1
Chemical Product Design – a New Approach in Product and Process Development

Summary

Chemical product design is a novel and comprehensive approach in product development. Chemical-based products are tailored to the application requirements by involving the customers via marketing. The development process is managed by a core team (product, process development and marketing), controlled by a steering committee. This interdisciplinary development represents a win-win situation. In case of major innovations, the principles of product design lead to a significantly faster market entry and an increase in market success.

1.1
Definitions

This elaboration about product design relates to raw materials, chemicals, chemical-based or chemically treated products, preparations, and their processing technologies. People of the following industries are mainly affected: chemistry and consumer goods, pharmaceutical, biotech, cosmetic, food and plastics, agriculture, textiles, and ceramics. Because the fundamentals of product design are similar in all areas, a transfer of many principles is possible, or even innovations arising from diverse viewpoints. Learning from neighboring areas (how others handle product design) requires a correspondingly broader teaching range for students to get a wider view of topics based on similar theoretical foundations.

> Product design includes learning from adjacent areas, where already a chemical or technological problem solution exists.

The core issue in ''product design'' is the development, in an optimal way, of the product desired by the customer. The clear definition of Cussler and Moggridge [1] is:

> Product design is the procedure by which customer needs are translated into commercial products.

Another definition includes the elements of product design: ''Product design describes the development of customized products, which satisfy all requirements

Industrial Product Design of Solids and Liquids: A Practical Guide, First Edition. Wilfried Rähse.

of customer regarding to performance, handling, and design'' [2]. Solid and multiphase products are predominantly of interest in product design, as also liquid mixtures and emulsions. The focus of all activities is the new or improved product and the further utilization or processing by the customers. The question for development of the product is this, ''What do the customers do with the product?''

On the one hand, there are industrial customers. Employees of companies in the supply chain department buy raw materials or other substances and formulations for further processing in the production or in pilot processes. These and the people from the application laboratories are referred to as *industrial customers* in this chapter. On the other hand, every individual is also involved in buying something or other, and is therefore also a customer. *Consumers* are people who buy such daily necessities for themselves and their families.

A design of molecules (molecular modeling) toward a particular substance [3, 4] is not what is meant here and is not covered by the term *product design*, also because computer-aided molecular designs are quite removed from the usual customer products.

New products generally require new or changed processes. This needs a close cooperation between product and process development. Some people, mostly chemists with postgraduate degrees in chemical engineering, are involved both functions.

> Product design brings together product and process development, because they belong together.

In the development of chemical-based products, the customer's needs are in the main focus [5]. These include the critical product performance such as the decision to buy, as well as handling and appearance of the product (Figure 1.1). Customers decide not only on these bases but they are also interested in value for money. Therefore, customers are willing to pay more if their (special) requirements are met.

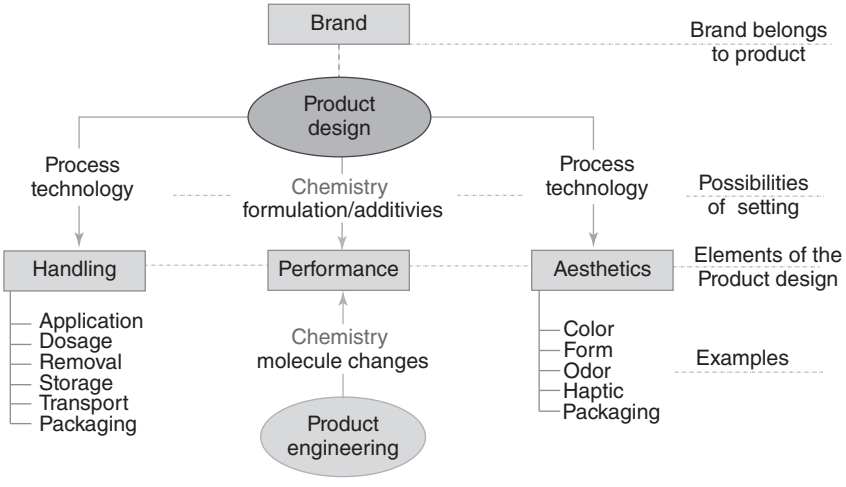

Figure 1.1 General structure of product design.

Chemistry realizes product performance either through changes in the molecule, commonly referred as *product engineering*, or by formulation of various substances. Appropriate technologies (especially design technologies) enable the adjustment of handling and aesthetics. Accordingly, the success of product development is ensured by the *chemistry* and *chemical engineering*. However, *marketing* should be involved from the start, because the responsible person in this area knows the market and is linked with the customers. Marketing must answer the question whether the new product makes sense economically. A strong product or manufacturer brand allows for successful marketing. A part of the brand and product design is in the packaging and packaging design.

- In large-scale development projects, product design requires the cooperation of product and process developers with the marketing people, including the customer.
- The members of the core team should gather the knowledge required for the development and for launch of the product in question, in order to be able to discuss properly any possible problems that may arise (this can be done by learning from others and from literature).

In case of major innovations, the principles of product design lead to a significantly faster market entry and an increase in market success. Chemical-based products are tailored to the application requirements of customers.

The elements of product design, namely, ''performance, convenience (of handling), and aesthetics,'' and for water-containing products, the additional requirement of microbial stability, refer primarily to parameters that the customers perceives. They buy products, when good product performances are guaranteed for long periods. Customers experience the product performance in terms of quality. There are two other elements that contribute to quality. Performance is controlled by chemicals, either directly, by chemical reactions, or by varying the formulation of some of the chemicals. The handling and aesthetics aspects are influenced by the technologies in the preparation processes. In disperse products (particles, suspensions, and emulsions), chemical and dispersion properties (Figure 1.2) determine product design. Concrete possibilities for setting quality depend on product type, hence this is discussed in the appropriate place.

A few successful companies work with the principles of product design for some time when they take on major projects. Although many managers are aware of the elements of advantageous product design, they do not follow them. Switching to consistent product development strategies requires a series of far-reaching measures in business organization, in thinking, and in the organization of work.

1.2 Customer Involvement

In the development of new or modified products, whether the product is based on the developer's ideas or on those initiated by customers, the needs of customers

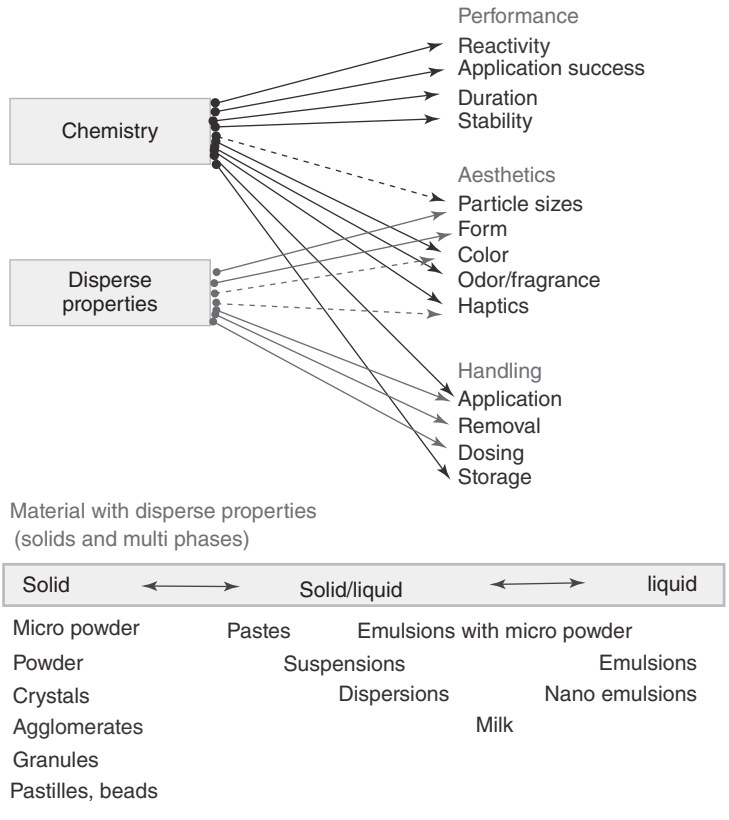

Figure 1.2 Adjustment of product design for disperse products.

are in of utmost importance. Before starting work in the laboratory, the following questions should be answered through a discussion with the customers:

- Do the customers really need this product?
- In what shape do they want the product?
- Do the customers gain their objective in the form of (additional) benefits?
- Do the customers like the product?
- Will the customers accept the value for money?
- How have the customers' experiences been with manufacturers and brands?
- Will customers buy the product?

Success in market presupposes positive response to these questions. Customers will buy a product in order to realize an important improvement for themselves or for their own product. The more accurately that a customers' needs are met, and at acceptable price levels, the better the products sell. For customers, production processes are normally of no interest.

Cooperation with industrial customers in the development stages, usually with the involvement of one to four employees from the applications technology, and

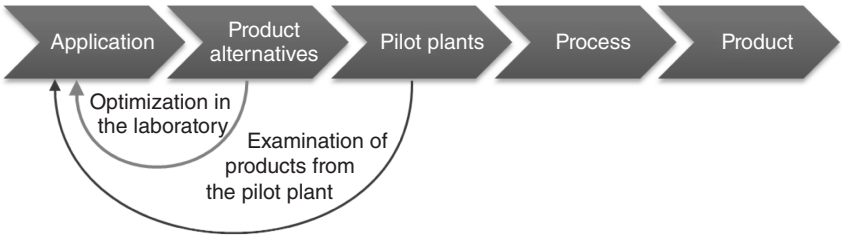

Figure 1.3 Product development in-house or in cooperation with a manufacturer of raw materials, based on the needs of customers.

with several consumers, is important for the success of a novel product. This includes product testing by customers. Formerly, selected *industrial customers* checked out the new products developed by the raw material suppliers for usability, often without a concrete testing proposal. Today, the trend is just the opposite. In fact – as in biotechnology – developments start from the applications point of view (see Figure 1.3). Industrial customers, mostly product developers, discuss their problems in application with different raw material suppliers, in order to obtain information or solutions. These in turn generate attention to new products at fairs, at trade shows in the customer's company, and in conferences. Furthermore, substances are presented in publications and brochures or to business contacts, more frequently delivered to customers as product samples for targeted experiments. In addition to product samples, the customers receive a technical description, a certificate of analysis, and safety data sheets.

Industrial customers want a comprehensive solution to problems, also known as a *system solution*. Therefore, modern developments deal with the applications of customers. If no suitable solution is available that meets completely the demands of the users, then development department starts on a new project. This project is either internal or in cooperation with a raw material supplier. Project partners will be chosen on the basis of the range of their existing products and on their expertise. With the inclusion of raw material manufacturers, executed development projects bring profit to both parties (a win-win-situation). Application chemists of the raw material supplier, design qualified alternatives in consultation with their customers. Industrial customers check the developed products in relation to their needs and then optimize formulations with the new substances.

Because industrial customers order large volumes of products for a considerable sums of money, they examine new product samples intensively. Tests are performed in several applications in comparison to competition and to previously used products. In case of a positive evaluation of the product, they complete longer term contracts with fixed prices for minimum purchase quantities or with a price scale for the expected quantities. In large companies, especially well-trained buyers negotiate purchase agreements for new products. Products are extensively investigated in advance. For understanding of the extent, we consider an example from the detergent industry. The raw material ''sodium percarbonate,'' a hydrogen peroxide-containing bleaching agent in detergents, must pass many tests (see

Test area	Product properties
Analytical chemistry	• Active(oxygen) content • Coating layer – Quality – Composition • Heavy metal content
Physical chemistry	• Particle size distribution • Dissolution and release rate • Particle stability (mechanical and chemical) • Safety checks
Application technology	• Storage(3 month,30° C/80% relative humidity) – Pure substance – Matrix incorporated(detergent) • Effects on soils in different detergents • Interactions with enzymes
Process engineering	• Pneumatic conveying • Storage in silos, silo design • Dosing • Separation tendency • Dust collection and processing, safety

Figure 1.4 Testing of raw materials through industrial customers using the example of sodium percarbonate: (a) crystallization – small crystals and (b) spray agglomerization – spherical granules of any size.

Figure 1.4). Extensive testing in various departments indicate the magnitude of the time needed and costs involved. Investigations include a safety assessment of the production facilities.

As team members, industrial customers bring in their product requirements and, if necessary, they demand modifications in each stage of development. In joint developments of a solution, both sides take responsibility for the outcome. Both parties may use the solution. How and when marketing starts is regulated by previously signed agreements. In this context, industrial customers differ significantly from consumers, who have only a very limited impact on product development (see Figure 1.5).

Because *consumers* do not transmit their thoughts, ideas, and desires directly to the company, brand manufacturers consult selected people. This allows to tune products better on the tastes of consumers and reduces risks of a flop. Under instruction from the manufacturing company, agencies invite 12–15 clients to discuss new or modified products. This panel is called the *focus group*. In the group, customers express their wishes and suggestions to improve product and packaging, as also brand name and color design of the logo and lettering. The final questions are, ''Would you buy the product?''; ''Would you buy at the price XY?'' If less than 7 of 12 agree, this product idea is not accepted. Under certain circumstances, the developer adapts the product according to the results of a discussion, and places it

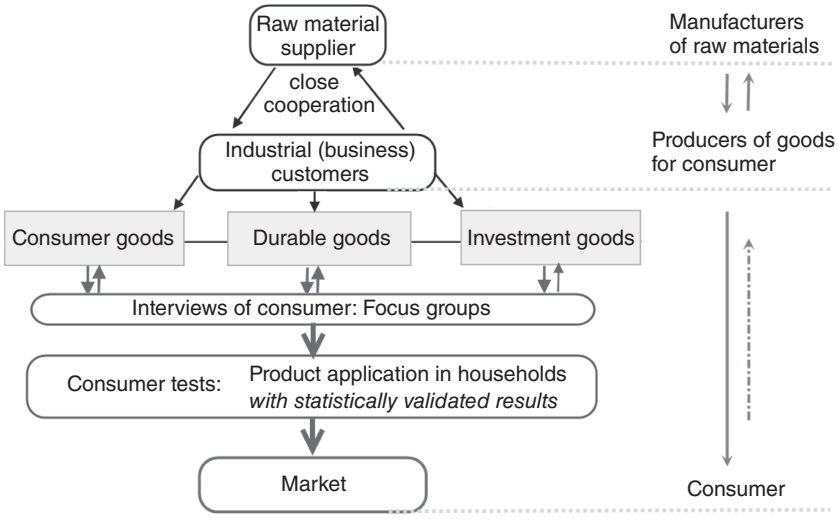

Figure 1.5 Path of a new product from the idea into market.

again in another group discussion. When there are eight or more positive votes, the next step follows.

The next step is to review the product in a concept test (CT). This test runs monadic, that means without reference product, with 100–250 customers (m/f) on the basis of a written and oral product description. The product is only viewed, but not tried. Participants evaluate the featured product ideas on the basis of the following criteria: buying intention, uniqueness, personal relevance, and credibility in school grades 1–5. Customers can be divided into groups, for example, identified as users of a predecessor or competing product, and classified into different age and income groups. A separate evaluation of the different groups is possible. Customers specify, up to what price the offer is interesting to them (''price meter'').

In some cases, it is important to clarify haptic feeling in a ''sensory assessment'' and/or the product odor (smell or perfume) in an ''odor evaluation board'' (OEB). Twenty to thirty participants in a discussion board judge the products, often in the presence of other products or fragrances as benchmark. In the case of worldwide sales, these tests should be repeated in some distant regions of the world.

With positive evaluation of concept, odor, and haptic test, an extended CT, called the *concept-to-use test (CTU)*, starts. This test includes product applications by the consumers, usually taking place at the customer's home without reference products, as single tests. After product usage, participants fill out a questionnaire and report their experiences and impressions. If use of the product convinces skeptical consumers of its benefits, the CTU is successful. The results bring more clarity regarding market acceptance.

Another consumer test involving about 200 customers (m/f) represents the home-use test (HUT). Participants receive two products for testing, sequentially or simultaneously (successive or simultaneous pair comparison). The first product is

the new development; the second may be a competitor's product or predecessor. After application, the participants fill out questionnaires. On the basis of these results, it is possible to determine and quantify the strengths and weaknesses of the test product.

For a full test, on the one hand, customers evaluate product quality, packaging, and design, and on the other hand, there are the advertising claims of the brand and company. Filled up in a white packaging without any information, the product runs through a blind test. The term *partial test* covers the review and evaluation of specific aspects, for example, the need to characterize products with true, credible, and convincing advertising claims (selling proposition). Unfortunately, test results often depend on local customs, so that a test market is only of limited value. Therefore, performance of HUT's in different regions would be more promising. Ultimately, it is the customers who decide whether they will buy the product.

Customers for consumer goods are much less involved in development, compared to customers for industrial goods. Only a very small fraction of the clientele is questioned regarding the product. Furthermore, surveys are usually unknot representative of the population. However, everyone who participates contributes to design. The developers take all opinions seriously and consider all ideas suggested. Accordingly, they modify the product, packaging, or advertising claims. An assessment of market success results from the inclusion of essential customer information after a HUT or CTU. Hence, these methods will apply despite the substantially high costs.

1.3 Specifications

The developer translates all identified customer' needs into the language of science and elaborates a specific product list (Table 1.1). Required chemistry and adjusted measurements, derived from former application testing, form the basis of development work. After extensive laboratory tests, an appraisal takes place with individual product characteristics in order of their importance and volatility. The description of the product with fixing of measured values including their allowable fluctuation are the features of a specification. Using the specification, an identical product is producible anywhere in the world.

1.4 Tasks of Development Team

For steering and supervision of significantly large development projects, two or three employees form a core team. The team leader is usually a chemist, who controls the product development. In addition, a chemical engineer for process development as well as a staff from marketing must be integrated into project management, to cover all areas. This core team appoints suitable employees to participate in the group or to collaborate in subprojects.

Table 1.1 General framework for specification lists of disperse products.

Particle characterization (disperse parameter)	Aesthetics	Physicochemical characteristics
Particle size and distribution	Size/form	Water content
Flowability and silo storability	Color	Dissolution rate
Pneumatic conveying	Whiteness	Porosity
Abrasion resistance	Odor	Specific surface
Explosive dust	Taste	Melting point/glass temperature
Strength, hardness, and elasticity	Haptic	Flocculation point
Crystallinity	Freshness	Density
Analytical parameters		*Application technology*
Composition/purity		Bulk density
Grade of polymerization or substitution		Dosability
Active matter		Dust content
Toxicity		Sterility
		Composition/concentration
		Insoluble residue
		Incorporability
		Storage stability
		Wettability

Employees of marketing are mainly economists, but businessmen or chemists are also included. The focus of their duties differs depending on the product type and customer. These are either industrial partners or consumers. For consumer goods, there are four main tasks of marketing , which are partially distributed among several people:

- Management of brand (brand core, design, advertising claims, target groups, extensions, and internationalization).
- Sales control, especially at events and product launches.
- Hiring of agencies, which execute customer surveys, market analysis, market research, and HUTs and, furthermore design the advertising appearance. The marketing manager evaluates the results and implements the marketing strategies.
- Participation in major development projects.

The key components to success of a project are the contacts with customers and consideration of their desires and experiences. Marketing initiates product tests, weights results, and market analysis. Knowledge of the market with own products, as also from activities of competition, enables to determine the direction of development work.

Furthermore, marketing people bring in market and brand-specific elements from the beginning. Examples include elaboration of key statements, determination of target groups, price–cost relation, design of the packaging, and product shape or color (see Figure 1.6). In the advanced project stage, marketing plans and manages the market entry.

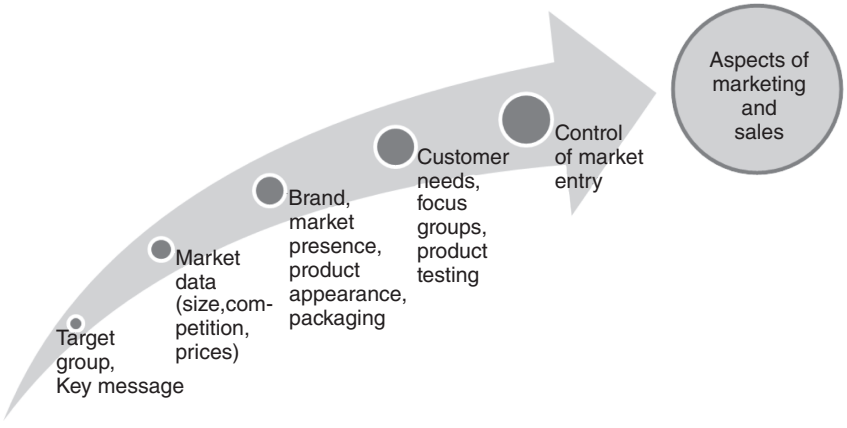

Figure 1.6 Contributions of marketing staff to project management in relevant projects.

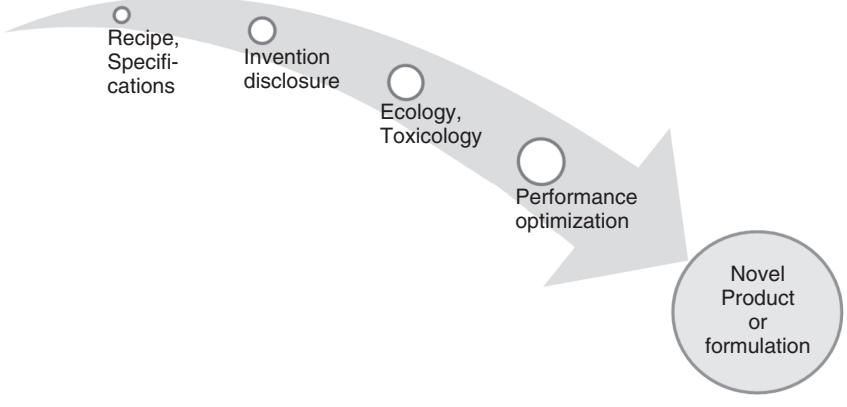

Figure 1.7 Contributions of the product development.

The responsibility for *product development* is in the hands of experienced chemists, pharmacists, or chemical engineers. In the time period from laboratory to pilot plant, several laboratory assistants and technicians are involved, directed by one or two chemists. According to information provided by the project management, they work out formulations, preparation methods for the laboratory, and specifications (including allowable fluctuation of individual components). The responsible chemist takes care of ecology and toxicology, passes formulations to the patent department, and arranges performance tests, in particular, storage tests (Figure 1.7). He reports results weekly to the project core team.

A technical chemist or a chemical engineer with his team (several technicians) executes the *development of process*. The focus is the development of a procedure that allows production of specified products in the most effective way. The so-called design technologies that combine basic operations with shapings are preferred. Following this, a coating procedure is possible for controlling some application

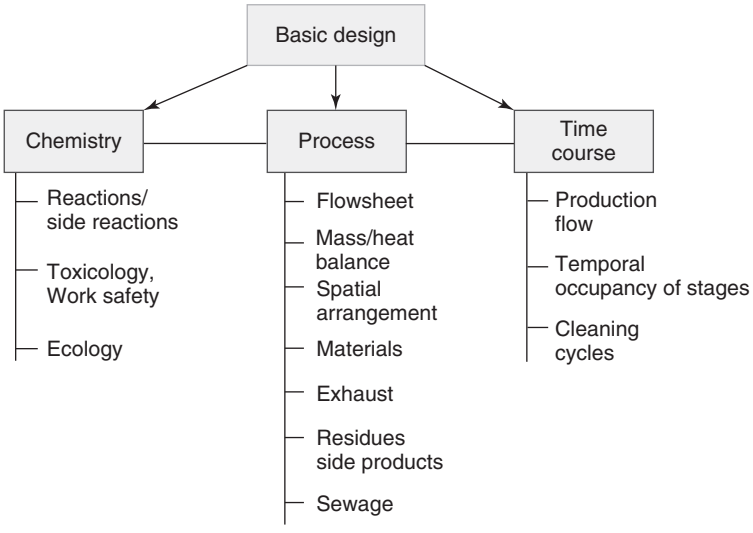

Figure 1.8 Elements of basic design.

parameters. The product design is limited not only to solid, mostly dispersed products, but operates also to pastes, suspensions, emulsions, and liquid mixtures (see Chapter 5).

The work of the process developer focuses on basic design (Figure 1.8). This includes discussions of the chemistry with toxicology and ecology, especially descriptions of procedures with balance sheets. The central part represents the process flow diagram, design of individual stages, and proposals for the arrangement of machinery. For batch processes, it is important to coordinate the time required for product and cleaning in each stage.

After determination of all process stages, production of samples (total of about 20–200 kg) starts in a pilot plant for testing by customers. Thereafter the scale-up from pilot plant to production scale follows (Figure 1.9). Production facilities, if not available, will be designed in detail and built. All phases of design and construction are coordinated by the process developer as a responsible member of the core team, monitored by a steering committee. Further, the process developer controls common subprojects with the packaging department, and with plant construction and production. If the process is new and interesting for the company, it is advisable to apply for a patent. After completion of the production plant, the process developer directs startup. Once the projected capacity is reached, the production people take over the management of the plant.

1.5 Steering of Projects

Depending on the size and importance of project, different levels of management and control ensue. Figure 1.10 shows the steering of two alternative project

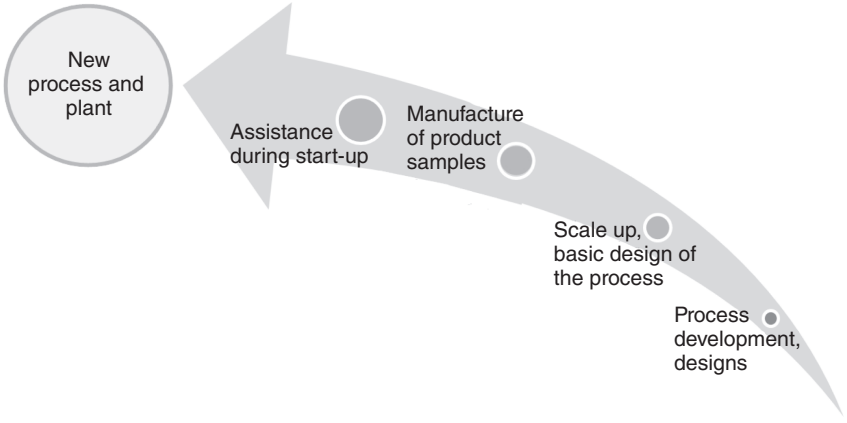

Figure 1.9 Contributions of process development.

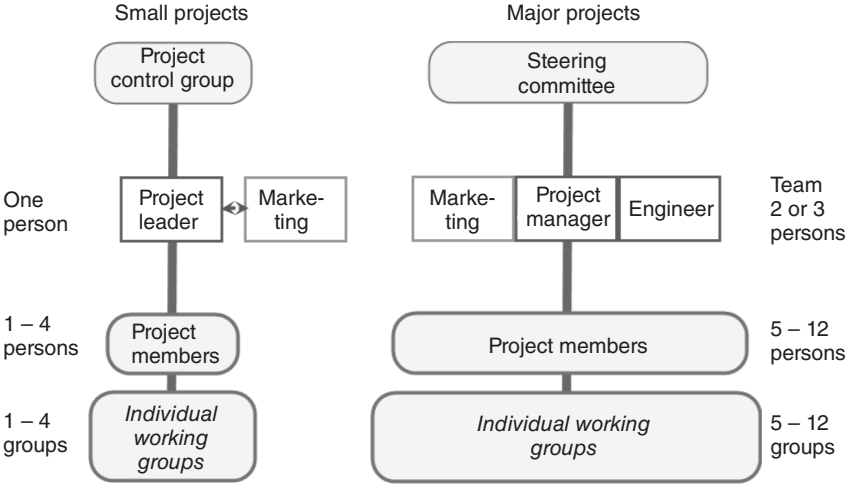

Figure 1.10 Steering of projects.

situations. Small projects are controlled from time to time by several superiors in meetings that take place routinely. For large projects, a high-level steering committee will convene two to four times in a year. The project manager presents the results as well as particulars of expenditure incurred.

Toward the end of a project, a presentation takes place in a large circle. The *management board* of big companies shows great interest in new, improved, and innovative products, furthermore for brands, markets and competitors, product benefits, as well as for required investment and production costs. Usually at the presentation of a new product, the production process is not discussed with the management board (also not with customers). This does not include very new

technologies or processes that allow significant cost advantages. Therefore, the development process focuses on aesthetic, easy-to-handle products, meeting the requirements of customers. Only professionals demonstrate interest in process alternatives or novel solutions. All processes that lead directly to the shaped final product, are preferred. Intermediate steps should work fine, but find no attention.

For the implementation of product design, there are a number of alternative variants described in the literature [1, 5–7]. The theoretical background with several examples for the product design of solids and liquids are shown in three volumes [8]. Besides chemical-based products, there are many other applications for ''product development according to consumer needs'' and the theoretical background [9, 10].

1.6 Learnings

- √ Product design stands for development of new products, including marketing and customers.
- √ Predominantly solid and multiphase products are of interest for product design.
- √ Product design covers the product performance, handling, and aesthetics.
- √ Product design realizes comprehensive solutions for the customer's problems.
- √ The development process is managed by a team (product, process development, and marketing), controlled by a steering committee.
- √ For industrial products, customers are members of the development team; for consumer products, an indirect participation of few selected customers takes place.
- √ In all cases, customers test the new products and verify the progress in comparison to former solutions.
- √ The HUT is the best known test panel involving 200–250 households.
- √ Product design shortens the time to market and reduces the risk of flops.

References

1. Cussler, E.L. and Moggridge, G.D. (2011) *Chemical Product Design*, 2nd edn, Cambridge University Press, Cambridge.
2. Rähse, W. (2007) *Produktdesign in der chemischen Industrie, Schnelle Umsetzung kundenspezifischer Lösungen (Product Design in the Chemical Industry, fast Implementation of Customized Solutions)*, Springer-Verlag, Berlin.
3. Ng, K.M., Gani, R., and Dam-Johansen, K. (eds) (2007) *Chemical Product Design: Toward a Perspective Through Case Studies*, Elsevier, Amsterdam.
4. Kontogeorgis, G.M. and Gani, R. (eds) (2004) *Computer Aided Property Estimation for Process and Product Design*, Elsevier, Amsterdam.
5. Wesselingh, A.J., Kiil, S., and Vigild, M.E. (2007) *Design & Development of Biological, Chemical, Food and Pharmaceutical Products*, John Wiley & Sons, Ltd, Chichester.

6. Ulrich, K.T. and Eppinger, S.D. (2012) *Product Design and Development*, 5th edn, Irwin McGraw-Hill, New York.
7. Seider, W.D., Seader, J.D., and Lewin, D.R. (2008) *Product and Process Design Principles: Synthesis, Analysis and Design*, 3rd edn, Wiley Global Education.
8. Bröckel, U., Meier, W., and Wagner, G. (eds) (2007) *Product Design and Engineering*, Vols. 1 and 2, Vol. 3 (2013), Wiley-VCH Verlag GmbH, Weinheim.
9. Tooley, M. (ed.) (2010) *Design Engineering Manual*, Elsevier, Amsterdam.
10. Pahl, G., Beitz, W., Feldhusen, J., and Grote, K.-H. (eds) (2007) *Engineering Design: A Systematic Approach*, 3rd edn, London, Springer.