The current learning module is part of a suite of training material developed to disseminate outputs from the Flexible, Fast and Future Factory (F³ Factory) project. It is targeted to chemists, engineers and other professionals who work in teams that develop processes, and who are considering using modular production technology. It should also be of interest for university Masters-level students in subjects relevant to process development and design.

The current module presents a generic approach for the identification of business drivers for implementation of modular continuous production as an enabling technology.
The module covers the following topics:

- An introduction describing the traditional division of the chemical sector into two major categories, and explaining why this simple division into two categories is insufficient for description of many business-production scenarios
- Presentation of typical criteria of interest for the description of business-production scenarios in the chemical process industries
- Definition of business-production scenarios using a “multi-criteria” based approach
- Identification of business drivers for implementation of modular continuous production as an enabling technology
- Application to two specific F³ Factory case studies
- Summary
Introduction
The community of process engineers and chemists generally employs two major categories to describe business in the chemical sector. These two categories are "bulk chemicals / commodities" and "fine chemicals / pharmaceuticals". The two categories define two distinct business-production environments and are generally described by comparing various qualitative criteria.

The division into two distinct categories is very often useful and relevant. Nevertheless, business-production scenarios cannot always be described solely in terms of one of these two categories. Indeed, many realistic business-production scenarios are more complex and require a wider variety of categories for accurate description.

The additional variety and diversity of categories required to describe more complex scenarios can be developed by extending and generalising the qualitative criteria employed for the two traditional categories.

Following a brief presentation of the two traditional categories, a more generic multi-criteria based approach will be introduced and applied to describe several example scenarios.
To define the distribution between the two traditional categories, several qualitative criteria are used: production scale, product price, added-value, production mode and type of plant, investments and flexibility. Using these criteria, the bulk chemicals/commodities sector is defined as high tonnage, low price and low added value with production in dedicated continuous units which are often inflexible. This type of production requires high investment and optimal operation through detailed engineering design for the desired product.

In contrast, the fine chemicals / pharmaceuticals sector is associated with more complex and sophisticated products, produced in smaller quantities with higher added value. The products are often produced in more flexible, less optimised batch vessel units, capable of producing several different products as needed.

The criteria described above are of fundamental importance, but to establish relevant business-production scenarios for industrial strategy, it is often necessary to take into account additional factors related to the economic environment, such as market demand, competition and the specificities linked to raw materials supply.
Presentation of typical criteria of interest for the description of business-production scenarios in the chemical process industries
Presentation of typical criteria of interest for the description of business-production scenarios in the chemical process industries

<table>
<thead>
<tr>
<th>Production and product criteria</th>
<th>Business environment criteria</th>
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<tbody>
<tr>
<td>• Product price</td>
<td>• Market demand</td>
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<tr>
<td>• Added value</td>
<td>• Market volatility</td>
</tr>
<tr>
<td>• Capital investment / kg of product</td>
<td>• Customer centralization</td>
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<tr>
<td>• Operating cost / kg of product</td>
<td>• Market needs in innovation</td>
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<tr>
<td>• Production scale</td>
<td>• Competition</td>
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<tr>
<td>• Production flexibility</td>
<td>• Raw material proximity</td>
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<tr>
<td>• Continuous processing (vs batch)</td>
<td>• Raw material cost</td>
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<tr>
<td>• Centralized production (vs decentralized production)</td>
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<td>• Dedicated production (vs multi-product production)</td>
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To facilitate presentation, two characteristic domains are employed in this module to classify criteria for the description of business-production scenarios. The list of criteria is not exhaustive and certain situations may require additional criteria as well.

The first domain concerns criteria associated primarily with production and product characteristics. The second domain primarily with the business environment.

The criteria chosen here for the production and product domain are:

Product price  
Added value  
Capital investment / kg of product  
Operating cost / kg of product  
Production scale  
Production flexibility  
Continuous processing (vs batch)  
Centralized production (vs decentralized production)  
Dedicated production (vs multi-product production)

The criteria chosen here for the business environment domain are:
Market demand
Market volatility
Customer centralization
Market needs in innovation
Competition
Raw material proximity
Raw material cost
Definition of business-production scenarios using a multi-criteria-based approach
To describe a business-production scenario, values are assigned to a complete set or to a subset of the various criteria in the two domains.

For simplicity, only two qualitative values are employed for illustration: low and high. For higher precision when comparing scenarios, it is possible to introduce intermediate or quantitative values as well. A scenario is defined by the criteria used and the associated values.

Selection of criteria and assignment of values are performed first for the production and product domain ...
... and then in the same fashion for the business environment domain. Three examples of typical scenarios are provided in the following slides to illustrate the approach.

<table>
<thead>
<tr>
<th>Criteria</th>
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<tr>
<td>Market demand</td>
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The first example scenario is described on the basis of six criteria. The production and product domain is characterised by continuous small-scale production, and the business environment domain is characterized by strong but highly volatile market demand, high demand for innovation (new products and services) and strong competition. A possible descriptive title for scenario 1 might be:

**Low-to-medium scale, continuous production with strong competition and strong but highly volatile market demand**

The scenario has characteristics of both the traditional « bulk chemicals / commodities » and « fine chemicals / pharmaceuticals » categories.
The second example scenario is described on the basis of seven criteria. The production and product domain is characterised by high price and high added-value, as well as high investment and operating costs. The business environment domain is characterized by strong demand for new innovative products, but with low competition due to the absence (at least for the moment) of major competitors due to the novelty of the products developed. A possible descriptive title for scenario 2 might be:

**New high-price, high-value-added products responding to innovative market needs in the absence of immediate competition**

Once again, the scenario cannot be situated clearly in one of the traditional « bulk chemicals / commodities » or « fine chemicals / pharmaceuticals » categories.
The third example scenario is described on the basis of seven criteria. The production and product domain is characterised by large-scale, continuous, dedicated and centralized production. The business environment domain is characterised by strong, decentralised demand, and the raw material supply is also decentralised. A possible descriptive title for scenario 3 might be:

**Large scale, continuous, dedicated and centralized production, employing a decentralised raw material supply, for a strong but highly decentralised market**

As for scenarios 1 and 2, scenario 3 cannot be situated completely in one or the other of the traditional « bulk chemicals / commodities » or « fine chemicals / pharmaceuticals » categories.

### Example of business-production scenarios

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**Scenario 3**

Large scale, continuous, dedicated and centralised production, employing a decentralised raw material supply, for a strong but highly decentralised market
Identification of business drivers for implementation of modular continuous production as an enabling technology
What are business drivers? Business drivers are brief statements that define clearly and specifically the desired business outcomes of an organisation along with the necessary actions required to reach those outcomes.

Business drivers are focused, targeted orientations in industrial strategy, identified by the organisation as desirable to provide impetus and drive future business development. Drivers are selected for their ability to offer strong leveraging effects to improve profitability, competitiveness or market share. Although the outcomes targeted by the business drivers can be achieved in many different ways, actions such as business alliances, marketing development or internal reorganisation are often employed. In the chemical process industries, technological innovation is an essential component.

The focus here will therefore be on technological innovation, and in this connection, modular continuous production, as developed and demonstrated in the F3 Factory project, as an enabling technology.
What are enabling technologies? Enabling technologies are defined as equipment and/or methodologies that, alone or in combination with associated technologies, provide the means to generate significantly improved performance and capabilities.

The modular continuous production developed in the F3 Factory project is an enabling technology and can be implemented as an action to achieve desired outcomes for certain business drivers.

Which specific business drivers are most appropriate for implementation of modular continuous production as an enabling technology? The most appropriate business drivers are those associated with business outcomes likely to be facilitated or enhanced by the technological innovations resulting from the use of modular continuous production in a given business-production scenario.

In the following slide, four specific business drivers are suggested for which implementation of modular continuous production may be of interest. Not all drivers are appropriate for all business-production scenarios, however, and it is important that the choice of business driver be scenario based. In the following slides, each of the four drivers is positioned according to its relevance on the basis of business arguments for the three example business-production scenarios presented earlier.
Potential business drivers can be as numerous as business-production scenarios. For simplicity, four business drivers are proposed here that are likely to be of relevance for one or another of the three example business-production scenarios. The four suggested drivers are:

A. rapid product changeover,
B. flexible production throughput,
C. fast time-to-market and
D. decentralized production

Each of the drivers can be associated with business outcomes for which the modular continuous production approach of F3 Factory is potential enabling technology.
The concept of modular continuous production, as developed and demonstrated in the F³ Factory project, is presented in the learning module entitled “Modular and flexible continuous chemical production concept”. Please refer to that learning module for more details. Modular continuous production offers new engineering tools for the implementation of industrial strategies and achievement of the business outcomes associated with those strategies. Without entering into too much detail, the table on the present slide summarises some of the potential business outcomes enabled by the F3 approach for each of the four suggested business drivers.

For business driver A (rapid product changeover), the F3 modular continuous production approach offers opportunities for standardisation of equipment and interconnection, and the associated F3 methodologies facilitate ease of installation and modularisation through the use of interchangeable Process Equipment Containers (PECs). Replacement of one PEC by another through quick removal and installation allows for rapid adaptation of operating conditions to adjust production for the desired product. As an alternative to replacement of a complete PEC container, product changeover can also be achieved by replacement of a particular Process Equipment Assembly (PEA) within a PEC as well.

For business driver B (flexible production throughput), the F³ Factory approach offers the opportunity to increase or decrease production throughput by numbering-up or numbering-down the PEC containers connected to the F3 backbone facility. Once
developed, new PECs can be developed quickly and simply duplicated. Installation for replacement or retrofit is facilitated by the high degree of standardization of interconnection and commissioning. The possibility of an incremental increase or decrease in production throughput enables production outputs to be adapted to changing market demand. For an incremental increase in production capacity, the simple duplication of modular PEC units allows for an incremental approach to capital investment (and a corresponding reduction in the associated financial risk) as well.

For business driver C (fast time-to-market), technologies resulting from the process intensification employed in the F$^3$ Factory approach can reduce process development time and in some cases provide direct transfer from laboratory devices to production. The F$^3$ modular production technologies facilitate the transition from batch to continuous operation, thereby offering significant potential for improvements in process control and implementation of quality control by design, including process analytical technologies.

For business driver D (decentralisation), standard modular PEC units can be replicated and moved from one site to another (or from one backbone facility to another), thereby providing clear potential for the development of delocalised production and reduction in transportation costs both for raw material supply and products. For much larger PEC units that cannot be transported themselves, the standardised modular design offers the opportunity for the construction of sister plants on different locations, thereby reducing time and cost for engineering design of each new plant.

All business drivers are not appropriate for all business-production scenarios. To determine which business drivers to adopt for a given business-production scenario, business arguments are required to justify potential opportunities for profitability, competitiveness, market share or other factors.

The three slides that follow illustrate some of the possible business arguments associated with the appropriate choice among the four business drivers for each of the three example business-production scenarios.
For scenario 1 (low-to-medium scale, continuous production with strong competition and strong but highly volatile market demand), the two drivers A (rapid product changeover) and B (flexible production throughput) appear to be the most appropriate. This choice is supported by the business arguments of better response to changing market demand / needs by offering a wider range of products, reduction in operating costs, increased competitiveness and reduction in financial risk by diversifying the product offering. (The list of arguments is naturally not exhaustive and other arguments could be added.)
For scenario 2 (new high-price, high-value-added products responding to innovative market needs in the absence of immediate competition), the two drivers B (flexible production throughput) and C (fast time-to-market) appear to be the most appropriate. This choice is supported by the business arguments of more rapid introduction of new products onto the market, response to changing market demand / needs (in particular by adapting production volumes to market demand, in order to limit the probability of direct competitors entering the market), increased reliability for scale-up (through more efficient process development) and faster return on investment.
For scenario 3 (large scale, continuous, dedicated and centralised production, employing a decentralised raw material supply, for a strong but highly decentralised market), driver D (decentralised production) appears to be the most appropriate. This choice is supported by the business arguments of reduction in transportation costs (due to proximity to raw material supply and customers), decreased engineering and construction costs (through design of sister plants) and low risks of difficulties with raw materials supply.
Application to two specific F3 Factory case studies
The first case study concerns flexible continuous manufacturing for the synthesis of pharmaceutical intermediates. The pharmaceutical intermediates are generally new products prepared initially in small quantities for clinical trials. The marketing of these products, due to the uncertainty of the clinical trials and regulatory obstacles, is not guaranteed. The new products are unique, and competition on the market for the same identical product does not exist.

The business-production scenario can be described as continuous small-scale production of high-price products responding to low market demand (at least initially). The market needs in terms of innovation (new products and services) is high. Although direct competition for the same product is absent, the market demand is uncertain and therapeutically similar (but molecularly different) products can be introduced by competitors, creating high demand volatility in many cases. The scenario contains many similar features to example scenarios 1 and 2 presented earlier.
Application to two specific F3 Factory case studies

**Case study 1:**
Flexible continuous manufacturing of pharmaceutical intermediates

**Business drivers / business arguments:**

- **A : Rapid product changeover /**
  - In the event of failure in clinical trials:
    - rapid adjustment of production conditions
    - new product available in clinical quantities
  - In the event of success in clinical trials:
    - rapid scale-up for increased production
    - opportunities for increased market share

- **B : Flexible production throughput /**
  - reduction in time from research to production
  - adjustment to volatile market demand
  - preservation of market share

The business drivers for this scenario are the same as those presented for the example scenarios 1 and 2:

**Driver A : Rapid product changeover**

If clinical trials for a given new product are not successful, the product is abandoned. It then becomes necessary either to adapt the product for better results or to develop a new product to meet expectations. Rapid adjustment of production conditions to produce sufficient quantities of the new product for new clinical trials requires rapid changeover of processing conditions.

**Driver B : Flexible production throughput**

If clinical trials are successful and authorisation for introduction onto the market is obtained, market demand can increase very rapidly in a very short period of time. Production must be scaled up and adapted quickly. If the production capabilities allow for rapidly increased production, increases in market share by replacement of older, less effective pharmaceutical intermediates by the new product become possible. Life cycles for these products are often short, however, and market volatility can lead also to very rapid and sharp decreases in demand. Here again, the ability to adapt production throughput to the new situation constitutes a strong competitive advantage.
Driver C: Fast time-to-market

Shortened process development times are essential for introduction of new products in a volatile, innovative market. Among the numerous advantages of faster time-to-market is the capacity to prevent the emergence of competition from similar (although perhaps molecularly different) products for corresponding therapeutic targets.
The second case study concerns large / medium scale production of acrylic acid from bio-based process. Given the required size of the production facilities, the production operation can be qualified as centralised, although both the required biomass feedstock (glycerol produced as a side-product in the production of biodiesel) and the consumer markets are distributed geographically.

The business-production scenario can be described as large scale, continuous, dedicated and centralised production, employing a decentralised raw material supply, for a strong but highly decentralised market. Acrylic acid is an important intermediate for many consumer products and demand is strong. Traditionally, production is carried out in dedicated high capacity plants, requiring large investments and costly engineering development for optimal operation. Due to the geographical distribution both of raw material supply and markets, transportation costs are high.

Case study 2 is very similar to example scenario 3 presented earlier.
Application to two specific F3 Factory case studies

Case study 2:
Large / medium scale production of bio-based acrylic acid

Business drivers / business arguments:

- **D : Decentralised production /**
  - development of standardised sister plants offers significant reduction in cost and time for engineering design, without loss of production capacity to satisfy market demand
  - construction of plants in close proximity to raw material supply and / or customers reduces transportation costs and distributes financial and market risk

The business driver for this scenario is the same as that presented for example scenario 3:

Driver D : Decentralised production

As previously suggested for scenario 3, the choice of decentralised production appears to be an attractive choice of business driver for the implementation of modular continuous production as an enabling technology for case study 2. Development of medium-scale sister plants at several locations rather than one single large-scale plant reduces financial investment risk by offering modulation in production capacity and diversification in raw material supply. By applying standardised modular design, time and cost for engineering design for each additional plant are reduced, without loss of overall potential production capacity. Geographical proximity to raw material supply and / or consumer markets leads to reductions in transportation cost as well.
Summary
Summary

An explanation is provided of the limitations of the traditional division of the chemical sector into two major categories (bulk chemicals and fine chemicals). Although helpful, the division into two categories is insufficient for description of many realistic business-production scenarios.

A multi-criteria-based approach is proposed, including both production/product criteria and business-environment criteria, to enrich the description of business-production scenarios and improve clarity in the expression of industrial strategies.

The multi-criteria approach is used to describe three example business-production scenarios.

Four possible business drivers are suggested for implementation of modular continuous production as an enabling technology in industrial strategy.

The relevance of the four business drivers is examined for each of the three example business-production scenarios. The relevant drivers in each case are justified on the basis of business arguments for desired outcomes in the context of each business-production scenario.

Two industrial case studies from the F3 Factory project are used to illustrate the generic approach to identification of business drivers for implementation of modular continuous production as an enabling technology.
This training module is part of a suite of training material developed for the F³ Factory project. The training modules in this series include:

- Overview of the F³ Factory project
- Modular and flexible continuous chemical production concept
- Business drivers for implementation of modular production technologies
- Eco-efficiency evaluation of flexible, modular continuous production
- Conceptual process design methodologies.

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