexible plants offers a great opportunity to the European chemical industry to strengthen its competitive position. During the interviews industry representatives have indicated that the concept replies to a number of important business drivers.

Currently the concept of flexible production is mainly applied in R&D and pilot setting. Recently quite some examples of successful commercial implementation were reported. Most implementations relate to capacity, innovation and location flexibility. Product and feedstock flexibility will get relevant on a longer term. Like with most innovations that are in an early stage, early adopters can be found mainly in areas where the innovation has the highest value, that must compensate for relatively high investments in early stage innovation. That makes it not surprising that most commercial implementations can be found in higher value segments, i.e. pharma, fine chemicals and specialties. Early adopters will drive developments, making the technology proven and eliminating childhood diseases. In this way they will pave the way towards broader market adoption.

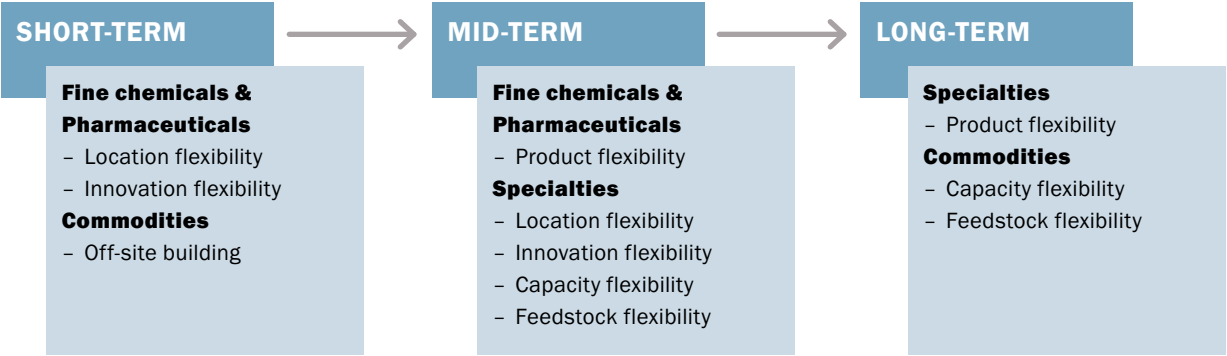
However, to keep Europe's competitive position with respect to the rest of the world, implementation and innovation should be accelerated. Businesses and ecosystems that do not innovate will be too late when competition has taken over their position. However, as is usually the case in innovation, the route from concept and first application towards broad adoption is long and bumpy. Even when technologies and novel business approaches have proven themselves, many barriers have to be overcome.

The basis to overcome these barriers is the common interest of the EU chemical industry to utilise the advantages offered by flexible production (see page 11, textbox Business drivers for small scale flexible production).

During the interviews, a the following barriers were named that should be overcome to let broad adoption take off:

- Economic
  - Financial feasibility not proven yet
  - Amortisation of installed base
- Technical
  - Lack of standards
  - Some crucial components are missing: separation, formulation, system engineering approaches and integration of ICT
- Organisational
  - Conservative character of the industry
  - Cultural: every problem is seen as unique
- Regulation
  - Is perceived as a barrier for innovation

There are already a number of public-private initiatives in the field that drive flexible production: EUROPIC, Britest (UK), FISCH (Belgium), Provide (TNO in the Netherlands) and INVITE (BTS in Germany). Apart from that there are multiple private collaborations and platforms. By joining forces in North Western Europe development in flexible production can get even stronger. Therefore, it is key that companies, knowledge suppliers and governments follow the same direction together, each organisation in its own role and with its own strength. In this way the industry can overcome the barriers. A collaborative business and technology roadmap, combining the knowledge, information and capabilities of the main players will greatly facilitate the innovation process. Then the way to broad adoption is open and the concept of flexible production can be implemented on a wide scale, contributing to a stronger competitive position of the EU chemical industry.



*A collaborative business and technology roadmap will accelerate implementation*



## FULL REPORT

Besides this whitepaper, a more extensive report on small-scale flexible production is freely available at [TNO.NL/FLEXPLANTS](http://TNO.NL/FLEXPLANTS). This report will give you a deeper understanding of the topics treated in this whitepaper.

Besides a further elaboration of the topic, it contains:

- Elaboration of market trends towards flexibility
- A more extensive description of relevant technologies
- An elaboration of the business model canvas
- A business case example on capacity flexibility, with a financial comparison of stepwise capacity expansion and a large-scale plant
- Possible solutions to overcome existing barriers and accelerate innovation

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» For more information,  
 please contact  
 Martijn de Graaff  
 E [martijn.degraaff@tno.nl](mailto:martijn.degraaff@tno.nl)  
 M +31 6 222 608 71

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