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Supplement to the Treatise

WOLFGANG RUNGE: TECHNOLOGY ENTREPRENEURSHIP

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Reference to this treatise will be made in the following form:
[Runge:page number(s), chapters (A.1.1) or other chunks, such as tables or figures].

This case relates to the case of Bada AG, a compounder in the polymers/plastics industry.

Wolfgang Runge

polyMaterials AG

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Introduction

It is estimated that roughly 70 percent of all technical innovations and developments depend directly or indirectly on properties of the used materials [Stebani 2010]. Drivers of material science are essentially the enormous cost pressure according to requirements to increase the efficiency of the material and to satisfy new requirements by multi-functional materials in continuously shorter innovation cycles, which requires the development of material systems in significantly reduced times [Stebani 2011].

Tailored material solutions play more than ever a key role and the chemical industry is important for that, for instance, its polymers and plastics segment.

The primary target of the current case study, polyMaterial AG, was founded in August 1999 and registered as a stock company (AG) in March 2000 as a firm focusing on *polymer and plastics research* located in the Innova-Technologiepark in Kaufbeuren/Allgäu (Germany). Foundations was by three experienced chemists, notably Dr. Jürgen Stebani and Dr. Gerhard Maier. Already in 2001 the spectrum of services was expanded by the area of *developing polymer compounds* [Runge 2006:693]. Further developments led to an industrial research specialist and integrated service provider in the area of polymeric materials including also production.

As a service organization for the plastics and polymers segment of the chemical industry, but also other industries polyMaterials AG is a Contract Research and Contract Manufacturing Organization (CRO/CMO). Two corresponding CRO/CMO cases (ChemCon GmbH and ASCA GmbH – Angewandte Synthesechemie Adlershof) referring to the pharmaceutical segment of the chemical industry were reported recently [Runge 2015a; 2015b].

Polymers and plastics represent the third largest division of the global chemical industry [Stebani 2011]. Variability of plastics concerning properties and processability was achieved by blends in terms of different polymers and amounts of polymers.

A *polymer blend* or polymer mixture is a member of a class of materials in which at least two polymers are blended together to create a new material with different physical properties – analogous to metal alloys.

Polymer *blends* can be broadly divided into three categories (according to Wikipedia):

- *Immiscible polymer blends* (heterogeneous polymer blends): This is by far the most populous group. If the blend is made of two polymers, two glass transition temperatures will be observed.
- *Compatible polymer blends*: Immiscible polymer blends that exhibit macroscopically uniform physical properties. The macroscopically uniform properties are usually caused by sufficiently strong interactions between the component polymers.
- *Miscible polymer blends* (homogeneous polymer blends): Polymer blend that is a single-phase structure. In this case, one glass transition temperature will be observed.

The other option to get plastic materials with various properties or optimization of a property profile is compounding.

Compounding technology or polymer/plastic compounding is a process for adding additional materials into a molten basic plastic to produce a material with desired properties. These *additives* and *modifiers* in very small amounts may result in plastic with a particular color, texture, strength, etc. A manufacturer may incorporate several additives into the base material in the process of compounding. The end-product is a homogenous blend of the different raw materials.

Plastic compounding typically involves several basic steps (Figure 8). Additives in the form of pellets, flakes, or powders are conveyed to a container of a molten plastic base material. The mixture goes through a number of blending and dispersal steps to incorporate these additives into the base material and achieve a homogeneous final product. Once all processing steps are complete, the material is cooled and extruded into pellets, which are then packaged for distribution or sale.

Additives and *modifiers* appear not only concerning chemical characteristics and applications, but will show up also concerning size from "small to nano" or physical state as solid fillers, for instance, fibers to produce fiber-reinforced plastics or plastics containing carbon nanotubes (CNT).

The last kinds of material made by combining two or more materials are called *composites*. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other. Polymer composites are usually made of a plastic base (called a matrix), which is reinforced with fillers of high strength, rigidity, etc.

Technology and the Industry – Industry Challenges Shape Opportunities

If technology entrepreneurs want to exploit industry challenges as opportunities related business concepts require rather detailed insights into the situation of the corresponding industry, in this case into the chemical industry or here specifically the *polymers and plastics* segments.

Technology innovations in the twenty-first century require often new materials which are provided by the chemical industry. In the race for innovation and firms' growth the demands on material competence of the processing companies grew steadily. Relatedly, over the last twenty-five years research and development (R&D) and innovation processes in the chemical industry encountered fundamental changes [Runge 2006].

In particular, some megatrends were shaping the polymers and plastics industry which is the focus of his case study:

- Internationalization (global trade: exchanging goods, services, capital) became globalization (global presence of sales, production and research; the enterprise as a networked unity)
- Competition concerning location has intensified; new players from Asia and South America emerged
- Scientific and technical know-how is globally distributable; a "war for talent has started"
- The governance of shareholders ("Shareholder value is overtaking innovation")
- Opportunities for outsourcing of corporate activities or functions to reduce cost has increased
- Decreasing sales from new products in chemicals (products less than three years old)
- Interdisciplinarities [Runge:98,1207] between scientific and engineering fields and co-evolutions of industries emerge [Runge 2006:21-25,79,215,219,324-330,434,565]
- In particular the plastics/polymers segment of the chemical industry (with polystyrene (PS), polyvinyl lchloride (PVC), polyethylene/polypropylene (PE/PP), polyethylene terephthalate (PET), acrylonitrile-butadiene-styrene (ABS)) appeared as a mature industry segment.

In particular, co-evolution of industries with the chemical industry was strongly emerging. Examples in terms of "three-way cooperation" are presented by Runge [2006:282-283].

Perceived opportunities for innovation in or out of the chemical industry are listed in Figure 1.

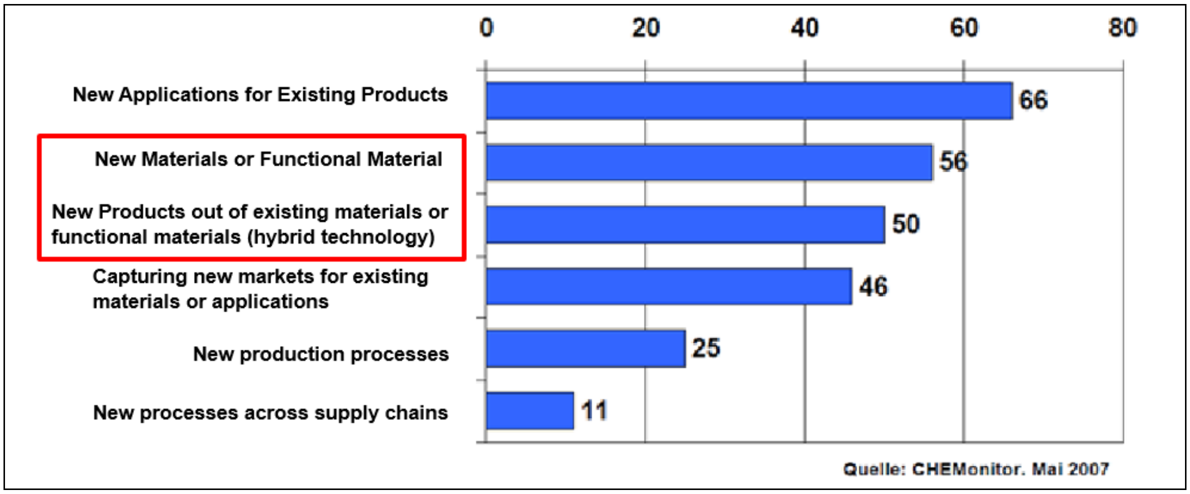


Figure 1: Viewing major areas of innovation in or out of the chemical industry [Stebani 2007c].

Basically, the potentially hazardous nature of chemicals and chemical compounds has caused the chemical industry to become highly regulated. *Regulations*, especially concerning health/safety and environmental matters, recycling and waste disposal exist to control almost every aspect of the chemicals' supply chain (particularly that of the plastics sector, Figure 4). As a result, the cost of compliance for the firms may be high.

Additionally the polymers/plastic industry segment parallels economic cycles and this means that during a recession usually a decrease of revenue of various amounts will show up. Following a boom-bust pattern with cycle peak and trough is called *cyclicality* [Runge 2006:140-141].

Since its advent in the 1970s, cyclicality is a basic characteristic of the chemical industry and "business cyclicality" of the chemical industry appears as a parameter for innovation or innovation configurations, respectively. Usually one has to differentiate industry cyclicality (chemical or other industries) and general (national/international) economic cycles. Specifically the "plastics additives" businesses for compounds are tied to the economic cycle of the "plastics industry".

Early on the firms' basic strategy relied on international presence and a broad range of products and services to level out cyclicality of demand among individual regions, customers, and product lines as far as possible.

Since the 1990s in R&D of major plastics producers two strategic trends emerged to dominate. On the one hand, the development process, which aimed to produce always cheaper larger volumes per plant to cover the ever growing demand for the established plastics and simultaneously to realize increased margins through economies of scale. This led to disappearance of numerous smaller raw materials producers, and the industry began to consolidate [Stebani et al. 2007].

The second trend concerned the raw material development. The main focus was no longer on totally new plastics, but the development targeted the combination of materials – new blends and new plastic formulations (recipes).

The new world-scale plants would be fully utilized. But the consolidation of raw material producers concerned subsequently also the capacities of development, compounding and testing of plastic formulations. In the course of tracking results on the level of the individual products small volumes of compounds became increasingly less lucrative and the provision of development and test resources for the continuous development of new user- or application-specific plastic formulations was questioned increasingly [Brandstetter 2004; Stebani et al. 2007]. Indeed, it was obvious that an *industry of compounders* would emerge.

After the last decade in the twentieth century the plastics industry was subjected to a dramatic change when it was hit by the 2001/2002 Dot-Com Recession (March 2001–Nov 2001 in the US). In contrast to the previous period the focus was no longer primarily on the development of new polymeric materials. Research of large companies related primarily to adapting existing plastics to mostly large-volume, existing or new applications or the development of technologies based on new materials.

After and in 2003 and the beginning of 2004 most companies of the chemical industry had weathered the storm through orientations towards the following "standard" means in various combinations [Runge 2006:121-122].

- General cost reductions under the heading of "keeping the organization lean" including plant shut downs and layoff of personnel and moving to lower cost geographies, such as the Middle East
- Specifically reducing R&D expenditures
- Putting pressure on R&D to become more productive and innovative, in particular, re-organizing the innovation processes
- Reducing capital expenditures
- Company re-organization and divestitures
- Orientation towards new markets, in particular, towards Asia or Eastern Europe.

In how far particular combinations generated paradoxes or counter-productive situations shall not be discussed here. In the context of this case it is important to focus on R&D and the implications for corporate innovation. Identified key drivers for the cycle trough were

- Cost,
- Time to market, fast cycle-times for products,
- Quality,
- Innovation.

But companies were still confronted with issues of high cost, longer product development cycles, and potential safety issues. As profitability in the polymer-making sector suffered, owners have sought cost savings by firing technical and sales staff as well as cutting back on the number of resin grades they produce [Editors 2005].

Polymer producers were putting emphasis on mass products with much less variety than was previously offered.

Stebani [2005] reported, for instance, a lucid example of decomplexifying a styrene-based business model which is a reduction of a large number of specialty plastics to few standard products: Originally 1,500 ABS-products should be limited to 10 standard products produced cost efficiently in three world-scale plants distributed globally.

Another question processors faced was: Where will new polymers and grades come from in the future? "In the future we won't see new polymers developed. Management of companies has lost patience. New polymers can take up to a 10-year cycle to develop. Companies are not as willing to take the risk today." [Editors 2005].

With the resources available, in the field of plastics all issues and questions could not be tackled and those which are worked on could no longer be run to the required speed. Therefore, competent and experienced service providers, such as polyMaterials AG, could be assumed to play an increasingly important role in the customer- or application-specific development or optimization of polymeric materials.

The situation could provide a boon to firms like polyMaterials AG, an independent research company that works on consignment for polymer producers in Europe and the US, said Jürgen Stebani, a managing director. "Polymer makers are cutting R&D budgets [to improve] profitability and they are unwilling to finance research of technical grades since they don't see short-term paybacks," Stebani said. "If this trend continues – and I believe it will – processors could be faced with fewer options and grades in the future." [Editors 2005]

With new developments in materials, using combinations of materials or hybrid materials, the plastic manufacturers and plastic processors tried to develop new applications and increasingly expanding the application range of plastics. But three increasingly important counteracting effects were working against this way of new developments, namely time, complexity and cost/price [Stebani et al. 2007].

The critical aspect for the chemical industry concerning speed and cost of product development and the product life-cycle time is determined by the end-users of different industries. For example, with regard to new materials needed by the information and communication technology (I&CT) industry and currently the microelectronics industry which as customers are driven by speed of development and cost, exerted heavy pressure on the plastics/chemical industry (functional polymers, specialty resins).

For the majority product life cycles of chemical products are 5-10 years with another large set of products having life time exceeding 10 years. Currently, product life-times for chemical products have been considerably reduced. It is estimated that for specialty chemicals “a product will be obsolete in three to five years”. However, this is still fundamentally different from the situation of the I&CT and computer industry where the life-times of the majority of products is in the range of 1 – 4 years and only ca. 25 percent of products exists for more than 4 years (Figure 2) [Runge 2006:655-656].

And for such customers an R&D development project with high speed may have serious consequences for fixing problems: Concerning efficiency of R&D projects there is a rule thumb relating costs of fixing problems to various project phases, the “rule of 10” [Runge 2006:656]. Accordingly [Runge 2006:655-656]:

> The cost of fixing a problem that should have been exposed and corrected in the planning phase increases

- 10 times if discovered in the testing phase,
- 100 times if discovered in the production stage, and
- 1,000 times if discovered by the customer.

The consequence is the requirement of early detection of failures/malfunctions when developing an offering: “Learning before doing”; do it right the first time!

Estimation of influences of various slippages on revenue is shown in Figure 3: For short product cycles, the time to enter the market is absolutely critical; with longer product cycles, the production costs are critical.

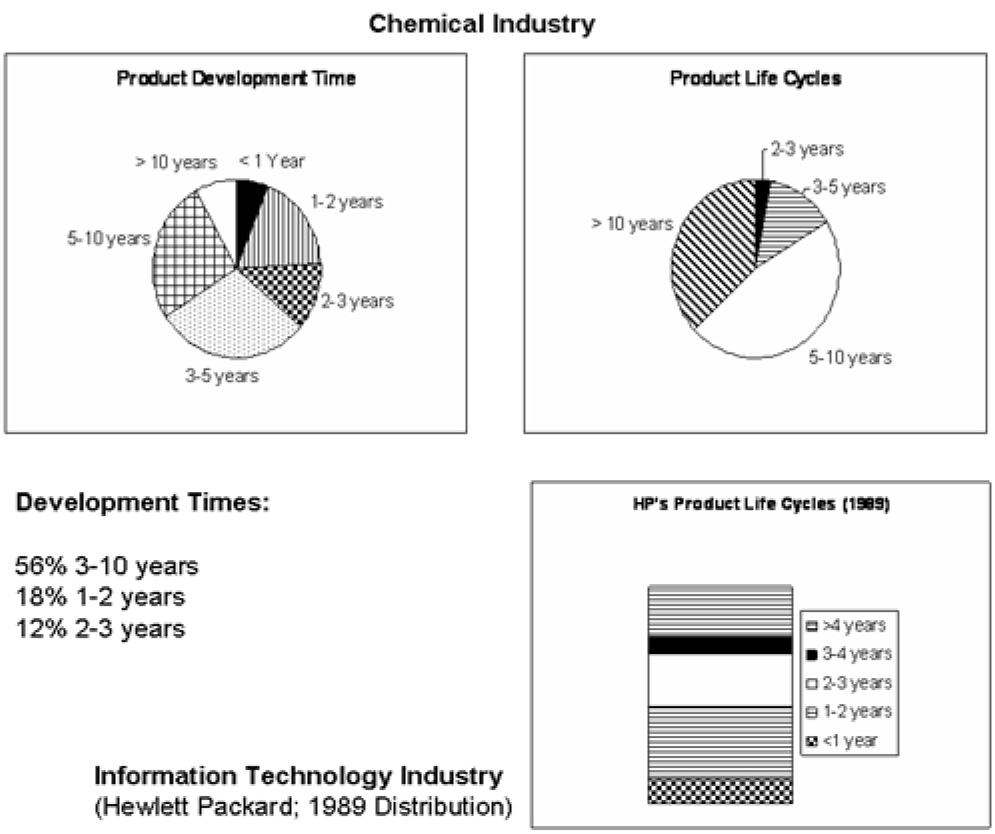


Figure 2: Product development times and product life cycles in the chemical industry and a comparison with life cycles for I&CT products [Runge 2006:655-656].

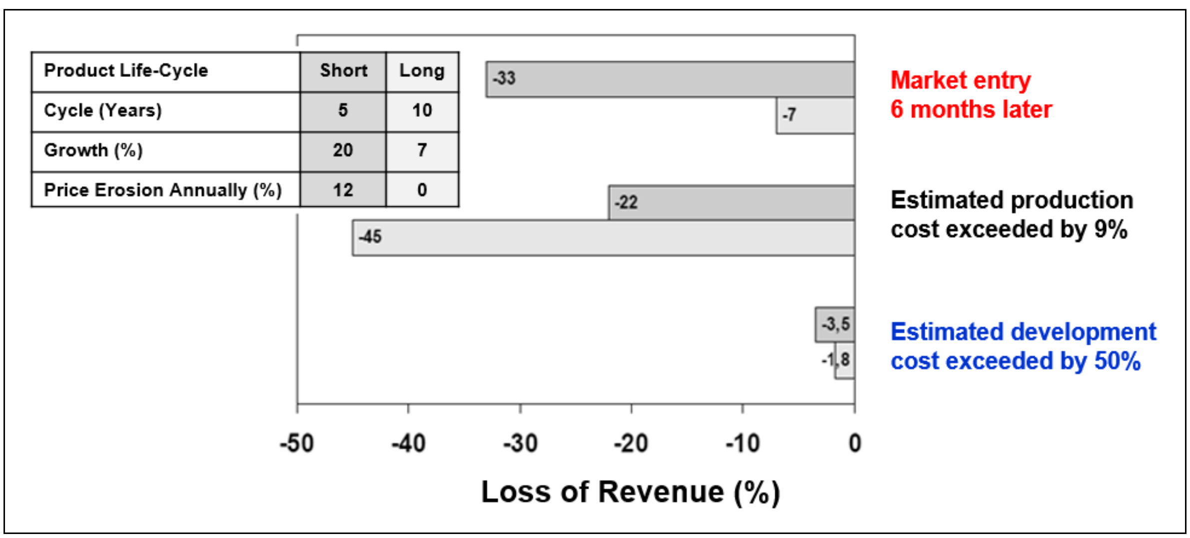


Figure 3: Estimation of influences of various slippages on revenue [Maier 2007a].

Processors were finding less resin variety that meets specific processing requirements as big plastics suppliers work to raise profitability by limiting production to fewer grades of material. Plastics suppliers have become leaner and in many cases their R&D departments have been downsized in recent years. Hence, many processors asked where future plastics will come from or if there will only be a choice of 'refined' existing grades [Colvin 2008].

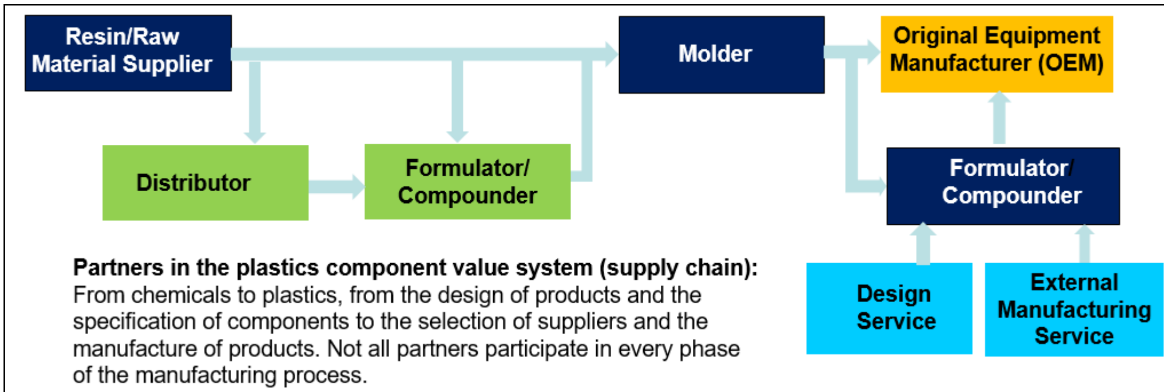
Stebani thought companies like his will be the ones in the future that are contracted to develop compounds and market-ready products that big suppliers shy away from developing themselves [Colvin 2008].

Companies that want to stay ahead of the competition or entrepreneurs who want to exploit opportunities in the polymers/plastics segment need insight into innovation, change and disruption across the related value system.

The value system (supply chain) [Runge:58-60] of the plastics industry segment can be divided broadly into the following constituents [PlasticsEurope]:

- Raw material suppliers (who supply the petrochemical and chemical feedstocks and additives)
- Plastics producers (who manufacture the different types of plastic resins)
- Plastics compounders (who prepare plastic formulations by mixing or/and blending polymers and additives into process ready pellets)
- Plastics machinery manufacturers (who manufacture the machinery used in the industry)
- Plastics converters (who form the plastic resins and compounds into finished products)
- Plastic product distributors/users: OEM manufacturers, retailers etc. who put plastic products onto the market
- Plastics end-of-life businesses: Waste management companies, recyclers and energy-from-waste operators.

Rebello and Bari [2014] provide a description which focuses on the key generic interconnections of the supply chain (Figure 4).



Resin Suppliers	Provide the raw materials for plastic components. When volumes are large or OEMs are influential, they work closely (often directly) with molders, contract manufacturers, and OEMs
Distributors	Ensuring that resins from multiple suppliers make their way to customers. Their role is shrinking. Many distributors work with smaller OEMs and molders.
Compounders	Ca. 75% to 80% of resins go through compounding. They tailor material properties to the specifications required by certain products, customizing/optimizing properties.
Molders	They procure raw materials from resin suppliers, compounders, or distributors and then create finished plastic products, which are designed to be used in OEM products.
OEMs	OEMs may sell their product to consumers through a network of distributors and retailers or through service providers. Some OEMs rely on outsourced manufacturers.

Figure 4: Commercialization of plastics: The value system – Starting in one industry and finishing in another [Rebello and Bari 2014].

Investigations in material sciences have often one fundamental drawback: The actual producer of the material participated little in the later, high value added in the component or system, although with him the vast R&D cost portion incurred (Figure 5). Moreover, the market requires usually only small quantities of material, particularly of functional materials [Stebani 2007b].

This is further illustrated for functional polymers using an example for fuel cells in automobiles (Figure 7).

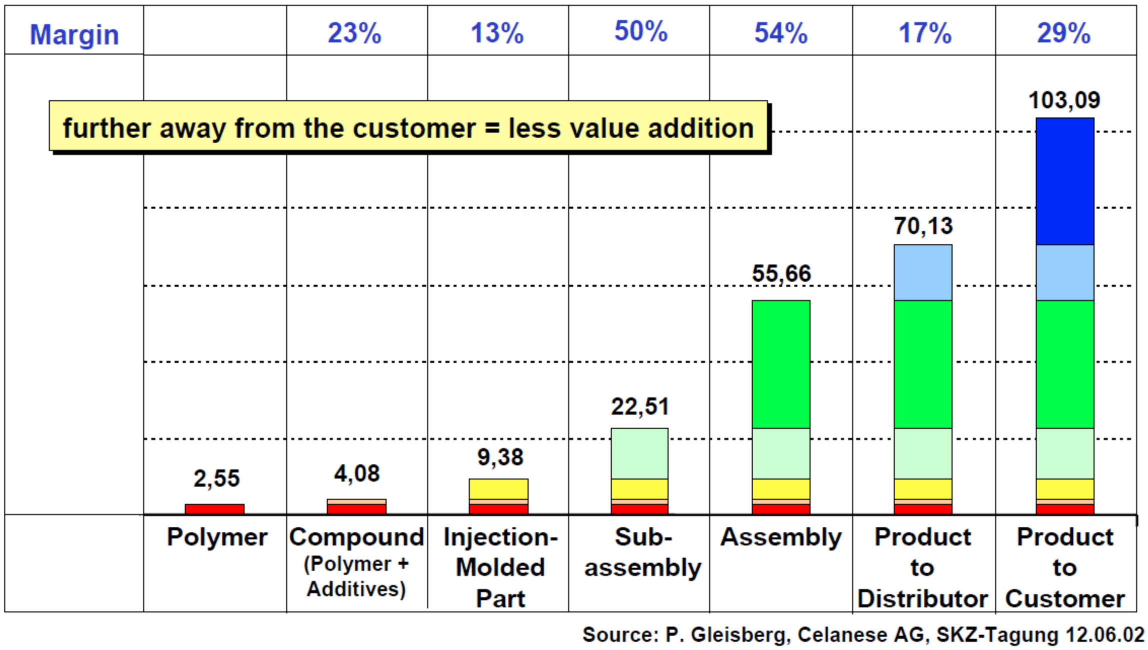


Figure 5: The value system for conventional plastics – Example injection molded parts [Maier 2007b].

There are two types of polymers/plastics as materials which will have different approaches to the market, “structure *versus* function” (Figure 6):

- Structural material – structural polymers market with many applications
- Functional material – functional polymers = one particular application means high dependency on technology.

In the chemical industry and, of course, also on the part of large plastics manufacturer, a partially dramatic change in the corporate structure had taken place during the period 1990-2010, which has not yet fully implemented in a number of customer industries in its consequence. The change of strategy towards a focus either on large volumes or customized product solutions (for specific applications) has taken place. And simultaneously previous research structures were modified or disappeared, respectively.

> *Tailored material solutions* play more than ever a key role in innovation and the growth race. The demands on the material competence of the processing companies grow.

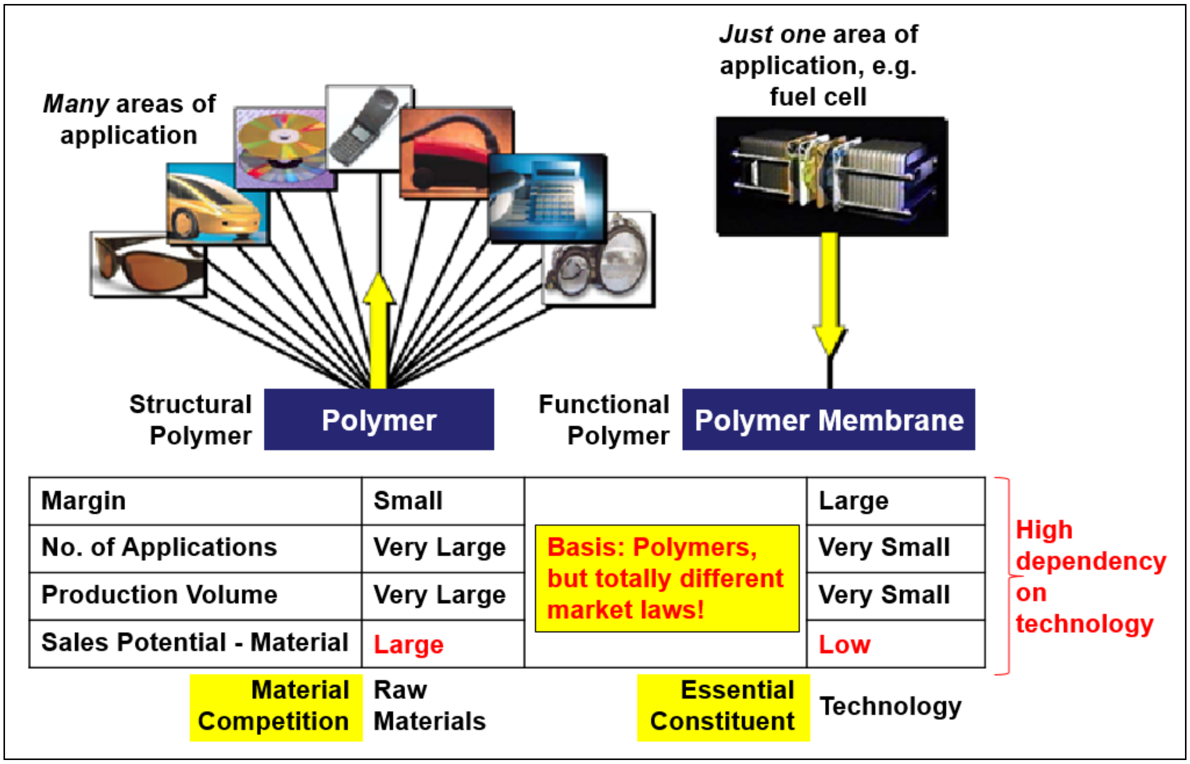


Figure 6: Characteristics of structural material *versus* functional material [Stebani 2005; Stebani 2007b].

In Figure 7 fuel cells in automobiles as an example for economies of plastics are outlined [Stebani 2005; 2007a].

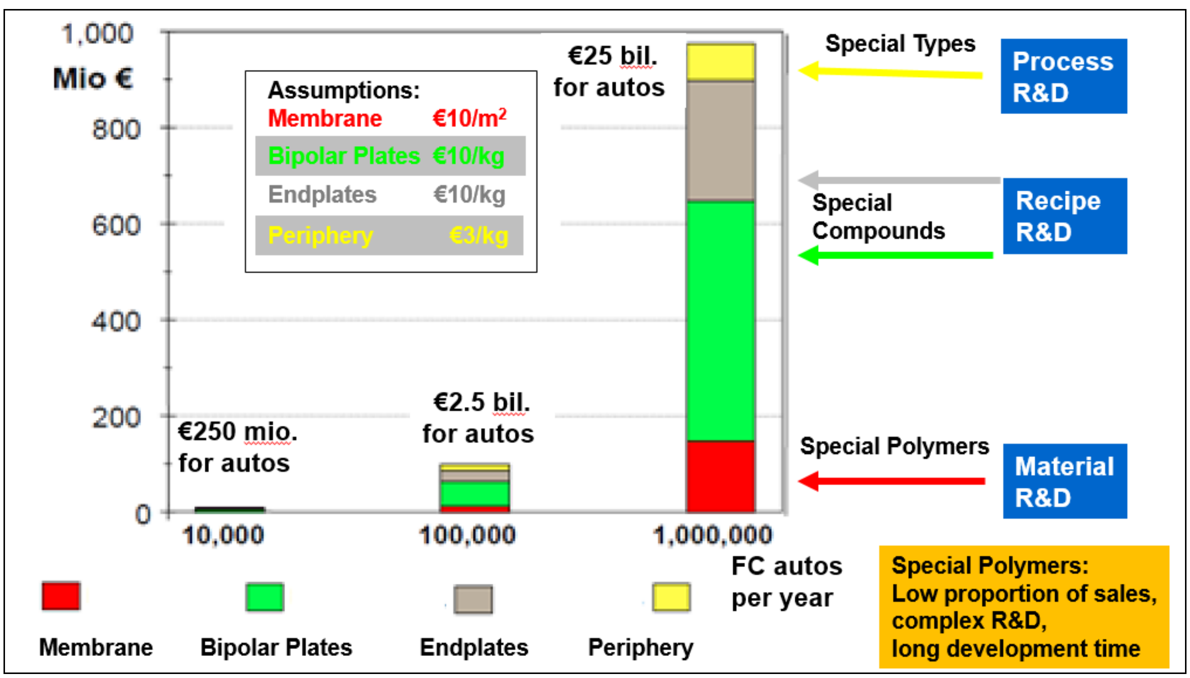


Figure 7: Estimating economies of polymers: Polymers for fuel cells in automobiles as an example [Stebani 2005; 2007a].

In the development departments of companies the subject “innovation in materials” is often underestimated – not concerning pioneering inventions, but just with the classic development and improvement of machinery, equipment or processes. "Often the customer will come only when he has a problem – that is, if it turns out that the materials previously used or those available on the market reached their limits," said Dr. Roland Rehmet, CFO of polyMaterials, which offers plastic development and providing optimization as a service [Burkhardt 2003].

"Then, it may be too late." For example, a Swiss company had put two million francs in the development of a new machine for PCB manufacturing. However, it could only work with a photoresist which had certain characteristics. But this one was not available – the project was an expensive flop."

"You cannot buy plastics meeting the highest standards just in a store, such as wood in the construction market," Rehmet noted. His advice: "If you want to develop something more powerful or need completely new materials, then you should take care of it as soon as possible." And certainly not only to avoid the failures, but also to successfully go on the offensive.” "Access to the right and optimum material allows the user often to gain a key technology and market advantage over its competitors," emphasized the polyMaterials manager [Burkhardt 2003].

Towards the end of last and the beginning of the 21st century the required sales volume for economical compound development and production was rising steadily. There was a large and continuously growing need for specific plastic recipes, but – if the *economy* is not given – no development product [Stebani et al. 2007].

Not only the amount discredits the development of specialties, but – also the expenditure of time and its realizable proceeds. While – shown very generally – previously the market was waiting for the new materials, this then was no longer the case. In ever shorter intervals on the user side ever *more individualized* products were brought into the market in *ever smaller quantities*.

If standard plastics can be used for all these individual or small series, this is, of course, no problem from the perspective of raw material producers. If you need individual plastic compounds or have increasing demands on the materials, for instance, by rising temperature strain and substrate strain in the automotive sector, it is a problem – not necessarily for the manufacturer, but definitely for the user. Often, the user does not want to reward the costs associated with a specific development by a related price. But in times of prices calculated for an individual product level specialties at standard prices can no longer be achieved or subsidized [Stebani et al. 2007].

> The problem does not lie in the economic production of the required smaller quantities – it could be taken over by specialized compounders, occasionally even by raw material producers. It is the required time and the increasing effort of developing new recipes and their optimal adaptation to the requirements.

More detailed analysis of the expenditure for a recipe development shows that particularly the established development process of new plastic compounds is one of the main reasons for the time required for a new development.

Despite extensive process developments in the production of basic plastics in recent decades for the process flow of recipe development for plastic compounds comparatively little has been done. As shown in Figure 8, the common process chain for the production of a number of compounds in the form of granules, the injection molding of test specimens, their testing in the laboratory and return of data to the developer exists substantially this way for over fifty years [Stebani et al. 2007].

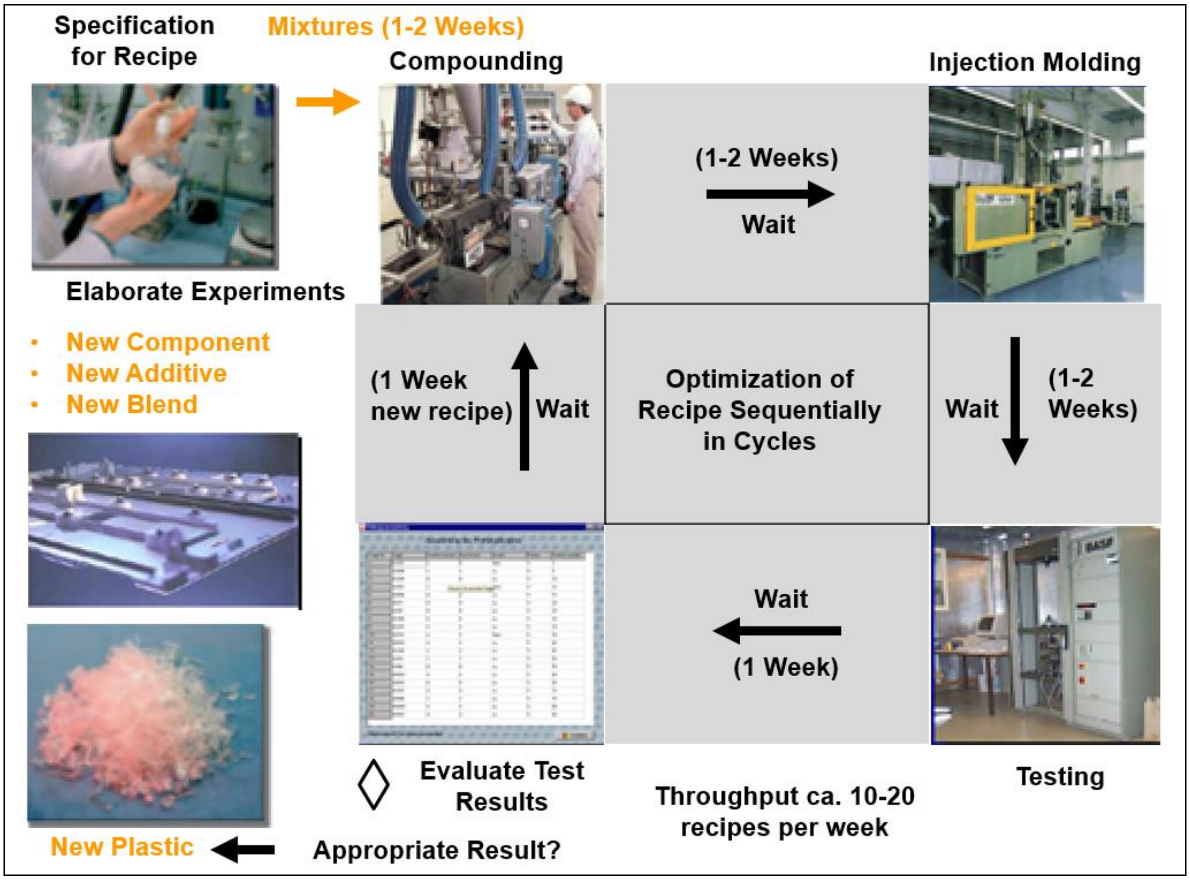


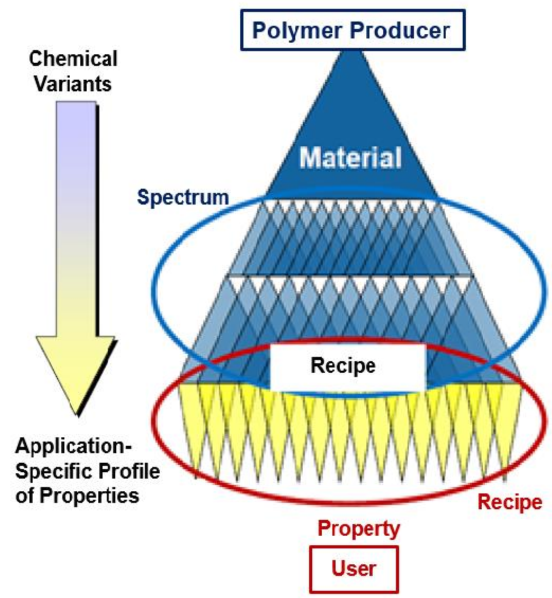
Figure 8: Conventional steps for developing new plastic recipes [Stebani 2007c; Stebani et al. 2007].

In the *traditional approach* the decisive success and speed factors are still the *experience and the specific expertise of developers*. It depends on this knowledge whether a material's optimization or a new development in terms of production and testing of maybe 20 recipes will take only a few months or they may be stopped due to high complexity and/or time expenditure. Even if sufficient development capabilities in terms of equipment and trained personnel is present, for short product cycles this situation is not satisfactory, but with reduced resources the bottleneck for new formulations will be blatantly noticed.

The fundamental problem of compounding plastics is a "combinatorial explosion" (Figure 9). Types of plastic do not only refer to the gross chemical formula of constituents, but also, for instance, grouping of monomers and morphology of polymer chain types [Brandstetter 2004; Stebani 2011:21].

Product *differentiation* is a key feature of modern economies. Customers or consumers perceive the differences among differentiated products to be real and there is often approximate agreement on which ones are, and are not, close substitutes.

The "address approach" distinguishes between horizontal and vertical product differentiation. In the former, customers or consumers do not agree on the quality ranking of commodities, while in the second they do. The main assumption is that higher variants of vertically differentiated commodities require highly-skilled input.



> 100 Basic Polymers (Types of Plastic)

>>   10,000 **binäre** Blends (2 Polymers)
>>   1,000,000 **ternary** Blends (3 Polymers)
>> 100,000,000 **quarternary** Blends (4 Polymers)

>> 1,000 **Additive-Variants** per Blend

Hence, there are billions of recipe variations and time-consuming search for the optimum

=> Conventional solution: experience, focusing (reduction), prioritization of known formulation range

However: For new components there is a very costly and time-consuming building of experience

Figure 9: Not manageable diversity of recipes for compounding [Stebani 2011].

Around 2000 for chemical products the definitions of product differentiation did not only use a binary scale, commodities *versus* specialties, but the following grades were found for differentiated products of the petrochemical (including plastics) industry [Runge 2006:151-152]:

- *Commodities* are the very *large volume* products that are sold by a *large number of suppliers* to *large number of customers*, with less product differentiation and price as the major criteria (**high volume – low value**)
- *Differentiated Commodities* are the very *large volume* products that are sold by *selected suppliers* to a *large number of customers*, differentiating product based on *performance* and *price*
- *Large Volume Specialties* are large/medium volume products that are sold based on technology, performance and meeting *end-use requirements* as the major criteria
- *Specialties* are small volume products supplied by *limited suppliers* with *high profit margins* and high barriers to entry based on technology (**low volume – high value**).

The further evolution of the polymers and plastics of product offerings in Figure 10 shows that *individualization and customization* requirements are notably increased and determined by *customers from other industries* with very specific requirements to solve their problems concerning needed materials.

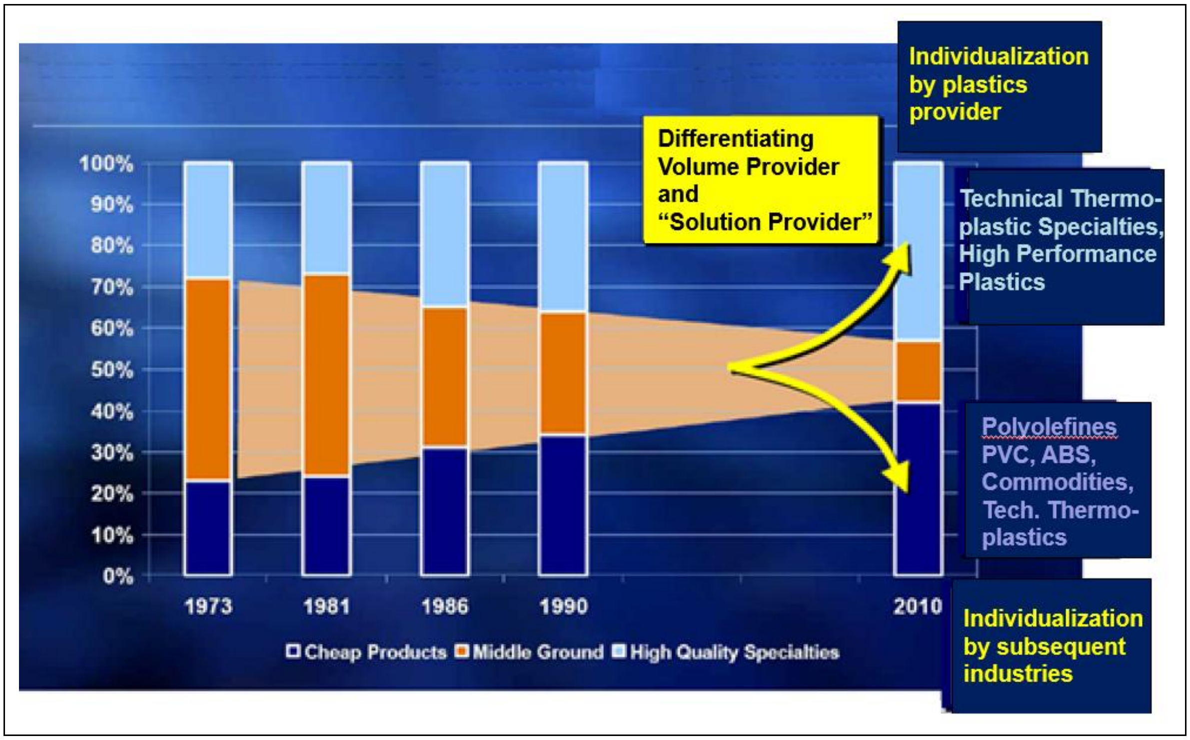


Figure 10: Individualization as the driver for the development of the polymers/plastics industry [Maier 2007a].

In terms of the roles of players for innovation and to respond to the trend of individualization of products polyMaterials positioned itself as an R&D service provider indicating a prospect of becoming active also for the level of fundamental (basic) research, which is essentially the domain of universities and public research organizations or institutes, respectively.

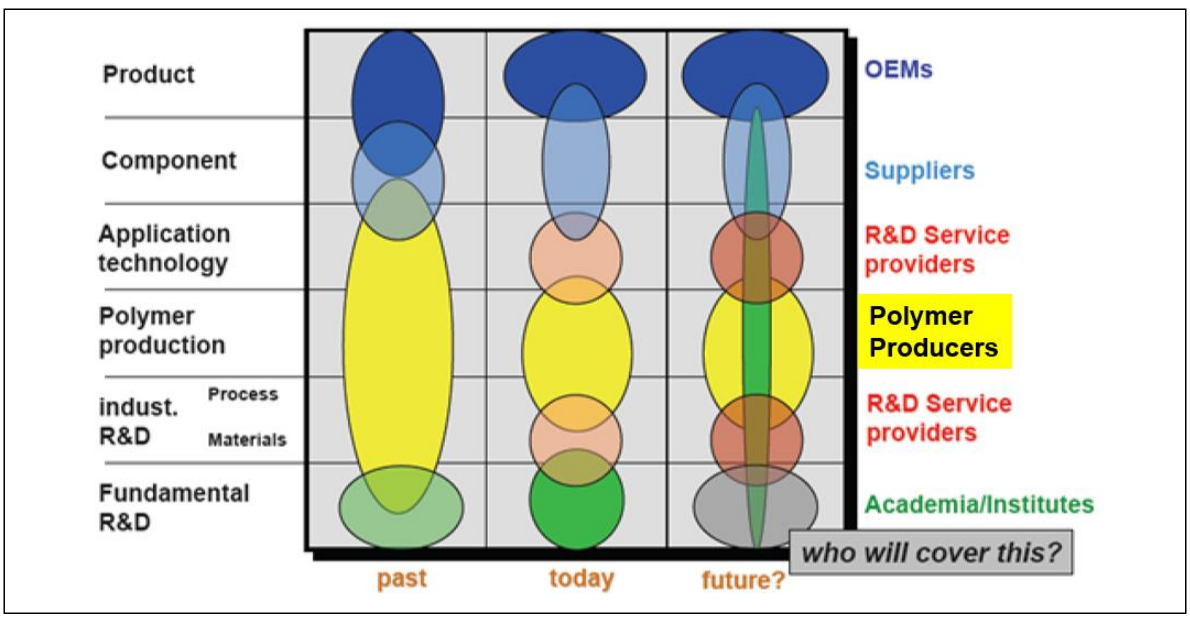


Figure 11: Consequences of a past trend for players of the innovation chain [Maier 2007b].

The basis for all these developments in the chemical industry are changes of the corporate R&D approach, for instance, in terms of 1st – 4th generation R&D (Figure 13) [Runge 2006:598-609].

Furthermore, as a streamlined way to project selection and execution and reducing uncertainty for new product development (NPD) the "stage-gate process" [Runge:396-397,605; 2006:653-654] was relatively widely adopted as an archetype in large firms. And focused customer-orientation of the R&D organization should be achieved by establishing dedicated R&D units for the various business units ("Business Research") [Runge 2006:619,632,693,718-719] keeping the original monolithic Corporate (Central) Research Division often as a corporate technology platform with special R&D-related tasks or services.

The stage-gate process is essentially sequential which initiated the metaphor of a linear, "direct flow through a pipeline" with "filters" and "valves" (gates and switches). The gate requires that all activities be finished up for review before the next phase can start. Decision making in the gates are usually done by multifunctional "selection teams" or "decision teams".

For the changed market situations chemical companies needed to respond to market opportunities, even if they cannot meet the challenges alone. Hence, with regard to resource management, considerations of "build, cooperate, buy" decisions (Figure 12) suggested "decoupling" in the gates by "cross-flows", a term "borrowed" from membrane technology. Cross-flow would be, for instance, to external basic or contract research, contract manufacturing or license-in, etc. [Runge 2006:791-793].

But, in the new business environment in large firms "build, cooperate, or buy" considerations with regard to *external resource management* of R&D and innovation including new business development (NBD) emphasizing uncertainty *versus* cost to acquire competencies became generally common [Runge 2006:618,727,792].

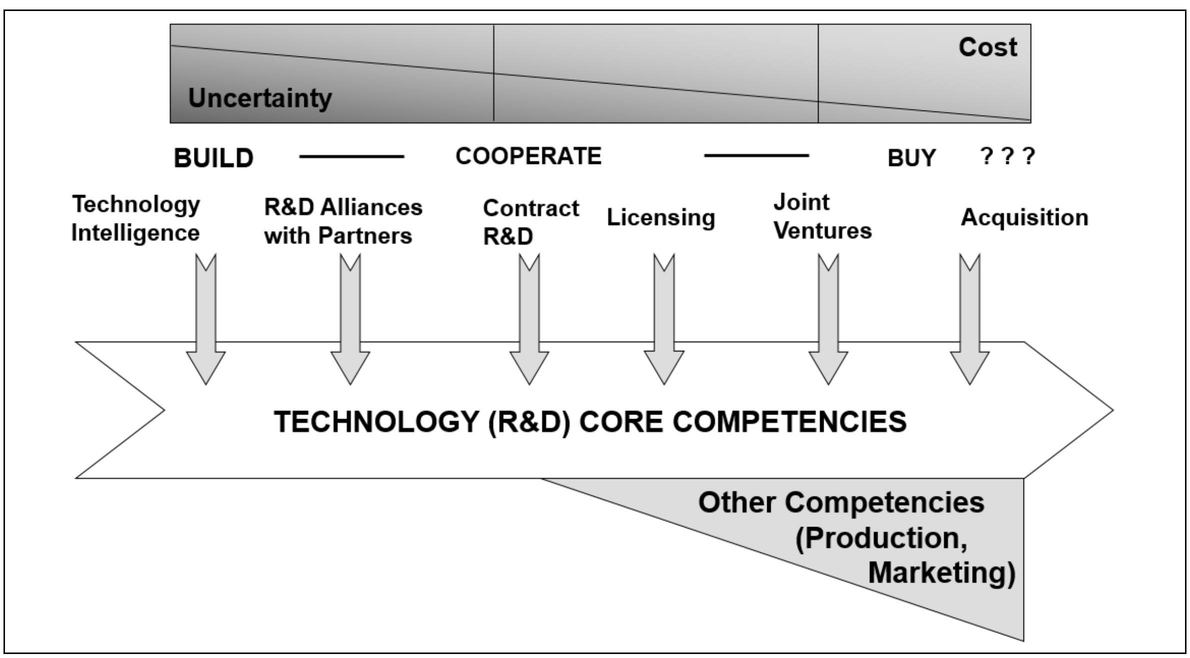


Figure 12: Modes of acquiring particular competencies and/or new resources through various means associated inversely with levels of uncertainty of success and cost [Runge 2006:618].

Using external R&D facilities, such as cooperation with universities, was not new for the chemical industry, on the contrary (Figure 13).

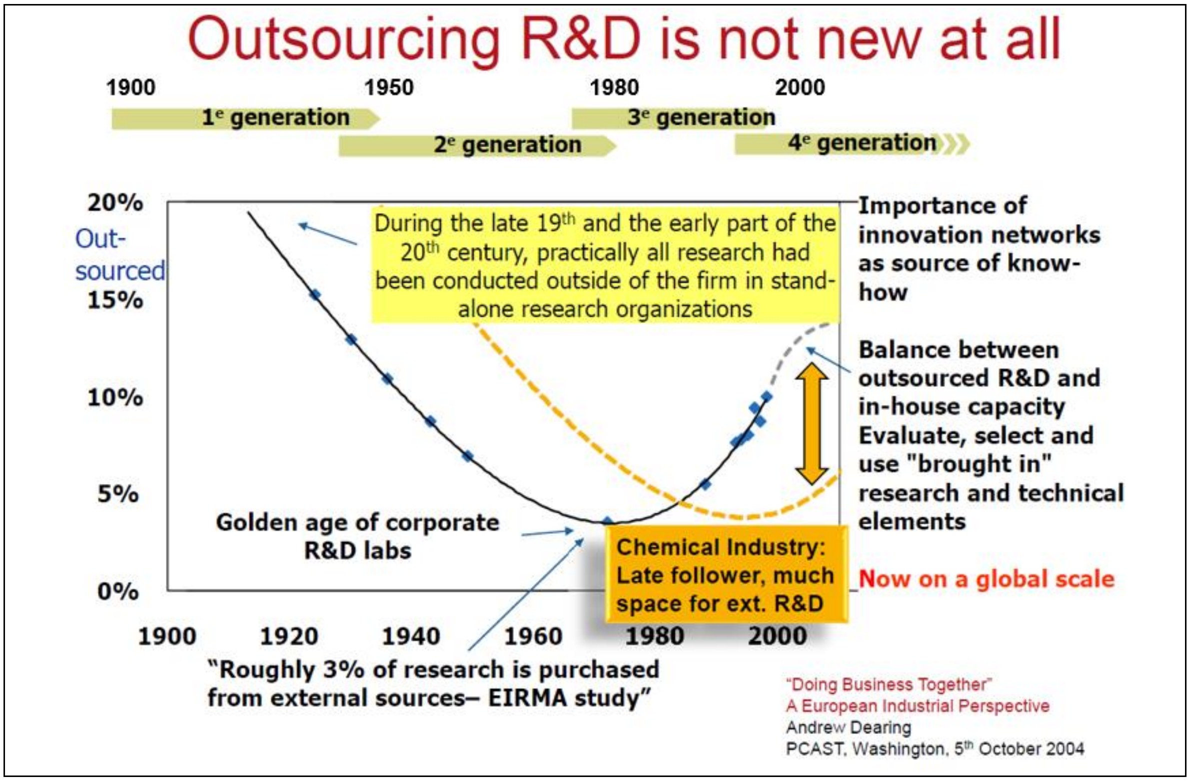


Figure 13: Contribution of external research to industrial research and innovation [Runge 2006:684; Stebani 2008b].

Correspondingly, in the new century for existing large or giant firms *networking* with various partners, such as startups, universities, public research institutes, small and medium-sized enterprises (SMEs) and large firms and even governmental agencies, has become an organizational challenge (Figure 14).

And concerning the need to accelerate innovation and identify new technical business opportunities [Runge 2006:745-750] large firms set up spin-offs acting relatively independent from the parent company to mimic entrepreneurial situations (Figure 14, lower right to upper left relation), for instance, by identifying and initiating common projects to gain access to new competencies and/or new resources.

These spin-offs operate formally (and often legally) separated from the parent company and manage "external research" for New Business Development (NBD) including financing startups through a related Corporate Venturing branch [Runge:241-243].

Typical (German) examples of such spin-offs of German chemical firms are BASF Future Business GmbH [Runge 2006:555,695-698; Jahn 2007] (Figure 15), Bayer Innovation [Runge 2006:698] and Creavis Innovation & Technology GmbH of Evonik Industries (formerly Degussa) [Runge 2006:540,556-557,696,698,728-729; Dröscher 2008] with additionally its Project House concept [Runge 2006:556-557].

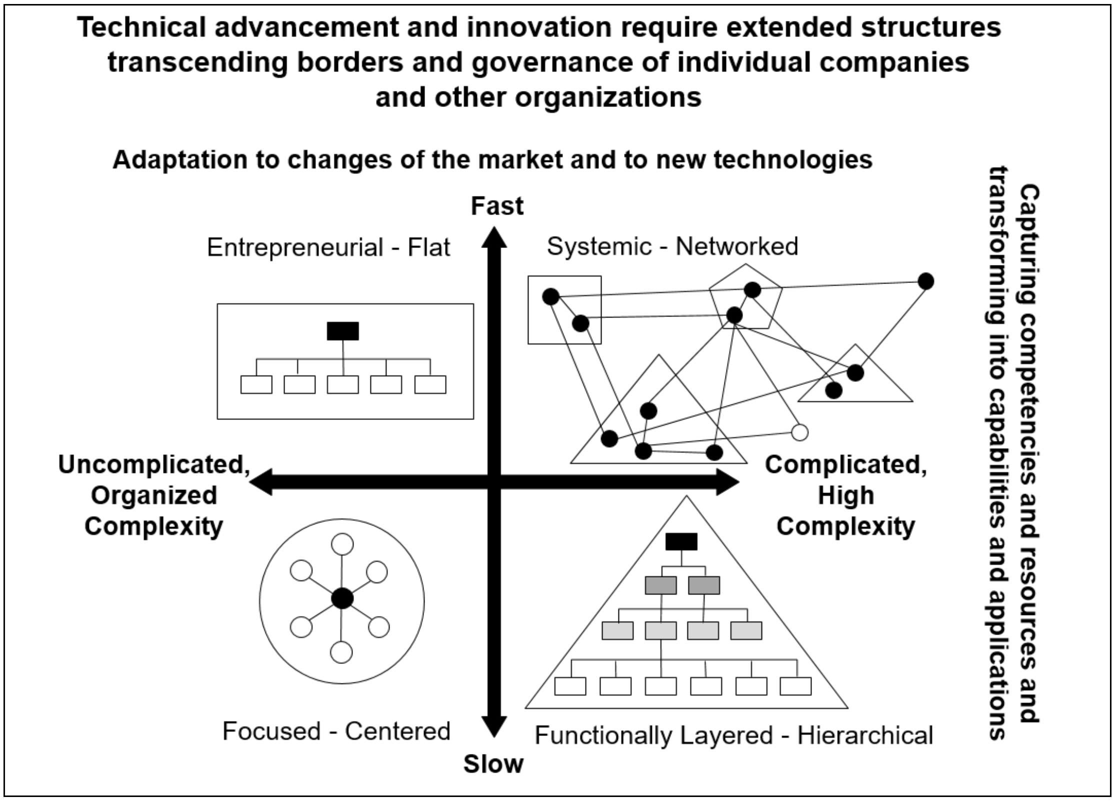


Figure 14: Interrelating innovation and technical advancement to complexity and pace of involved organizational orientations.

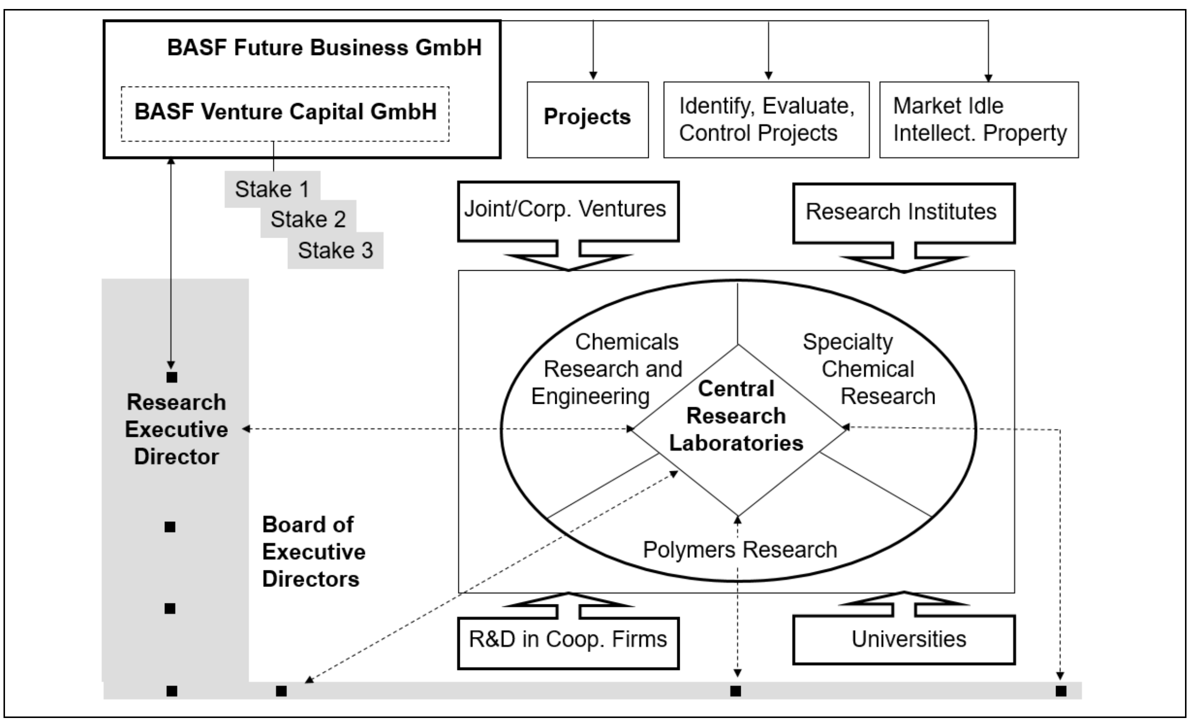
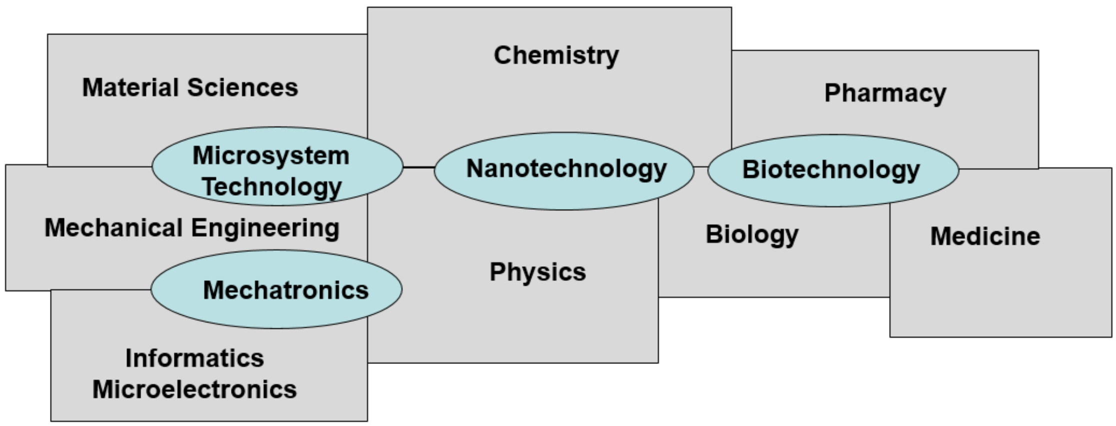


Figure 15: The structure and organizational position of BASF R&D in 2006 (Business Research not considered) showing also responsibility of executive directors for particular research areas [Runge 2006:698].

However, apart from learning, acquisition of competencies and acquiring other firms, after 2000 the trend towards *interdisciplinarity* [Runge:98,1207], particularly helpfully associated with special types of employees, was augmenting the trend to increased complexity (Figure 16).

New key technologies require special knowledge of different science and engineering disciplines



Adapted/modified from [Handelsblatt 2002], 3. Handelsblatt Tagung für die Chemische Industrie 2002 (Slide of J. Stebani)

Figure 16: The map of interwoven scientific and engineering disciplines for the chemical industry to serve other industries.

Between two systems the common boundary is called the interface. In case of human activity systems persons taking the roles of interfaces are called *gatekeepers* [Runge 2006:9,738] or "*boundary spanners*." The notion "gatekeeper" was introduced as an interface, if "differences" between intervening parts are too large to allow direct contact and communication between the parts.

In analogy to the "technical gatekeeper" who interconnects various scientific and technical disciplines or corporate-internal and external research the R&D Marketing interface can be approached through an R&D role of a "marketing gatekeeper" [Runge 2006:9,537,783]. Finally, in multinational organizations there may be also general language barriers which have to be overcome.

Interdisciplinarity for innovation or in NTBFs often means "elevated" experts in one field with some knowledge of other fields who get on with each other, not all-singing all-dancing polymaths. Related advances will often occur at the interfaces and require experts with corresponding "gatekeeper" qualities in order to recognize and exploit them efficiently.

"*Gatekeeper functionality*" ("boundary spanners") is a "glue" of a team or group, which will facilitate communication. This reduces communication channels and presumably also reduces coordination efforts. Gatekeeper functionality is also observed for the ca. 10 percent of founders who have both technical/engineering and commercial competencies [Runge:98.242,1205].

In particular in (multidisciplinary) joint projects ("Verbund-Projekte", Figure 32 and related text) with several interfaces between different discipline- and function-oriented partners gatekeepers play an important role.

The relevance of "boundary spanning" was shown by Lakhani et al. [2006] who inquired into the effectiveness of the problem solving process at InnoCentive analyzing hundreds of challenges posted on the site [Runge:436]. Accordingly nearly 30 percent of the difficult problems posted on InnoCentive were solved within six months. Sometimes, the problems were solved within days.

InnoCentive® established a Web-based community matching scientists (“solvers”) to relevant R&D challenges (“seekers”) facing leading companies from around the globe. It is an online forum enabling major companies to reward scientific innovation through financial incentives.

In their survey they asked the Solvers if the problem they created a solution for lies inside their field of expertise, at the boundary of their field of expertise or outside their field of expertise to come up with a notable finding. The secret was *outsider thinking*: The problem solvers on InnoCentive were most effective at the margins of their own fields. Chemists did not solve chemistry problems; they solved molecular biology problems and *vice versa*. While these people were close enough to understand the challenge, they were not so close that their knowledge held them back, causing them to run into the same stumbling blocks that held back their more expert peers [Runge:436].

Finally, since the beginning of the 21th century the polymers and plastics industry also encountered the ubiquitously emerging “green” trend and, in particular, tremendous entrepreneurship and innovation activities in biobased and “drop-in” chemicals [Runge:935-1133]. Here chemicals mean essentially biofuels, raw materials, additives and polymers.

Awards and Publicity

During its first six years of existence polyMaterials received awards for various aspects.

For 2001/2002 in the contest of the “BJU-Gründerwerkstatt-Wettbewerb” polyMaterials received the 3rd prize and thus €5,000. At that time 15 fixed and more freelancers were working at polyMaterials. By projects ordered by customers topics were processed which enable customers to gain competitive advantage through own material solutions and implementing them in new products [BJU 2002].

A special prize of the Bavarian Ministry of Economic Affairs with an amount of €10,000 for sustainable job creation was awarded to the former StartUp winner polyMaterials AG from Kaufbeuren [Sparkassenverband Bayern 2005].

When the four regional winners of the innovation competition 2006 “Initiative Mittelstand” had been announced polyMaterials was one of those: polyMaterials AG, Kaufbeuren (Allgäu) had developed new polymer materials for repair or replace missing or damaged human tissue. In developing their new materials polyMaterials worked closely together with the Institute of Pharmaceutical Technology, University of Regensburg and the hospital "Rechts der Isar" of the Technical University (TU) in Munich [Gruenderregion-Schwaben 2006].

In 2011 for the category R&D polyMaterials was awarded by the “Industriepreis 2011” for its high-throughput compounding (HTC) technology for plastics compounds. HTC for thermoplastics is an integrated technology for accelerated development and optimization of plastic formulations for customer-specific requirement profiles [Industriepreis 2011].

The Entrepreneurs

polyMaterials AG was founded by three chemists.

Dr. Jürgen Stebani (born 1964) is married and has two children. He passed the Abitur (final examination of a German Gymnasium, a prerequisite for studying at a university) in 1983 in Schweinfurt/Germany and then served as a soldier for time (1983-1985) and officer of the reserve [Stebani 2014]. He studied chemistry (1985-1990) at the University of Bayreuth (Bavaria, Germany), obtained a diploma degree in 1991 and finished with the degree of a Dr. rer. nat. in polymer chemistry in 1993 [Stebani 2014; Hanser 2012].

Then Dr. Stebani was employed at Bayer AG from 1993 to 1999 and he gained experiences in industry for fifteen years in various positions. From 1993 to 1995 he worked as an R&D Project Leader for polycarbonates, then as Head of the Staff ("Stabsgruppe") of the Department of Research. From 1996 to 1998 he worked as Head of the department "Strategic Planning and Business Unit Controlling" in the Staff of the Plastics Business Division [Handelsblatt 2002].

As an R&D Project Leader for the polycarbonates business and then involved in strategic planning he became aware of the issues of the polymers and plastics segment of the chemical industry at the end of the twentieth century. In particular, he saw the need of this industry for change of the actual research and development processes of the big chemical firms and change of players' roles in the supply chain (also called value system [Runge:59-62,66-68]).

In the field of polycarbonates Dr. Stebani appeared as a co-inventor of several patents of Bayer, but also with Prof. Oskar Nuyken (of the University of Bayreuth, who later changed to the Technical University of Munich).

During the early phase of polyMaterials, when there was a three-person leadership team of the founders, Dr. Stebani was responsible for coordination, planning and controlling [Handelsblatt 2002]. Currently Dr. Stebani is the Chief Executive Officer (CEO) of polyMaterials. By integrating company strategy with business and organizational development, he has focused the firm's development to a powerful partner for customers in the Research, Technology and New Materials sectors [polyMaterials].

Additionally Dr. Stebani is networked in several industry associations as a member, for instance, [Stebani 2014]:

- The Board of "PlasticsEurope Deutschland"
- The Board of DECHEMA e.V. (Dechema Gesellschaft für Chemische Technik und Biotechnologie)
- AiF Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e.V.
- The Committee for Industry and Innovation of the DIHK (Der Deutsche Industrie- und Handelskammertag e. V. – IHK, Chamber of Commerce and Industry).

As will be seen via Dr. Stebani and his past in Bayer AG there was not only deep experience in the current and the developing polymer business, but polyMaterials could utilize networking and cooperation with Bayer for its further development.

Dr. Gerhard Maier (born 1960) is a polymer chemist with an additionally (specifically German) university degree for his "Habilitation" (Dr. habil.), which is usually one prerequisite to become a professor in a science discipline at a German university. Correspondingly, he has the title of a "Privatdozent" (PD) which implies obligations to provide lectures at the university.

For instance, in summer 2015 Dr. Maier (and Prof. B. Rieger) gave a lecture on "High Performance Polymere" at the Faculty of Chemistry of the Technical University of Munich.

As a PD Dr. Maier has demonstrated his competencies and experiences via numerous scientific publications and being a co-inventor of many patents of polyMaterials (Table 7).

His view was that one is not born to be an entrepreneur. "I was actually set on a university career," Dr. Maier said. The polymer chemist studied in Munich where he received his doctoral degree and turned to Bayreuth University to get there his Habilitation degree in 1996. With his work group, he had continuously contacts with industrial companies [Handelsblatt 2006].

Dr. Maier appeared in several patents as a co-inventor together with Prof. Oskar Nuyken who later became a member of polyMaterials' Scientific Advisory Board.

Specifically Dr. Maier is a polymer chemist at professorial level (PD), with almost 20 years of experience in the field of industry-related polymer research. Responsible for both research and production of polyMaterials, he ensures that projects address production requirements from the outset of the research phase for smooth scale-up to the production phase [polyMaterials].

Currently PD Dr. Maier is the Chief Technology Officer (CTO) of polyMaterials. And currently he is a member of the "Wissenschaftlicher Beirat der Bayerische Forschungsstiftung (Science Board of the Bavarian Research Foundation), seen as a flexible tool to promote strategic, application-oriented research [Bayerische Forschungsstiftung].

Dr. Roland Rehmet (born 1966) studied chemistry at the Technical University of Berlin and the Technical University of Munich. After a one-year stopover in the IT industry as a UNIX expert, he founded in 1999 polyMaterials AG in Kaufbeuren (Allgäu) with the two above mentioned partners. He supervised the functions Finance (CFO) and Infrastructure [aiti-park 2006], but also Human Resources. Dr. Rehmet was additionally politically engaged for the German Liberals (Free Democratic Party, FDP) [kandidatenwatch.de].

Dr. Rehmet left polyMaterials at the end of 2007 [Handelsregister 2007] for private, personal reasons. In 2014 Dr. Rehmet committed suicide in Hamburg/Germany because of personal reasons [Hirschbiegel and Iksanov 2014].

The original entrepreneurial triple [Runge:319-320,336-340-342] had broad experiences in polymer and macromolecular science and partly in industry or with industry [Runge:90-91,303,306].

And the three founders also shared a common "origin": Prof. Oskar Nuyken, the renowned Polymer Researcher at the Technical University of Munich. He did not only educate the Board of Executive Directors ("Vorstand") of polyMaterials to various degrees but supported also the startup as a scientific advisor [Jopp 2000].

Professor Dr. Oskar Nuyken, born 1939, studied Engineering Economics (Specialization Chemistry) at the Technical University Dresden and studied chemistry at the Technical University of Berlin. He got the Habilitation in Polymer Chemistry at the Technical University (TU) Munich. In 1985, he took a professorial position at the University of Mainz, but already in the following year he turned to the University of Bayreuth (Professor of Macromolecular Chemistry). From 1992 to 2007 he held the Professorship and Chair of Macromolecular Chemistry at the TU Munich. His scientific focus was on high-temperature resistant polymers, polymers for communication technology, medical applications and membrane materials [Theoretical Chemistry Genealogy Project].

Remarks Concerning Corporate Culture

polyMaterials' Kaufbeuren branch as its headquarters and center for R&D is located at an area where other people spend their holidays. The inspiring environment with high recreational value is favorable for creative activities.

polyMaterials is a research-based startup (RBSU) with a high proportion of employees in R&D and particularly chemists with a doctoral degree. Early in 2007 (Table 4), it had 35 employees in two relatively distant (Figure 24) locations (29 Kaufbeuren, 6 Leverkusen). It covered 11 chemists with a doctoral degree (in Kaufbeuren) and overall 18 chemical lab technicians, technical employees (TAs, "technische Angestellte"), (chemical) craft masters and chemically skilled workers [Stebani 2007a].

Correspondingly, the firm has essentially a "science culture" [Runge 2006:626-632].

During its early phase Dr. Rehmet viewed the company's small staff as a distinct advantage in this field. "Our team is small, but very efficient," he said. There is a broad knowledge of polymer chemistry enhanced by the Scientific Advisory Board of polyMaterials which includes several plastics experts from well-known academic and industrial research groups [Devicelink 2000].

Concerning employees the structure of the *personality* of professionals is regarded as very important. Due to the mandatory *customer-orientation* of the firm to deliver experiment-oriented services and consulting customer relationships via personal contacts of polyMaterials' employees with *customers or external cooperation partners* and *networking* communication (and presentation) skills are a must as is project execution [polyMaterials – Employees].

For R&D services *creativity and problem-solving* means mostly intelligent transfer of the known to the new. Tasks usually are associated with a high degree of responsibility.

For the highly specialized firm there is *continuous employee development*: What is lacking in experience and methodological skills will be developed through "training on the job" or through seminars or workshops [polyMaterials – Employees].

polyMaterials has a heavy focus on *teaming up and teamwork*. When hiring new employees (project leaders or lab personnel) applicants will be assessed whether they fit in a team [polyMaterials – Employees; Stebani 2007a].

Business Idea, Opportunity, Foundation and Service and Product Developments

Purposeful, systemic innovation begins with the analysis of the sources of new opportunities.
(Peter F. Drucker: Harvard Business Review, November-December 1998, p. 7)

The customization of products and the reduction of product cycles with simultaneously rising material requirements lead to a constantly growing demand for optimized plastics. The ensuing need for acceleration and higher efficiency of previous R&D methods for compounds can only be met by intelligent system concepts.

polyMaterials' answer is an integrated concept for accelerated formulation and optimization of compound formulations for customer-specific job specifications.

The current chapter will deal with the first years of existence of polyMaterials after foundation in 1999/2000 and a structured and successful development until the Great Recession (1999/2000-2008/2009) [Stebani 2014].

- The first quarter (Q1) of 2008 was a record quarter concerning sales – with 38 employees including 10 chemists with a doctoral degree.
- In 2008 polyMaterials opened a sales office in the US (NC) run by one PhD.

After Foundation until the Great Recession

To develop the fundamental base of material in most cases polymer chemistry is necessary. However, the share of value added and the specific marketing of the product was shifting from a focus on raw material to a focus on technology with other distribution requirements. For this reason, material R&D should be very well obtained from external services [Stebani 2011].

According to Dr. Stebani "There is an increasing need for cooperation with external (polymer-) experts, either to complete in-house resources or to have access to research capacities on a basis of variable cost for a certain time."

Especially medium-sized supplier companies have to adapt to increasing demands on their material expertise. The more development responsibility they must take for systems and components they produce, the higher are also their R&D needs in materials engineering. This means: On the one hand they have to build up their own know-how basis in key areas; on the other hand they have to work more closely with external specialists for specific groups of materials and applications, manufacturing processes and test methods to cover the entire range of requirements [Burkhardt 2003].

In Kaufbeuren it was thought in grams' dimensions, of *highly specialized applications*. Dr. Stebani saw this field as a market opportunity. "Many innovations, especially in medium-sized firms (in Germany Mittelstand), fail because no established company can produce the required small quantities economically," said Oskar Nuyken, the renowned Polymer Researcher at the Technical University of Munich and member of the Scientific Advisory Board of polyMaterials [Jopp 2000].

According to Dr. Rehmet, an *increase in the demand for custom materials* is a natural evolution in the R&D domain. "Until now, many problems could be solved by engineering," he said. "But now, these engineering solutions are calling for specialized polymers with specific parameters." Rehmet added that it is possible for a company to perform in-house R&D for as long as two years and still be at a loss for a material [Devicelink 2000].

polyMaterials assumed to benefit not only from the growing consulting and problem solving required by the users, but also from the fact that the plastics manufacturers were increasingly focusing on production. Consequently, they would largely withdraw from the material research and development, partially also from process development and the application technology. "These gaps in the supply chain generate a market for new services and products," explained Dr. Rehmet [Burkhardt 2003; Stebani 2004].

The related business idea had actually two roots: As described in the entry chapter, first, industry challenges in 1999/2000 shaped opportunities and expectations/assessments of future developments of the polymers and plastics industry and, second, the expected role of contract services.

polyMaterials started directly as a CRO and also a CMO for small-scale production, but it could also organize production of larger quantities [Devicelink 2000]. It started with the three founders and five further employees, three of them with a doctoral degree [All-in.de 2000].

After foundation in the Kaufbeuren (Germany) Innova Park polyMaterials AG created and produced customized polymers in small amounts for both *customer projects and proprietary purposes*. polyMaterials AG developed on its own and on behalf of customers modern polymers and special applications for new polymers used in high-performance technologies. Application examples were fuel cells, medical technology, microelectronics and energy storage.

> State-of-the-art research and analysis laboratories and a staff of experienced chemists made the company well equipped for such activities. "If a polymer is made, was made, or can be made, then we can get it," said Roland Rehmet, executive board member and principal chemist at polyMaterials. He added that the company constructed a mini-plant for custom materials with a production capacity of 10-20 kg [Devicelink 2000].

Dr. Rehmet viewed the company's small staff as a distinct advantage in this field. "Our team is small, but very efficient," he said. "Large-scale industry does not do this type of research – it's not profitable for them, because they have high overhead costs," he added. Still, Dr. Rehmet noted that his firm's strong contacts with major polymer producers will serve it well. "We have partners who can produce large quantities if they are needed," he said, adding that the *Scientific Advisory Board* of polyMaterials includes several plastics experts from well-known academic and industrial research groups [Devicelink 2000].

The *range of services* included material processing, consulting, feasibility studies, screening, contract research, analytics and laboratory synthesis of plastics and specialty polymers, and the *production* in kg – later to level of tons. Carrying out the R&D jobs and production was in compliance with strict rules of *confidentiality*.

Specifically custom R&D services related to *materials research* focused on additives, polymers, functional materials and compounds and the development and production of completely new plastics upon request (functional polymeric smart materials, for instance, for optical and medical applications, membranes, applications in the automotive and electronics sectors).

polyMaterials was following a typical business process that carries from project to project with customers. On the other hand, the CRO ASCA GmbH [Runge 2015b] goes preferentially for long-term research contracts with its partners. Through long-lasting contracts with permanent customers ASCA has a sound basis for financial management, planning investments and keeping the firm in a stable state.

Early projects included also the development of a special polymer for the production of lab-on-a-chip products by laser etching as well as the creation of analyte-specific polymers for microsensors. The company was also working on bespoke materials for micro-injection molding applications [Devicelink 2000].

> Executive Director Dr. Rehmet, responsible for Finance and Human Resources, was confident of success even before the actual start of the firm. “We have already reserved rooms for expansion." [Jopp 2000]

The first customer contact came with the plastic parts manufacturer Horst Scholz GmbH & Co. KG in Kronach (Germany). The Kaufbeuren people developed for the firm a special material from which it produced one microscopically tiny wheel using a relatively new production technique, the micro-injection molding. "For such applications, we need materials that flow very easily, so that no micro-pores arise. There our partner helped with its expertise in material," explained Karl-Herbert Ebert, Technical Director of the firm Horst Scholz [Jopp 2000].

"Here polyMaterials has identified *a real gap in the market* and strategically occupied because for products of micro-technology with its high added value first and foremost the material properties and not the material costs are important," said Wolfgang Ehrfeld, founder and director of the Institute of Microtechnology Mainz (IMM), Germany's most go-getting micro-technician, who also belonged to the Scientific Advisory Board of polyMaterials.

The plastic experts of polyMaterials were additionally encouraged by the fact that even *unexpected customers knocked at the door*, such as automotive giant Daimler. "We are looking for an alternative plastics *for fuel cell membranes*," said Werner Nendwich, Managing Director for Production Technology in the project house Fuel Cell of Daimler in Kirchheim unter Tech. polyMaterials' Dr. Rehmet was sure: "Again, here we can help." [Jopp 2000]

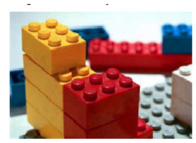
"R&D is vital for use, it is our business!" Projects are initiated by polyMaterials' customers, who own all intellectual properties (IPs). Publicly funded R&D projects are of interest if they are attractive to the customers and allow polyMaterials to participate under a subcontract [Maier 2007b].

In fields, which may offer a particularly interesting possibility for uniqueness in R&D services or polymeric materials, polyMaterials usually operates on its own account in internal projects with external partners.

polyMaterial followed essentially the engineering principle of COTS (Components off the Shelf): It utilized commercially available materials and starting substances to develop and produce new or optimized polymer materials ordered for a variety of applications [polyMaterials 2008a].

The development of custom and application-specific solutions is particularly promising in fields where products or technologies for the market can be improved or made more cost-efficient by the use of superior materials.

For new developments of new material, as a basis, polyMaterials relies on existing building blocks. But it will develop what is necessary and will not avoid new approaches where justified. Use known principles where possible; use existing ones [Maier 2007b]:

Reactions	**Compounds**	**Processes**
Play Lego: **Use the existing blocks in infinite combinations to create new materials and new combinations of properties**		
Techniques	**Morphologies**	**Analytics**

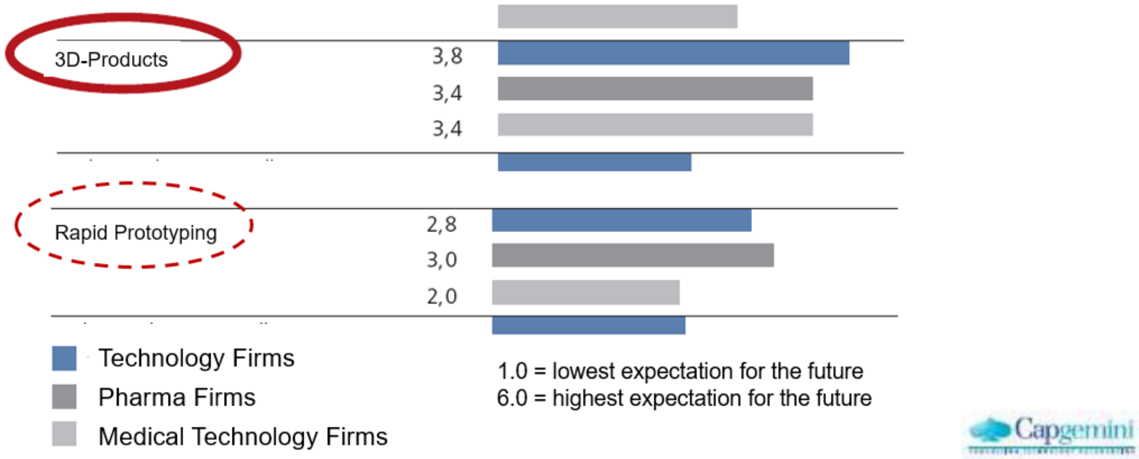
If needed building blocks are not available polyMaterials can "design" compounds for a customer's particular needs [Colvin 2008].

When polyMaterials researched on its own account it often did in the context of projects publicly supported by grants. For instance, together with university hospitals and university institutes they were working on the development of a material that can thrive on the cartilage. Target could be discs, cruciate ligaments or even ears to be developed on a plastic base [Anonymus 2006].

The above examples belong to the field of Regenerative Medicine (RM). According to experts' opinion regenerative medicine (56 percent) and prostheses and implants (50 percent) as the most important fields were assumed to win to 2020. Regenerative medicine may substitute in some areas medical technology (MT).

For the context of manufacturing in the medical area methods of Rapid Prototyping (RP) are important. Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data. Construction of the part or assembly can be done by (micro-)injection molding or since recently using 3D-printing, also called "additive layer manufacturing" technology.

Therefore their increasing importance for the industry was seen as relevant, even if the turnover in RM was still low (in early 2000s). Economic development and future of RM in Germany was assessed according to the below results [Stebani 2011]:



The topic biomedical materials comprises the development of a diverse formulation platform for Regenerative Medicine. Based on the broad expertise in the field polyMaterials was working on polymer materials and processing methods which would allow to make available indication-specific (cartilage, bone, soft tissue, etc.) and defect-specific (3D-components) material solutions for medical and pharmaceutical use. The polymer basis is polyurethanes (PUs, Figure 17). Dr. Stebani [2005; 2011] as well as Maier and Schieker [2010] describe the PU-approach in detail.

This RM-example illustrates a key part of the business idea for polyMaterials: Compounds. As starting compounds here there are about 10 commercially available isocyanates, about 100 polyalcohols (polyols) and ca. 1,000 possible additives which translates into millions of recipes (cf. Figure 9). For instance, for 3D-components there is a simple process chain, transferable to any components (meniscus, larynx, nose, ...).

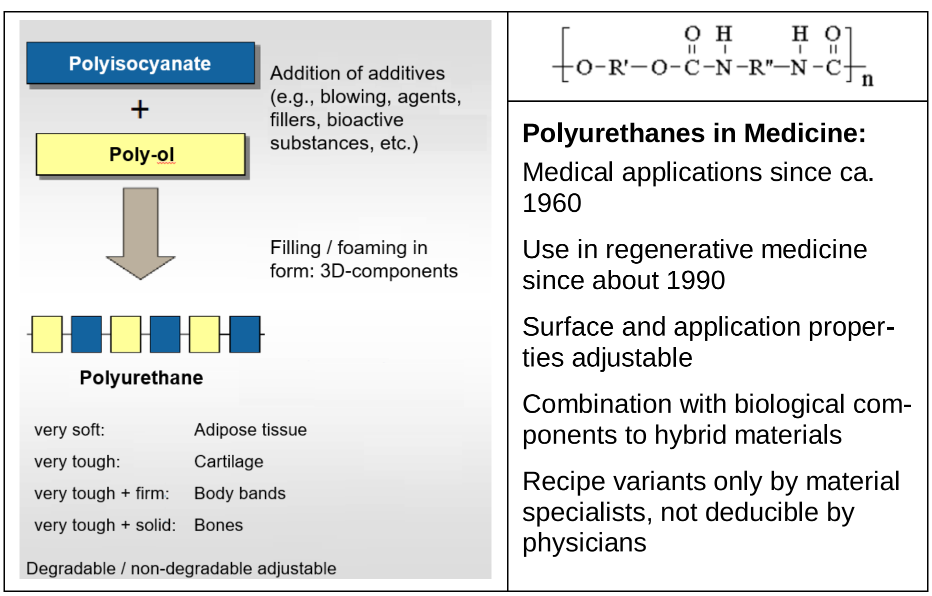


Figure 17: The role of polyurethanes for medical applications [Stebani 2011].

According to Stebani [2006:13] *tissue engineering* ("Gewebezüchtung") is associated with a huge market. It addresses:

Mechanically unloaded cartilage (huge market, no precise figures available!)

- Ear and nose (traumatology and plastic surgery)

Mechanically loaded cartilage

Degeneration, postural damage

- Shoulder
- Spinal column (market $3.1 billion in 2004)
- Hip
- Finger
- Sports injuries: Knee (market €1.5 billion in 1999).

For polyMaterials tissue engineering means healing with polymer chemistry [Stebani 2006] and projects with cooperation partners (Figure 18):

- polyMaterials AG
- HNO Klinik, Klinikum rechts der Isar, München (ENT Clinic, Klinikum rechts der Isar, Munich)
- Pharmazeutische Technologie, Universität Regensburg (Pharmaceutical Technology, University of Regensburg)
- KL-Technik GmbH, Krailling (RP-Dienstleister – Rapid Prototyping service provider).

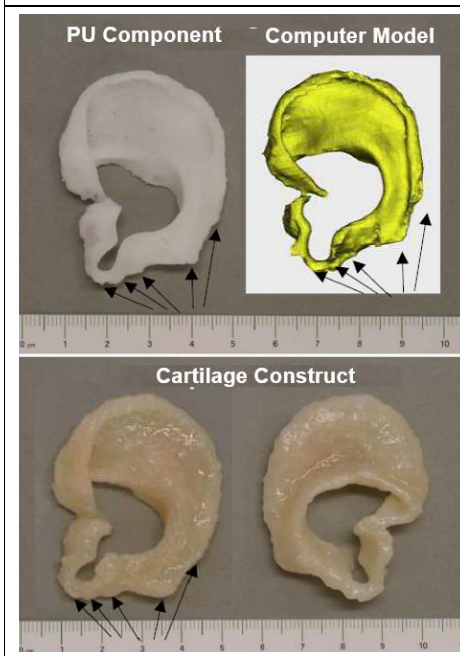
Example: Pinna	**Project Result polymer cell carriers:**
	• 2K molding system of polyurethane (PU) • Any 3D shape (Rapid Tooling) • Porous (> 80%), interconnecting pores • No formation of skin, completely open surface • Compatible with chondrocytes (and other cell types) • Degradable • Sterilizable (superheated steam) **Cartilage Construct:** Polymeric cell carrier + Fibrin gel + Bovine chondrocytes 4 Weeks *in vitro* (of statics) [Stebani 2006]

Figure 18: Forming accuracy on the basis of computer data for the sub-mm range, converting the "artificial" PU material into living tissue (cartilage) [Stebani 2006].

Furthermore, "Life Science" brings dynamics to the market for polymeric microtechnology as much of the miniature systems for medical diagnosis consists of plastic parts which are produced inexpensively in series. A majority of the products of microtechnology consists of plastics for which as production processes especially injection molding and hot stamping foils are used. In the manufacture of these small components specific procedures apply [Vollrath 2001].

"The major manufacturers of plastics have an eye on applications in which every component swallows several granules. On the other hand we produce starting materials for processes in which out of a single granule 20 or more components arise," said Dr. Maier of polyMaterials. "This led to very different requirements, for instance, the uniformity of the properties of the material, which cannot be achieved already technically by the "big" providers with their huge plants." The required materials can generally not simply "bought"; they would almost always be developed precisely for the specific application in close cooperation between material manufacturers and processors [Vollrath 2001].

The course has its price: While conventional plastics partly cost only 1 DM/kg to 2 DM/kg (€1/kg) processed micro-injection molded materials, sometimes reaches the price per kilogram of the order of DM10,000 (€5,000). However, by such figures, one should not be frightened, because what counts, according to Dr. Maier, was not the price per kilogram or per ton, but the price per component.

Hence, the medical technology business is characterized by SMEs [Maier 2010].

The result of combining the technology of rapid prototyping and polymer chemistry results in a new method of treatment in medicine for bone and cartilage defects. The method is illustrated by Stebani [2005:30-35].

The founders envisioned *a change of the role of compounding in the supply chain* (Figure 11) for individualized material solutions interconnecting raw material producers and users/processors as a further opportunity (Figure 19).

As individual product versions continue to proliferate polymers' users are increasingly demanding polymer formulations that are optimally suited for their specific applications. Such solutions will not be found by standardizing developmental experience of polymer formulations with new faster and, at the same time, more efficient R&D techniques to accelerate the development of specialty products [Stebani et al. 2007a].

The envisioned *market for plastics compounds* was viewed to exhibit the following key characteristics [Stebani 2007c]:

- Plastics consist of recipes (polymers and additives) or blends (two or more plastics or polymers)
- Typical additives are reinforcing agents, stabilizers, flame retardants, light or UV stabilizers, processing aids, dyes/pigments or various effect chemicals (nanotubes, ...
- "New" plastics do not result from production but from compounding
- Simultaneously the product cycle time decreases and individuality increases on the application side
- Due to the infinite number of possible plastics mixtures (Figure 9) experience is crucial; realizing entirely new mixtures is difficult and lengthy
- Speed is the success factor.

As an inference from this situation polyMaterials set up a technology project "high-throughput-screening" (HTS) which aimed at developing and establishing a new methodology for the rapid and efficient development of new polymer formulations based on the latest methods of polymer processing with a high-performance software for experimental design and analysis.

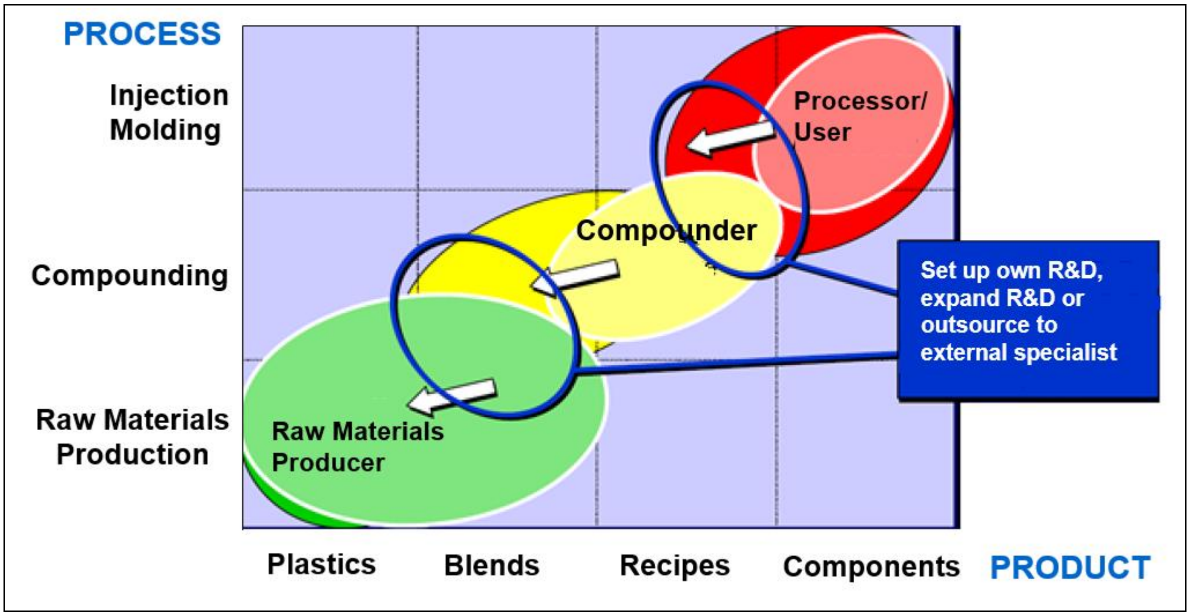
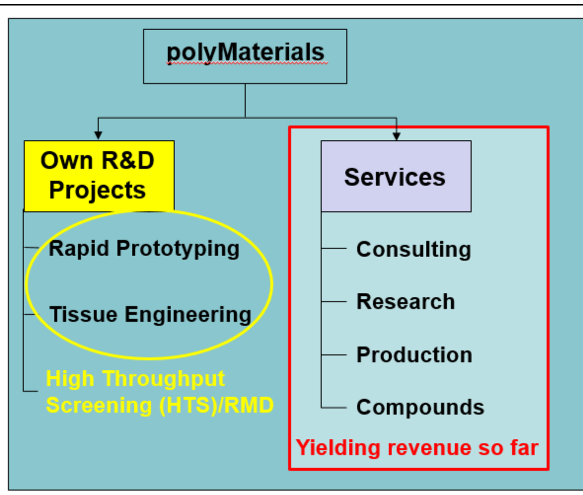


Figure 19: Compounding as a business opportunity for polyMaterials for individualized material solutions to interconnect raw material producers and users/processors [Stebani 2005].

By the end of 2004, as a reflection of the various business opportunities, the founders of polyMaterials envisioned related activities given in Figure 20.

Revenue was generated entirely by services. In 2003 polyMaterials achieved its breakeven, according to plan [Stebani 2014]. IP and infrastructure expansion could be generated by its own cash flow [Stebani 2011].

Customers from the chemical and automotive industry accounted for ca. 80 percent. Regionally customers were from Europe by ca. two thirds.



Customer Distribution by Industry

44% Chemistry

38% Automotive

1% Automotive Suppliers

4% Electric and Electronics (E&E)

5% Printing

8% Other

Regional Distribution:

64% EU

36% NA (North America)

Ca. 80% of revenues are from large companies of the chemical and automotive industry.

Figure 20: Activities and service offerings of polyMaterials and customer structure in terms of revenues' contributions in 2004 (RMD: Rapid Material Development) [Stebani 2005].

The early approach of polyMaterials to R&D targeted three business areas [Stebani 2005] as illustrated in Table 1.

Table 1: Business area and related success factors and focuses of polyMaterials [Stebani 2005].

Volume Plastics: • Individualizing products • Short product life-cycles • Complex requirements • Competition based on materials	**Functional Polymers:** • Low volume • High value (price) • Interdisciplinary R&D • Part of technology	**Materials Applied for Health:** • Low volume • High value (price) • Interdisciplinary R&D • Part of technology
Success Factor R&D: • Speed	**Success Factor R&D:** • Access to technology	**Success Factor R&D:** • Individuality
Focus of polyMaterials R&D: • Faster R&D methods (RMD)	**Focus of polyMaterials R&D:** • Contract R&D (fuel cell membranes, …)	**Focus of polyMaterials R&D:** "Compound R&D" (polymers + cells)

In 2005/2006 the client range of polyMaterials included corporations and innovative medium-sized companies that use the polymer experts to research on new areas or to support their own resources. Research topics of polyMaterials AG were fuel cell membranes, polymer electrolytes, energy storage, mechanical and electronic components, applications of plastics in medicine and compound development [GründerMagazin 2006].

For 2006 the spectrum of customers from various industries changed considerably compared with 2005 data. The chemistry and automotive industries showed proportions of 33 percent and 20 percent, respectively. But automotive suppliers now accounted for 15 percent and medicine for 22 percent.Two thirds of sales were generated from large companies of the "leading" industries. It is interesting to note that publicly funded projects accounted for 3 percent of the 2006 sales (until 7/2006) which means ca. €80,000 (Table 4) [Stebani 2006].

The proportions of sales from the various industries or customer segments, respectively, exhibits a distinct variations on a year-to-year basis. For instance, in 2007/2008 more than 47 percent of the customers came from the chemical industry followed by 36 percent from the automotive and vehicle vendor sectors, but 17 percent were from medical and medical device areas. Customers were mainly from Germany, Austria, Switzerland, Canada and the US [Colvin 2008].

The distinct variations of revenues on a year-to-year basis seem to reflect, at least partially, revenues to be generated by projects and not by permanent customers of the firm from particular industry segments with a more or less continuous need.

For the external situation of the customers polyMaterials' approach represented a continuous R&D chain (Figure 21). The related service offerings addressed essentially "big companies" assumed to generate a competitive advantage (by a USP – Unique Selling Proposition) for the firm in the market.

In order to increase the pace of innovation for the customer and relatedly generate its USP polyMaterials followed a staged approach in terms of process steps with structured activities. In this way a stepwise development of a basis of materials and a reduction of risk for the customer would be achieved (Figure 22).

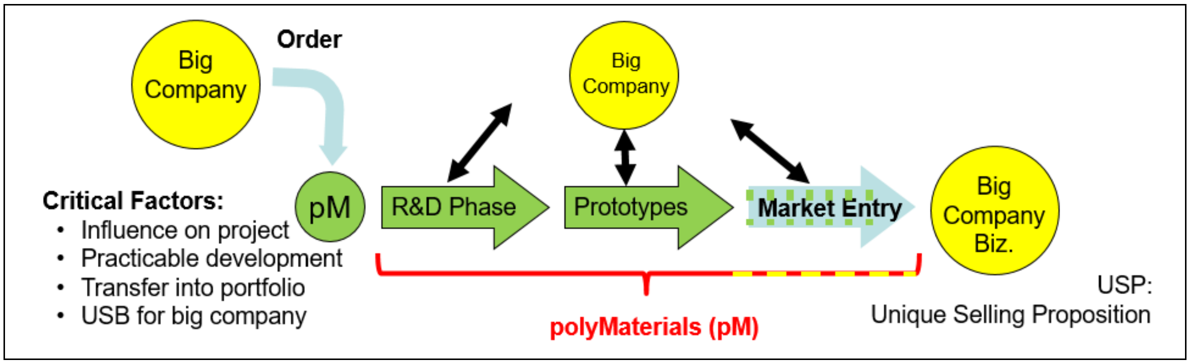


Figure 21: How to serve the customers' R&D chain [Stebani 2005].

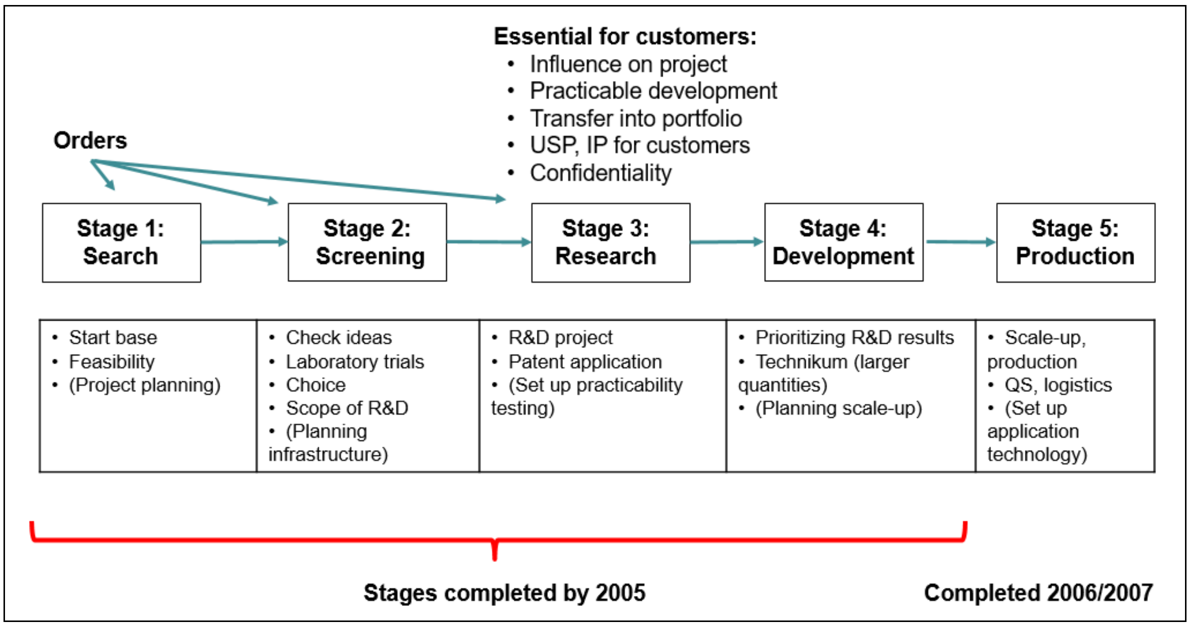


Figure 22: Stages of developing new (functional) polymers – USP: Process expertise R&D projects [Stebani 2005; 2006].

Figure 22 reflects the planning of polyMaterials to finally interconnect development (Stage 4) with small to medium-scale production (Stage 5). Synthetic/production methods require a service infrastructure, *inter alia*, consisting of engineering, analytics and safety services.

Correspondingly, in 2006, polyMaterials took ownership of a polymer synthesis pilot plant it acquired from the former Bayer Central Research Division at its Leverkusen (LEV, Germany) site. The second location in Leverkusen, the main site of Bayer AG, started with five employees. Correspondingly, polyMaterials then had had 33 employees including 11 chemists with a doctoral degree – and "no MBA ("und kein Betriebswirt") as emphasized by Dr. Stebani [Anonymus 2006; Leverkusen 2006].

The Leverkusen location meant developing and producing where the most appropriate infrastructure is available. Dr. Stebani's past in Bayer AG did not only let him gain deep experience in the polymer industry and developing a business. For the planned entry into production he could utilize networking and cooperation with Bayer for further development of the new venture.

Actually, polyMaterials entered the "Bayer Chemiepark Leverkusen" (then CHEMPARK Leverkusen, now CURRENTA GmbH & Co. OHG) to use the infrastructure and get support by the "Bayer

Chemie Start Up Initiative" available for new chemical ventures [Anonymus 2006; Plischke 2007; Runge 2006:130,320] [Runge:204-205,678-679].

The "Bayer Chemical Start-Up Initiative" was an initiative of the Chemiepark operator Bayer Industry Services (BIS). As a joint venture of Bayer AG and Lanxess AG, BIS is manager and operator of the Bayer Chemieparks with sites in Leverkusen, Dormagen and Krefeld-Uerdingen. The emphasis is on firms of the fields of chemistry, material science and life science [Leverkusen 2006].

Not only the Board of polyMaterials believed in a long existence and a prosperous growth of the Leverkusen pilot plant but also Wolfgang Paczenski: The site manager had worked for 25 years at Agfa AG (which was also located in Leverkusen).

For 2007 polyMaterials planned to hire apprentices. And also the core workforce was expected to grow depending on the success of the pilot/demonstration plant. Networking with a new process control and operation program of Bayer Technology Services (BTS) and the Analytics unit of the chemical park operator Bayer Industry Services (BIS) created good conditions [Anonymus 2006].

In 2008 polyMaterials had already 10 employees at the Leverkusen site [Stebani 2008b].

And polyMaterials gained also Bayer as a customer for working up of Baytubes® (carbon nanotubes – CNTs) manufactured by Bayer in Leverkusen [Plischke 2007].

The Bayer Chemical Start-Up Initiative targets cooperation with and across startups (or other firms) to increase innovation through networking along the startups' value chain and the value system (supply chain). Collaboration leads to mutual benefits [Plischke 2007]:

Startups	**Corporations**
• Offer special and sometimes unique expertise • Have specific skills and technologies • Are focused on clearly defined product developments	• Have global networks • Offer various expertise – including access to special services (consulting, analytics, IT, etc.) • Have broad market access and financial resources
Conditions for successful cooperation: • Complementary competencies • Motivated cooperation partners • Win-win situation: trust and executing real partnership	

In the Bayer Leverkusen Chemical Park polyMaterials can use a Technikum as well as research laboratories and has access to product-specific analytical methods as well as a representative office [GründerMagazin 2006]. And there is expertise of highly experienced staff including not only technical competence but especially also safety technology and quality issues.

A demonstration plant, also called market development plant or Technikum in Germany, in the chemical industry is the final link to "scale-up" [Runge:61-63] from laboratory and pilot plant to small scale production and then to large-scale production. In addition, in a market development plant first quantities will be prepared as samples for tests and use by (potential or real) customers.

With the expansion in the Chemiepark it was possible to produce larger quantities or modify material according to request. "With this orientation at the Bayer Chemiepark, the existing fields of synthesis, analysis and polymer processing provide ideal supplements," said Dr. Stebani. For access to special chemical methods in the chemical park there are also available competent network partners [GründerMagazin 2006].

And Bayer units played also an important role for polyMaterials' plan concerning its HTS-project (Figure 20). To overcome cost and reduction of margins as well as the need for speed of R&D and production for users developing compounds had been identified as the key bottleneck (Figure 8, Figure 10, Table 1) for finding new and optimized plastic formulations.

> "Trends driving plastics applications' introduction today include a reduction of the product cycle development time, a demand for lower materials costs (but with improved properties) and the need to stand out from the competition to provide purchaser appeal." [Colvin 2008]

Already in 2000 polyMaterials *planned to expand its offering by introducing the so-called combinatorial chemistry into the field of material development* – at first, under the heading of "rapid prototyping" or Rapid Material Development (RDM). The related method playing already an important role in drug discovery for pharmaceuticals and plant protection is called high throughput screening (HTS). For the plastics field it would allow the synthesis and testing of thousands of combinations of materials within a very short time in order to optimize certain properties [Jopp 2000].

A change in composition in order to improve one physical property also changes many, if not all, other properties as well. The interactions are not well studied, and are generally known only in a very generic way, if at all. Thus, *compound development is largely an empirical process*.

Often satisfactory solutions with reasonable effort can be found as long as the new requirements are within the limits of existing experience. Expanding into new areas outside prior experience requires a huge number of experiments, if done in a systematic way. Examples are adjusting the properties of an existing compound for a new application or replacing a component because of regulatory issues, or integrating new materials, such as biogenic polymers because of customer demand.

HTS-related know-how was used already by the chemical giants BASF and Bayer. In the US Symyx Technologies Inc. in Santa Clara, California had already demonstrated the usefulness of HTS. It was among the first which began with combinatorial chemistry in the field of material development.

In Germany in 1999 a related firm hte AG (High Throughput Experimentation) was founded with much investment and other support by BASF. Ultimately, hte was taken over by BASF [Stichert 2009].

Networking with a new data program of Bayer Technology Services and the analytical unit of the chemical park operator Bayer Industry Services (BIS) created good conditions to proceed toward HTS.

"As early as 2001, Polymaterials added compound development to its range of polymer research services, and a synthesis pilot plant at Bayer Chemiepark, Leverkusen, was established in 2006. The newest addition to polyMaterials' services was a high-speed formulation development service for plastic compounds, which was set up in collaboration with cooperation partners. The service featured a new system concept integrating state-of-the-art injection molding and computer technology." [polyMaterials 2008a]

While combinatorial compounding is based on the idea of combinatorial chemistry used in the pharmaceutical industry, it cannot process millions of samples as is the case in that market. "Experiments still need to be designed and individual components need to be carefully selected," said Dr. Maier. "But our system is still much faster than conventional methods. In one week we can do two or three iterations of a compound development. Using conventional methods this process would take several weeks [Anscombe 2009] (Figure 8).

With the two locations in Kaufbeuren (KF – R&D) and Leverkusen (LEV, production up to some tons per year/R&D) polyMaterials was in a position to present a complete offering of R&D, polymer synthesis, recipe HTS and compounding (samples, specialties), specifically [Stebani 2006]:

R&D-laboratories (up to 2 kg) Mini-plant KF (up to 15 kg per batch) Analytics (standard) Compounds (to 20 kg) Injection molding (test specimens)	Compound HTS including Injection molding (KF) Testing materials (KF)	Monomer synthesis and polymerization (kg, tons level), Many processes for workup, broad experience

Correspondingly the origin of the HTS technology project focusing on compounding was based on the following goal [Maier 2007a; Stebani 2008b; polyMaterials 2010]:

> Create (new) plastics recipes 10-20 times faster!
>
> Design a practical, general-purpose and to the respective mixing task modular customizable developer tool.

If you are 10-20 times faster than the conventional process you are able [Stebani 2008b]:

- to accelerate the development of new specific compounds
- to shorten response time for customer requests
- to allocate present resources more efficiently
- to revise existing product ranges on a cost base to develop new blends from 3 or more polymer classes
- to broaden the applications to new additives and additive systems
- to save all your test data in the included database
- to develop proprietary materials without own research department.

Specifically, key advantages will be [Stebani 2007c]:

- Significantly reducing needed time for a given number of recipes
- Significantly increasing generated data for a given time period
- Distinctly reduced cost (for instance, test at the customer).

The efficiencies of various approaches to run compounding show the clear advantages of an integrated approach.

Isolated	**Automated**	**Integrated**
Too slow	Too costly	
R&D Laboratory Unit: 1,000 compounds per year	R&D Dept., automated: 6,000 compounds per year	HTS Unit: 20,000 compounds per year

The basis for the HTS technology is the hardware-side integration of component dosing with the plasticizing and shaping the plastic mixture in injection molding machines. The generated DIN test specimens are tested by automatic test equipment on their mechanical properties. The complete system is controlled by a software of Bayer Technology Services, which outputs the recipes using statistical design of experiment and get back playing again to evaluate the resulting data from metering, processing and testing [Stebani 2008a].

polyMaterials' combinatorial compounding system (Figure 23) is based on an all-electric injection molding machine with two plasticizing units. Each plasticizing unit has four dosing units giving the system the capability to process as many as eight different materials. The melt streams are homogenized using static mixers, then combined and subsequently remixed using more static mixers. "Many people have expressed doubts about the use of static mixers and an injection molding machine [1] as opposed to a traditional twin-screw extruder for compounding," [2, 3] Dr.Maier said. "But our results are comparable to those obtained from a traditional compounder, even for reactive compounds where the residence time is critical." [Anscombe 2009].

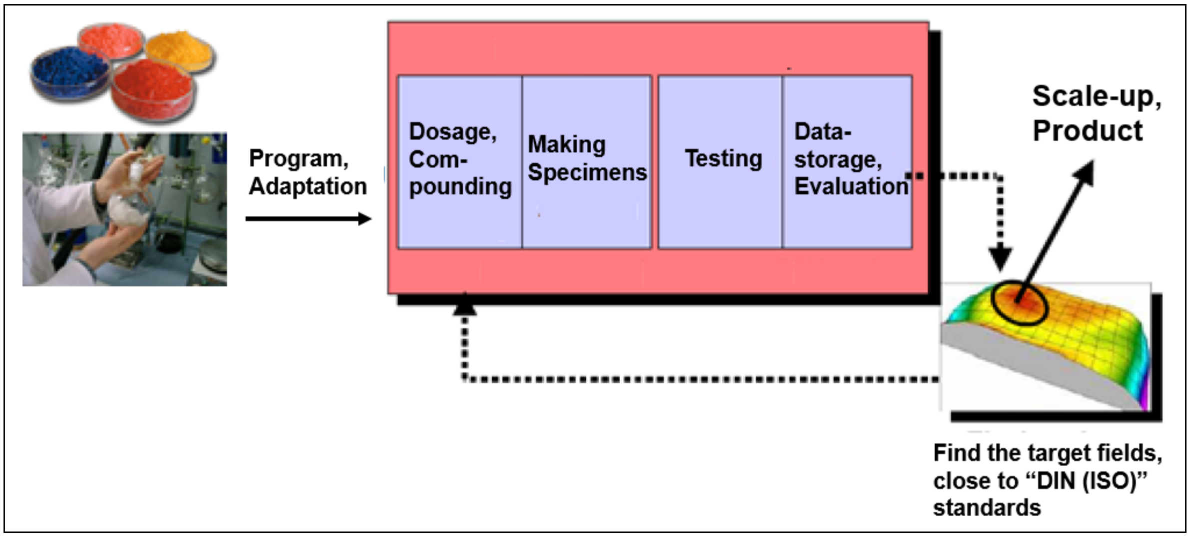


Figure 23: The basic process structure of polyMaterials' HTS technology [Maier [2007a].

The requirements of the project could only be achieved by cooperation of several experienced partner companies which together have the abilities to respond to the requirements given in Figure 23 [Stebani 2008b]:

The following components and corresponding supplier/cooperation partners were interlinked:

- polyMaterials (materials)
- "Product Design Workbench" software package (Bayer Technology Services) for test design and data analysis [4] [Stebani et al. 2006]
- Feeders, Plasticolor series (Woywod Kunststoffmaschinen GmbH & Co. Vertriebs-KG of PLASTICOLOR)
- Fully electric injection molding machine (ENGEL, Schwertberg, Austria)
- E-Motion Combi" (ENGEL, Schwertberg, Austria)
- DIN/ISO test specimen tool (Axxicon GmbH, Stuttgart)
- Automatic testing devices (Zwick Roell, Ulm).

"Cooperation partners Bayer Technology Services (developer of "Product Design Workbench" software for test design and data analysis) [4] and injection molding equipment builder Engel (Schwertberg, Austria) came up with a system, High-Throughput-Screening (HTS), that consists of conventional, marketable components but facilitated quick conversion of results into products. In the previous year Engel revealed its work on the system, an injection molding machine that officials there say can provide samples at a much faster pace than a compound extrusion line can. Woywod

Kunststoffmaschinen HTS allows all steps needed for recipe development starting from test design to production and processing of materials." [Colvin 2008]

The software module estimates in advance possibilities that will not provide particular application answers. "The software determines what experiments one needs to conduct in as little time as possible to get the answers need," said Thomas Mrziglad, from PT-AS-computational solutions, Bayer Technology Services. "From the data generated, one can build a model of unknown recipes of materials and then concentrate on testing these." Maier said HTS could cut specific R&D tests time that previously took one week to a single day [Colvin 2008].

"When we designed the equipment it was important to us that it could produce standard test pieces which could then be used in internationally recognized test procedures," said Dr. Maier. "Our high-throughput screening technique is much faster than conventional methods of compound development and also needs smaller amounts of material." This enables the system to work with experimental materials which are not available in large amounts [Anscombe 2009].

"Customers take advantage only of the elements that are applicable for their operations since HTS is modular," said Stebani [Colvin 2008].

Maier [2007a:20-24], Stebani et al. [2007] and polyMaterials [2010] provide more details of the process.

The project required two years [Stebani 2008b]. The new integration of design of experiments (DoE), feeding, fast polymer processing and automated testing allows the introduction of a completely new compound process chain which is also referred to as HTC (high throughput compounding). The HTC project as an own research project for 2006/2007 was envisioned to be finished in 2007 [Stebani 2006], but the market entry of new technology for compound R&D was in 2008 [Stebani 2014].

The aim was to position the HTS methodology as an ideal complement to existing methods of compound development, to use the customer's existing R&D resources in plastic compounds more efficiently and to open up new recipe variants significantly faster [Stebani 2008a].

At the end of 2007 polyMaterials' spectrum of customers comprised [Stebani 2007a]:

- 29% Chemical industry
- 23% Automotive
- 18% Automotive suppliers
- 21% Medical
- 9% Other.

Customers in Germany accounted for about 75 percent: 20 customers were from Germany, 7 customers from abroad (Figure 24).

The customer base included both renowned large companies and medium-sized enterprises that use the research teams of polyMaterials as external specialists to support their R&D and/or for variabilization of their R&D costs. As a professional R&D services provider polyMaterials worked *project and solution-oriented*.

As the basis of its offerings the 2007 status of the technical infrastructures and related activities of the two branches (KF, LEV) of polyMaterials is described by Stebani [2007a].

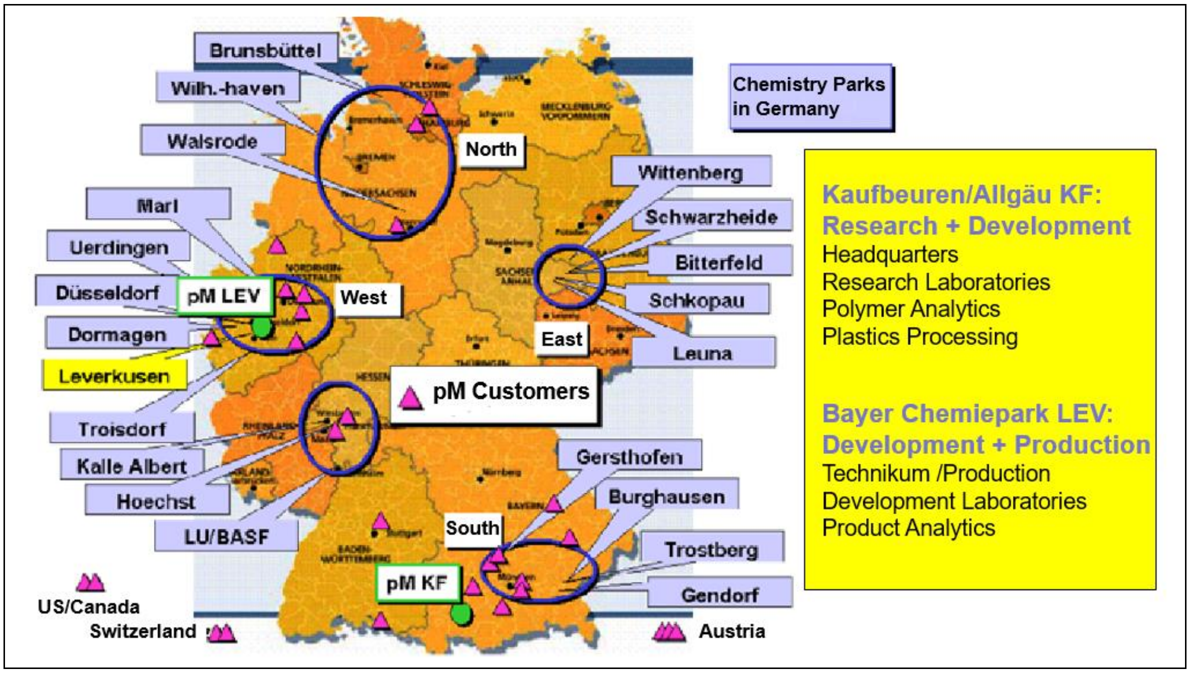


Figure 24: Customer structure of polyMaterials according to countries, locations in Germany and German customers' neighborhoods to chemistry/industry parks **[**Stebani 2007a].

Service Expansion for the Supply Chain Covering Invention to Innovation

The preceding outline described the development of polyMaterials to achieve a status which received little attention or was lacking entirely for three aspects targeting the supply chain.

- Concerning *industrial R&D* covering the whole process chain from the first scientific experiments in the lab to production (grams to tons) and compounds R&D. This represents the industrial innovation process from generating ideas to production of polymeric material.
- Including also *basic (fundamental) research* in universities or publicly financed research institutes as a missing step in a networked technology system: Ideas and inventions, also in terms of patents.
- Covering the complete process chain from the idea to R&D to production, in particular, covers also the *transfer from invention to innovation*, in particular, the transfer of invention in the chemical industry (material sciences) into another industry.

Including these aspects would emphasize the role of polyMaterials as a total external "R&D service provider" and "high-tech-innovation service provider" [Stebani 2007a].

The basis for the related further developments is summarized by Stebani [2008a]. In 1999 there was the environment and opportunity for founding polyMaterials with the clear aim to position itself as *a new, independent provider of R&D and manufacturing services in the field of polymer materials and functional polymers*.

Box 1: Characterizing polyMaterials' status before complementing what has been described so far [Stebani 2008a].

With the range of offerings from searching for material, then development of new polymeric materials or new plastic formulations to the production of specialty polymers by the ton (in the Leverkusen site), the company provided resources to its customers comparable with a corporate research unit, but with flexible structures of a medium-sized company.

In related projects polymer specialist of polyMaterials supported the application experts of customers by chemical expertise, which, via the synergy effects, resulted in faster appropriate and practical solutions than in a purely subject-specific approach ("*collaborative innovation*", Figure 29).

The pace of innovation in the transfer of new materials into application depends primarily on overcoming interfaces. An interface will show up at the latest with the commercial orientation of the materials on a pilot scale.

In an industrial company the use of new materials at competitive costs has highest priority. In such an environment polyMaterials can also play an important role in the transfer of technological and scientific approaches to industrial practice (*reduction of interfaces*). Establishing the scale-up [Runge:61-63] considering specific technological requirements can be offered.

A further issue concerns the development of new formulations based on various components. Generally plastics do not only consist of one material but of a mixture of the material with a number of additives and fillers, but also partly of other plastics, resulting in compounds or blends.

A wealth of experience is necessary to quickly respond to a request for a new application with an appropriate compound. The interfaces in the R&D process result from the serial link of compounding, specimen preparation, testing and evaluation, which usually run with high expenses for personnel in separate processes. Therefore, the development chain is complex, costly and relatively time-consuming.

With an appropriate tool, the "high-throughput-screening" (HTS) system of polyMaterials, a quick overview of achievable recipes and related combinations of properties has been made possible, so that at reasonable cost customers could be provided with a suitable material, to then achieve the innovation cycles and the individuality to keep pace (*fast R&D processes*).

A model of combining basic university research with professional R&D implementation into application as a service was seen by polyMaterials as a trend.

In Figure 25 it is shown how consideration of basic research may open or even require, respectively, a spectrum of more service options for polyMaterials which so far was focused on recipe development to interconnect the raw material industry in search for new businesses with the application industry in search for optimal materials.

This means, there may be a transfer of invention to innovation when basic research is taken into account which also means the appearance of political initiatives and programs to fund related pre-commercial research in universities or public research institutes and options of cooperation or (joint) projects for polyMaterials (Figure 27).

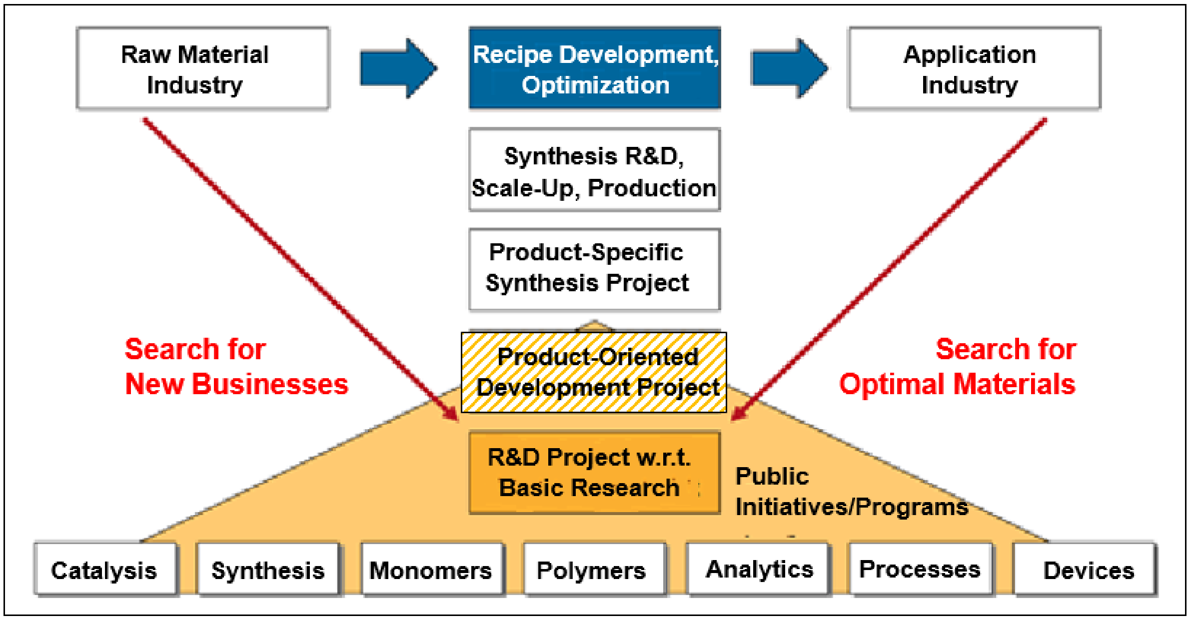


Figure 25: Task: Close the gap between innovation and invention by basic (fundamental) research [Stebani 2007b].

Figure 26 shows how production of a new product with new materials, the horizontal innovation process chain, requires an associated closed vertical process chain based on science to finally produce a new material. Figure 27 re-emphasizes this situation in terms of a corresponding universal innovation and process chain.

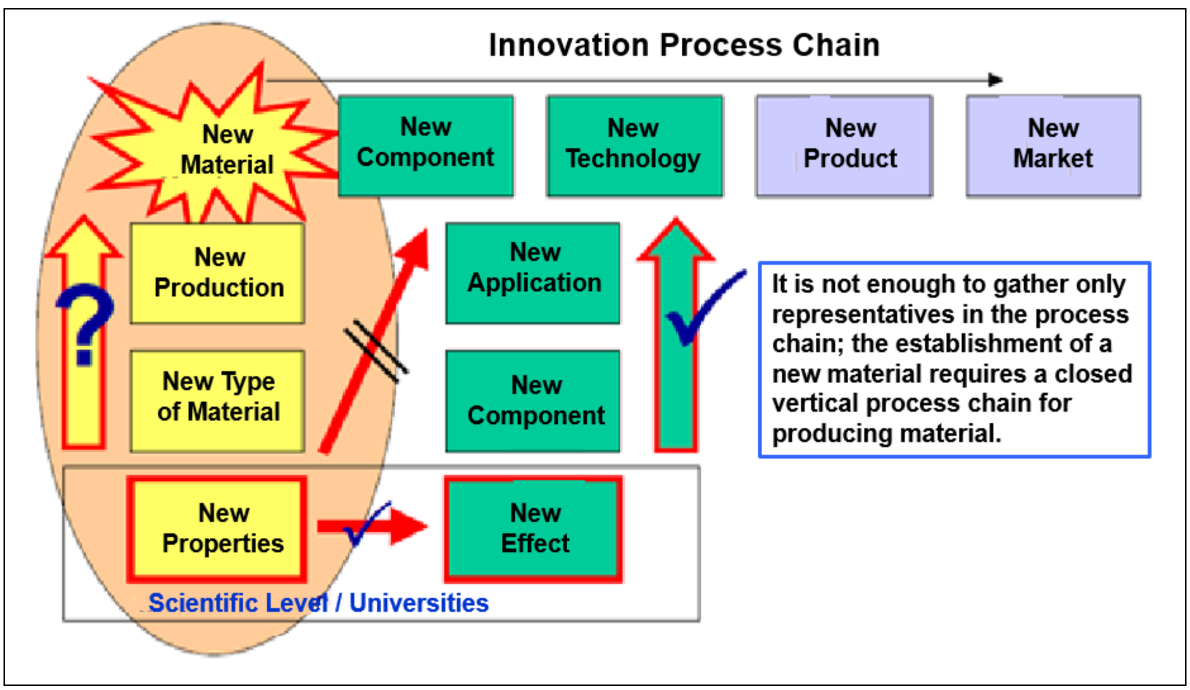


Figure 26: Requirements to close the gap of the innovation chain: chemical industry to other industry [Stebani 2007b].

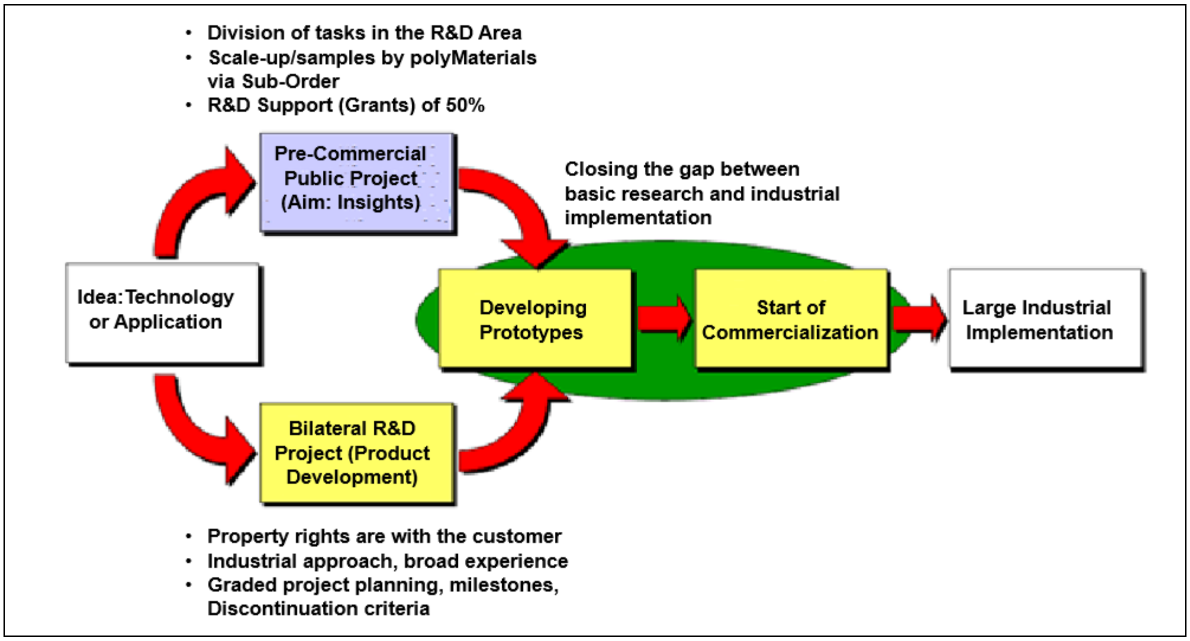


Figure 27: The universal innovation and process chain [Stebani 2007a].

Figure 28 displays the types of services that can be ordered from polyMaterials to initiate a transformation of invention to innovation which may be based on basic research and business idea generation to cover a collaborative product-oriented development project in line with a planned particular device.

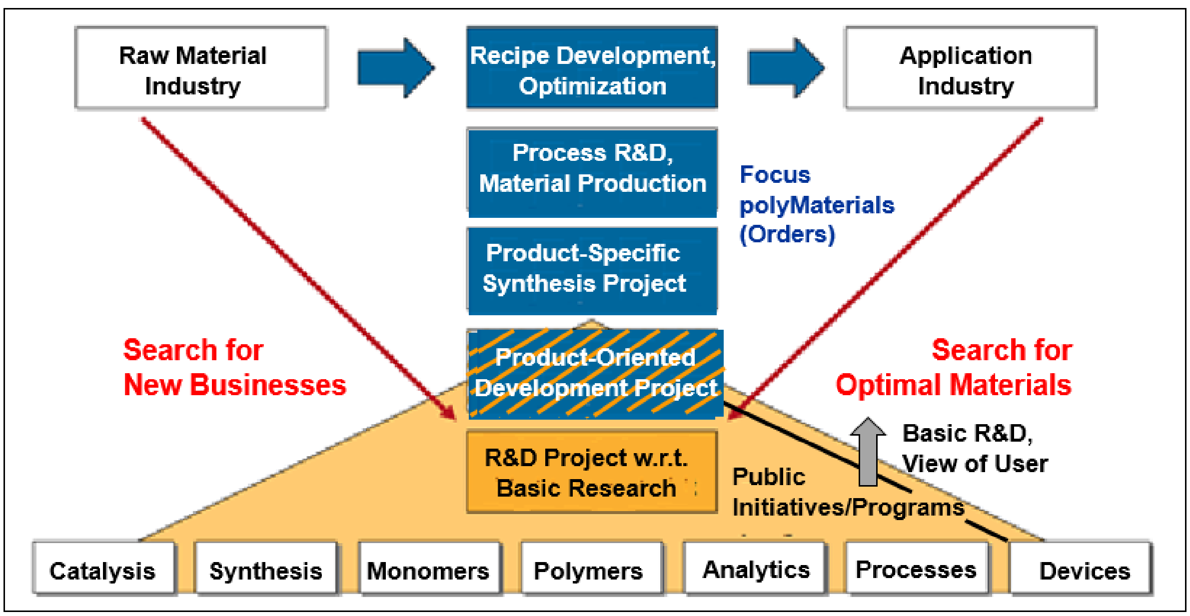


Figure 28: polyMaterials' approach to development and production by order [Stebani 2007b].

In Figure 29 detailed process steps for collaborative innovation are given.

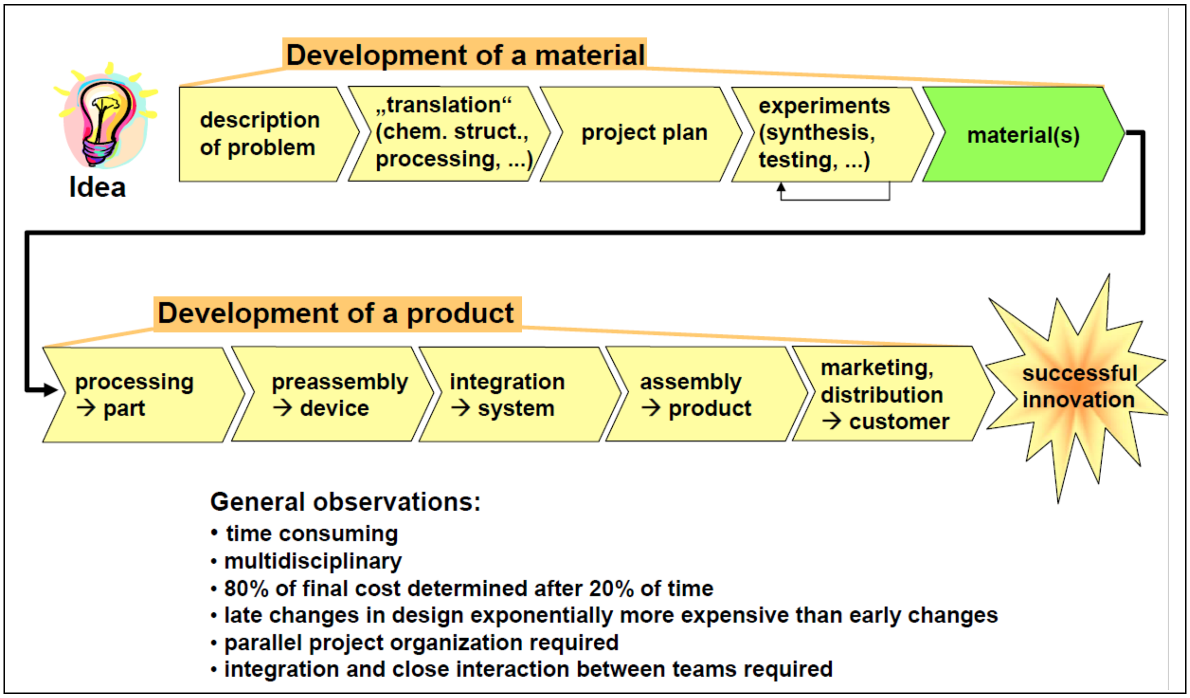


Figure 29: Explicit **d**etails of project steps for collaborative innovation [Maier 2007b].

And in Figure 30 the plastics value system (Figure 4) as seen to include also basic research of universities and public research institutes for collaborative innovation exhibits how polyMaterials is related to the players of the supply chain and lists its offered R&D services and the related activities associated with these services. This shows polyMaterials as an “innovation service provider” focused on the neuralgic points of “theory and practice” as well as “laboratory level and level of a Technikum” – "pilot plant and production scale" [Stebani 2011]

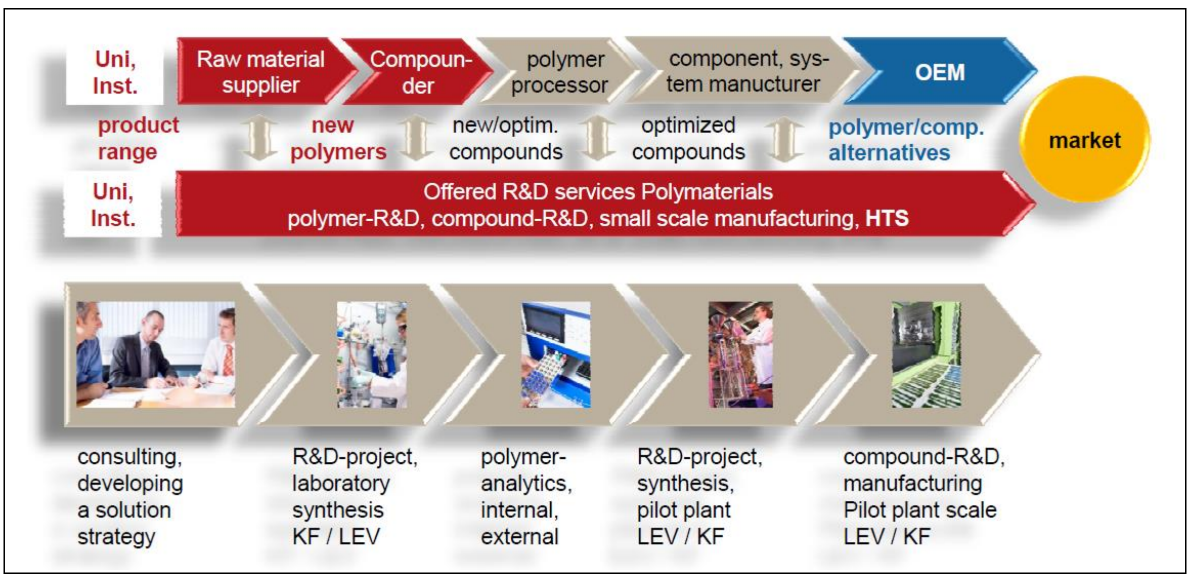


Figure 30: Relevance of a complete process chain for the supply of R&D services: Collaborative Innovation [Stebani 2008b].

Hence, polyMaterials provides an innovation process chain that is typical of big companies. But it positioned itself as a complement to universities and (public) research institutes as a "translator" of scientific approaches into functional products.

Table 2 presents a selected list of polyMaterials' projects which documents a very large variety of themes.

The volume of sales per contract was usually > €100,000 (for 3 months) and project durations encompass usually more than three months (up to seven years) [Stebani 2007c]. And there must be flexibility to manage a "moving target" for longer lasting projects.

Table 2: Selected R&D projects of polyMaterials [Maier 2007b; Stebani 2007a].

Contract Research (Functional and High-Performance Materials): • Fuel cell membranes (PEMFC – automobile, DMFC – I&CT [Runge 2006:327-329, 330-332] *) • High modulus thermoplastics • High temperature adhesion promotors • Materials for optical data storage • Shape-memory polymers • Functional fibers • Thermosets
Contract Research (Compounding): • Additives for laser welding of incompatible plastics • Compounds with improved metal adhesion • In-mold crosslinking materials • Reactive compounding for modifying materials
Proprietary Projects (R&D Methods; Medical Technology): • High throughput screening for thermoplastic materials • Scaffold materials for tissue engineering

*) PEMFC: Polymer Electrolyte Membrane Fuel Cell, DMFC: Direct Methanol Fuel Cell.

Started as an "external R&D-Department" the company has advanced its offerings to become a one-stop service provider in the field of polymer materials.

Financing and Organization

Financing

polyMaterials was founded in August 1999 and officially registered in March 2000 as a stock company (AG – Aktiengesellschaft) [Handelsregister 2007] starting in the Innova Hightech-Park in Kaufbeuren (KF} with five laboratory places and three offices and overall five employees. In 2003 polyMaterials achieved its *breakeven* [Stebani 2014]. It is a wholly owned (100 percent) private company [Stebani 2007c].

Share capital ("Grundkapital") was €50,000. The shares were issued to the amount of EUR 1.00. The founders of the company, who acquired all shares, were: Dr. Gerhard Maier, Munich, Dr. Jürgen Stebani, Krefeld and Dr. Roland Rehmet, Aichach, Of the shares in the company the following proportions were taken: Dr. Gerhard Maier €16,500, Dr. Jürgen Stebani other €16,500, Dr. Roland Rehmet €17,000 [Handelsregister 2007].

In contrast to the situation in many other countries, two separate bodies work together in German stock corporations (“Aktiengesellschaft – AG): a Board of Executive Directors (“Vorstand”) and a Supervisory Board (“Aufsichtsrat”). In Germany the Supervisory Board has often representatives from corporate owners and employees. The board controls the directors and may appoint or dismiss executive directors. The Chairman of the Board of Executive Directors” (“Vorstandsvorsitzender”) has similarities with the Chief Executive Officer (CEO) in the US [Runge 2006:228].

Members of the first Supervisory Board of polyMaterials were: Josef Doser, (Diplom-Betriebswirt FH, MBA), Steingaden; Dr. Winfried Wunderlich (Chemist), Roßdorf; Reinhold Maximilian Pamler (Banker), Vohburg. [Handelsregister 2007].

In 2006 a second location of the startup was established, with a so-called Technikum in the Chempark in Leverkusen (LEV, Germany). Until the end of 2007 polyMaterials sales increased linearly over time [Stebani 2007c]. Its sales was not even affected by the Dot-Com Recession (March 2001–Nov 2001 in the US). The first quarter of 2008 was a record quarter achieved with 38 employees (10 chemists) and in 2008 it opened a representation office in the US (NC) with one PhD [Stebani 2014].

However, in the last quarter of 2008, in line with typical effects of the Great Recession (Dec 2007 – June 2009 in the US), polyMaterials suffered from a dramatic sales slump of ca. 70 percent. This was associated with a strong decrease of research projects in the labs and resulted in a difficult setup of the new fields of activities “Technikum/Compounds”. Only in 2010 polyMaterials became again operatively positive, but then had only 29 employees (7 chemists).

According to Dr. Stebani during his presentation at the KIT in Karlsruhe [Stebani 2011] he explained that no employee was fired; they did not replace positions of employees who left the firm.

A recovery occurred in the period 2009-2014 with an average growth rate of eight percent for this time [Stebani 2014].

The key vehicle for financing polyMaterials was the savings banks (“Sparkassen”) of the Allgäu region (particularly the Kreis- und Stadtsparkasse Kaufbeuren) which provided *loans* and other special kinds of *capital* funding through special funds.

For example, typical conditions of a savings bank could be as follows. Funding was for all investments that must be made as part of a firm’s foundation. The credit allocation policy council (“Vergabe-Beirat”) will examine the startup’s projects, focusing on the "*security of the business idea*" and not the "collateralization". Often the city and county subsidize the interest rate of the loan. Relatedly, the business plan of polyMaterials was honored at a Founder Competition in the Allgäu region and on the country (Bavaria) level.

For 2008, an interest rate was (around) 8 percent per year, but the borrower was only billed 4 percent interest per year as a fixed interest rate. City and County assume the interest subsidy in amount of the difference of say €100,000 incurred during a ten-year term of the loan. This amount is already pre-paid as an annual total to an interest-bearing special account at the Sparkasse.

The risk of default in the amount of half of the loans is with the city and county, the Sparkasse accepts the second half of the default risk.

The interest rate is set at the beginning of each year as a 10-year condition and is subject to the refinancing options for 10-year loans on the capital market.

For a firm’s foundation savings banks of the Allgäu region provided *capital* via their “Risk Fonds” (Risikokapital-Fonds Allgäu GmbH & Co. KG.) – and also for polyMaterials’ foundation in the Innova High Tech Park [All-in.de 2000].

In the Electronic Federal Announcements [EB], for instance, for 2006, it is reported that the Risk Fonds has a *silent participation* [5] of ca. €1,533,875 and debts for a loan of ca. €178.952 with a maturity of under 5 years in both cases. polyMaterials had liabilities of €1,712,827 in 2006 with the savings banks.

Still in 2014 there are liabilities with a maturity less than five years in the amount of €862,328. There are also other liabilities amounting to €793,078 to the savings bank (total €1,655,406).

According to its balance sheets (Table 5) polyMaterials operates essentially without equity (0.0 on the balance sheets), which means negative shareholder equity and negative equity ratio expressed by the thus induced item “Not covered by equity loss” (“Nicht durch Eigenkapital gedeckter Fehlbetrag”). This will be discussed further in the “Key Metrics” chapter.

Participation in various types of publicly funded projects is one way to partially fund research of polyMaterials (cf. next sub-chapter). For instance, this accounted for 3 percent of the 2006 sales (until 7/2006) which means ca. €80,000 per year (text below Table 1) [Stebani 2006].

The development of polyMaterials from foundation until 2014 in terms of revenues and numbers of employees is discussed in a subsequent chapter (Table 4).

Organization

In the R&D area polyMaterials employs (non-polymer) chemists, polymer chemists, engineers and lab technicians [Forum MedTech Pharma].

Apart from Dr. Rehmet who left polyMaterials at the end of 2007 there remained two chemists as executive directors (CEO and CTO) and additionally as employees 8 chemists with a doctoral degree, 20 lab technicians or technical assistants, respectively, and 6 persons in Administration [Stebani 2007b]. Hence, polyMaterials had a high proportion of chemists with a doctoral degree which remained always at ca. 25 percent of all employees (without management) during all its years of existence.

In terms of corporate resources polyMaterials has a Scientific Advisory Board. This enables polyMaterials, next to its own range of skills, specifically tailored to the projects to make use of a very broad technical and scientific know-how in the field of polymer research, analytics, processing and application of special plastics in high technology and relatedly to offer these also via alliances.

Members the Scientific Advisory Board were staffed by renowned scientists from universities, public research institutes and industry [Forum MedTech Pharma]:

Prof. Dr.-Ing. W. Ehrfeld (IMM Mainz, Mikrosystem Technology), Prof. Dr. E. Killmann (TU Munich, polymeric interface), Prof. Dr.-Ing. O. Nuyken (TU München, polymer research), Ms. Prof. Dr. B. Voit (IPF, Institute for Polymer Research, Dresden, polymer research an processing), Dr. W. Wunderlich (Deutsches Kunststoffinstitut Darmstadt, industrial polymer-R&D).

As described above Professor Dr. Oskar Nuyken has been a member of the Scientific Advisory Board since polyMaterials’ foundation in 1999/2000. And also Ms. Prof. Dr. Brigitte Voit is a member since 1999.

She obtained her doctoral degree at the University of Bayreuth (1990) and got her Habilitation in 1996 at the TU Munich. And in so far she may have had contact with Dr. Maier and Dr. Stebani and Dr. Rehmet while being at these two universities.

Ms. Prof. Dr. Brigitte Voit is head of the IPF Institute Macromolecular Chemistry and Managing Director/Chief Scientific Officer (CSO), of the "Leibniz-Institut für Polymerforschung e.V."

Dresden/Germany. She is also member of the Faculty of Natural Sciences/Department of Chemistry at the TU Dresden and heads the Chair of "Organic Chemistry of Polymers'' [IPF].

The IPF is a public research institute which operates independently from the University. Presently, about 370 people (among them 220 scientists including PhD and diploma students) work on different aspects in polymer science.

The above described distribution of employees exhibits the fundamental R&D-orientation of polyMaterials and reflects a functional structure of a research department in a large firm: Management, Administration, Research including Analytics Units and Development including pilot plants and a Technikum for low levels of production to run research fields/projects (with a built-in flexibility to accommodate for changes by ordered projects or priorities) [Stebani 2008].

Figure 31 shows an organizational structure of polyMaterials with business-oriented activities as units of the R&D area.

Dr. Stebani as the CEO, through his responsibility for strategic expansion and identifying opportunities, closely monitors market trends [BIOPRO 2011].

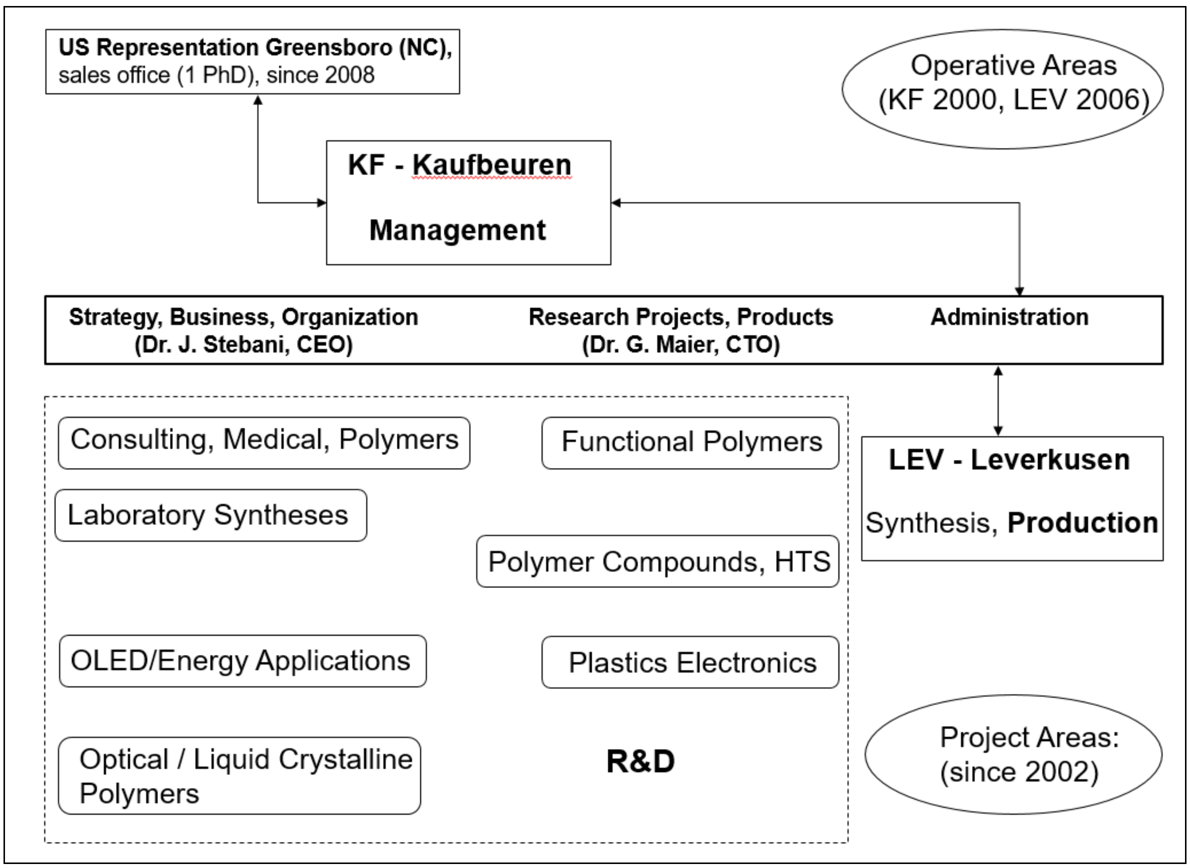


Figure 31: Outlining the organization of polyMaterials at 2007/2008 [polyMaterials 2008a].

Networking and Cooperation

When polyMaterials settled for the firm's foundation in Bavaria (in Kaufbeuren) it was the time when in Bavaria the center of excellence "New Materials North Bavaria" ("Kompetenzzentrum Neue Materialien Nordbayern") was located in the triangle of the cities Bayreuth, Würzburg and Nürnberg and its know-how potential emerged as a pilot and bridge builder for companies which research in the field of light metal, plastics, ceramic or composite material technology for new solutions [Burkhardt 2003].

> That actually opened for polyMaterials a potential for cooperation and a field of potential customers.

In particular, at the University of Bayreuth under the heading “Polymer Engineering“ there is scientific and practical research and teaching in the field of polymer materials. And at three locations there is a cooperative focus on material, construction and production, with the aim to develop high performance plastic products: The department of Polymer Engineering at the University of Bayreuth, the business area of plastics at the New Materials Bayreuth GmbH and the department of Polymer Engineering at the TuTech Innovation GmbH in Hamburg are linked under the guidance of Prof. Dr.-Ing. Altstädt [Polymer Engineering 2013]. This represents a further option for polyMaterials concerning advice and networking.

Since its start polyMaterials *focused its services on high-growth areas*, such as medicine and biotechnology, sensors and microsystems. To establish related contacts polyMaterials became early a member of the network “Interessengemeinschaft zur Verbreitung von Anwendungen der Mikrostrukturtechniken” in Dortmund (IVAM, Interest Group for the Promotion of Applications of Microstructure Techniques). "The production of small and very small components fails again and again due to a lack of materials," said the Project Manager at IVAM [Jopp 2000].

Generally polyMaterials is active primarily in projects in which it is acting as an R&D service provider to make money or to those whose subject relates to polyMaterials’ own projects providing preferentially some grants to the company (Figure 20).

As polyMaterials works on own R&D projects it is quite natural that it participates as a partner in relevant projects funded by various organizations based on corresponding networks. Figure 32 shows the network constellation in a networked economy [Runge:106-107,206-207,678-679] from the perspective of an R&D service provider running also its own R&D projects.

polyMaterials usually operates on its own account in internal projects with external partners in fields, which may offer a particularly interesting possibility for *uniqueness in R&D services or polymeric materials*.

“R&D is vital for us, it is our business!” Projects are initiated by polyMaterials’ customers, who own all intellectual properties (IPs). Publicly funded R&D projects are of interest if they are attractive to the customers and allow polyMaterials to participate under a subcontract [Maier 2007b].

Often related projects have the characteristics of joint projects (“Verbund Projekte”) [Runge:180-181,779,1029-1030] operating in a pre-commercial, pre-competitive environment comprising participants representing a supply chain or a part of it (Figure 27).

Such R&D projects are usually funded by national Federal Governments or Governments of Federal States or supra-national organizations (for instance, the EU). Furthermore, there is a number of public or private foundations which may serve with grants.

Apart from the various federal or state ministries in Germany there is on the federal level the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation comparable with the US National Science Foundation (NSF)) focusing on supporting pure science and basic research. And there is also the Deutsche Bundesstiftung Umwelt (DBU, German Federal Environmental Foundation), one of the largest foundations in Europe supporting innovative projects concerning environmental protection.

On the federal states' level, notable here for polyMaterials in Bavaria, there is the Bayerische Forschungsstiftung (BFS, Bavarian Research Foundation) and several governmentally supported programs and initiatives targeting particular topics, such as new materials or medical technologies. Further support may also be, for instance, via special centers of excellence.

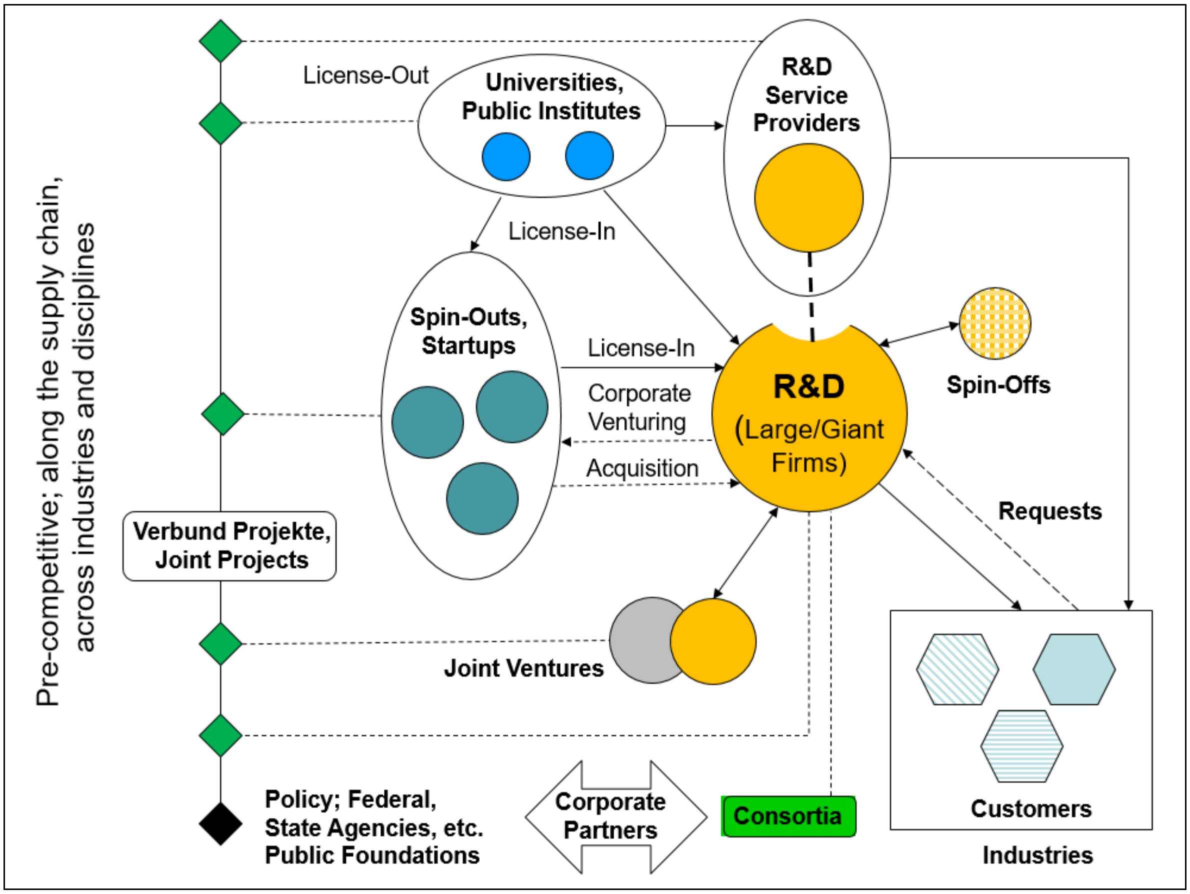


Figure 32: Network constellation in a networked economy from the perspective of an R&D service provider (Spin-out *versus* spin-off [Runge:13]).

The science/research orientation and related projects of polyMaterials is reflected by Dr. Maier. For instance, when he published an overview on "*Sulfonated Aromatic Polymers for Fuel Cell Membranes"* in *cooperation* with Dr. Jochen Meier-Haack [Maier and Meier-Haack 2008]. Polymers for fuel cell membranes is one of polyMaterials' R&D projects (Table 2).

Dr. Meier-Haack is scientist in the Department Reactive Processing leading the Membrane Group of the IPF. IPF is one of the largest polymer research institutions in Germany. And this shows also the importance how the Scientific Advisory Board can be utilized by a startup: IPF is the Leibniz Institute of Polymer Research, Dresden, led by Ms. Prof. B. Voit [IPF], the Scientific Director of IPF and a member of the Scientific Advisory Board of polyMaterials.

And later, the research-orientation of polyMaterials is also reflected when Dr. Maier published scientific results of publicly financed projects with cooperation partners, for instance,

> Eyrich D, *Wiese H, Maier* G, Skodacek D, Appel B, Sarhan H, Tessmar J, *Staudenmaier R*, Wenzel M, *Goepferich A, Blunk T*. *In vitro and in vivo cartilage engineering using a combination of chondrocyte-seeded long-term stable fibrin gels and polycaprolactone-based polyurethane scaffolds*. Tissue Engineering 13, 2207-2218 (2007).

> Eyrich D, Brandl F, Appel B, *Wiese H, Maier G*, Wenzel M, *Staudenmaier R, Goepferich A, Blunk T. Long-term stable fibrin gels for cartilage engineering*. Biomaterials 28, 55-65 (2007)

The names given above in italics represent persons with which polyMaterials pursued several publicly financed projects (described below). And this emphasizes that continuous cooperation is based on stable interpersonal relationships.

> After 2002 polyMaterials was always active in one or several projects per year, often funded by the Bayerische Forschungsstiftung (BFS) and often together with the same persons or organizations/firms, respectively.

At the time of foundation Dr. Maier received financial support for a research project "Synthesis and characterization of thermoplastic elastomers with soft segments derived from natural rubber oligomers having end functions" by the German Research Foundation (DFG, duration: 1999-2000) when the applicant already referred to his affiliation to "polyMaterials – creative polymer technologies" [Maier 2000].

Some selected prototypical examples for networking and cooperation shall be given; a timetable referring essentially to cooperation partners in publicly financed projects or joint projects, respectively, is presented by the company [polyMaterial – Kooperationspartner]

In 2001 the Bayerische Forschungsstiftung provided financial support for a project of three partners located in Bavaria dealing with intraocular lenses (IOL). Globally about 8 million intraocular lenses were implanted annually for correcting refraction after cataract extraction [Bayerische Forschungsstiftung 2002].

Regardless of the type of IOL used the eye loses its capability of accommodation on replacement of the natural lens. Through the project the disadvantage of the lack of accommodative capacity when using conventional IOLs should be lifted by a novel IOL developed by the applicants.

In producing this new IOL, the injection molding process was promoted to have major advantages over other manufacturing processes. To realize this method-specific advantages, however, a suitable material was required, which should be developed as part of the research project with partners.

This project had already typical features of a joint project along a process chain:

- As suitable polymer systems copolymers of acrylate and methacrylate monomers were considered as the basis. In order to determine the achievable property spectrum with these polymer systems polymers were synthesized on a laboratory scale by *polyMaterials* (Kaufbeuren).
- After characterizing the structure-property relationships at the *Department of Polymer Materials of the University of Erlangen* suitable polymer materials were selected and optimized for use as IOL material.
- In parallel, at the firm *HumanOptics AG* (Erlangen) processing technology to produce functional prototypes was developed and qualified according to standard materials. Once available suitable polymer materials for injection molding for the production of IOLs, the scope of processing with the developed processing technology would be identified and a working model of the new IOL produced.
- Finally, biocompatibility studies were carried out on the new IOL to evaluate the suitability of the material, the processing method and the process parameters for the production of long-term implants.

HumanOptics develops, produces and distributes innovative implants for ophthalmology. In July 2002 HumanOptics received the German Founders' Award ("Deutscher Gründerpreis") [Runge:572-573] in the category "Climber" ("Aufsteiger").

From 2004 to 2007 polyMaterials worked in cooperation with the company AcriTec and the University of Regensburg in a collaborative project to develop a cell-based vitreous equivalent for the treatment of vitreoretinal disorders [Bayerische Forschungsstiftung 2005].

Involved people and organizations of the project were: Prof. Dr. Achim Göpferich, Dr. Torsten Blunk (University of Regensburg, Department of Pharmaceutical Technology, University of Regensburg, Clinic of Ophthalmology), AcriTec GmbH and polyMaterials AG.

A project "process optimization for pairings of material for plastic welding with laser radiation" was supported by the Federal Ministry of Education and Research (BMBF, Project-No. 03N3116C (DKI 7834, duration 20030701 until 20060631) [Hellmann 2006].

The known incompatibility of most plastics results usually in little or non-adherent joints when welding dissimilar pairs of plastics. The problems of this project were tackled comprehensively by several companies and institutes (polyMaterials AG, Robert Bosch GmbH, Degussa AG (now Evonik Industries), BASF AG, Huf Tools GmbH, Treffert GmbH, Fraunhofer Institute for Laser Technology – ILT), DKI.

A major focus was the development of methods. Another focus was on the modification of plastics, whose transparency is lowered by crystallinity and by pigments or fillers, such as glass fibers or glass spheres. The approach of polyMaterials was to use customized block and graft copolymers which, as phase mediators, can themselves lay in the interface, where they can interconnect the to be joined surfaces. In some cases this was successful [Hellmann 2006].

For the period 2002-2005 polyMaterials was involved in the large project ForTEPro – Bavarian Research Association for Tissue Engineering and Rapid Prototyping (Figure 18, Figure 20) [ForTEPro 2002].

Tissue engineering is a *multidisciplinary approach* to the generation of living tissue *in vitro and in vivo* that offers new solutions for the treatment of tissue and organ loss. A frequently applied strategy involves biodegradable polymeric scaffolds that function as cell carriers in which the tissue develops.

The Bavarian Research Foundation supported the research network for "Tissue Engineering and Rapid Prototyping (ForTEPro)" over three years with €3 million. It involved 31 partners from industry and research. The 13 participating industrial partners financed the joint project additionally with €3 million. For instance, the subsidy for the public Friedrich-Baur- Forschungsinstitut für Biomaterialien (FBI) at Bayreuth amounted to estimated €300,000 over 3 years. ForTEPro comprised six subprojects [Wodal 2003].

ForTEPro was developing high-strength implants populated with autologous cells and individually customized for large bone and cartilage defects of the skull and locomotor system. The implants consist of three-dimensionally structured, absorbable support-scaffolds, which are fabricated by the medical rapid prototyping (RP) methods to receive a perfect fit. The scaffolds are seeded with autologous cells (such as bone marrow stem cells, cartilage or connective tissue cells) and, on this basis, they form new, natural tissue (tissue engineering).

Innovative scan technologies (3D ultrasound, holography) and mathematical methods of modelling and simulation enabled individual shaping of these implants. Such implants do not cause infection and have a minimum risk of graft rejection and, above all, have immediate mechanical strength. After a period of time, they are transformed entirely into autologous tissue (Figure 18).

The objectives of ForTePro were the development of new process technologies and implant prototypes so that small and medium-sized companies will be able in future to manufacture custom bio-implants quickly and economically. The following universities, institutes and hospitals participated in ForTePro: the Technical University of Munich, the Ludwig Maximilian University of Munich (LMU), the University of Bayreuth, the University of Regensburg, FORWISS Passau, the major European research center caesar (Center of Advanced European Studies and Research) in Bonn as well as 13 SMEs as industrial partners. The University Hospital in Basle/Switzerland was the international cooperation partner.

The development that was begun as part of “ForTEPro”, was continued by the project “RegImplant”. Both were sponsored by the Bavarian Research Foundation (BFS).

In ForTEPro polyMaterials was involved several times. It developed biocompatible binders for the direct installation of support structure, by which biocompatible ceramics, such as hydroxyapatite or calcium phosphate, may be joined by a 3D printing process to carriers for bone cells. In addition, a completely open-cell foam was developed that is cell compatible and is metabolized in the body to harmless degradation products (Figure 17). It was used in an indirect method. This means that the patient-specific forms were made with another rapid prototyping process of a project partner [polyMaterials 2004].

In particular, the aim of the project “Regenerative implants for the musculoskeletal system” (duration: 03/2006 - 02/2009) was the *in vivo* study and application of individual implants for the replacement of bone tissue and cartilage as well as the combination of both.

The newly developed materials, based on polymers and inductive matrix (for instance, 3D printed calcium phosphate scaffolds), was biologically tested for an appropriate support structure and appropriate methods of cell seeding. The final objective was to improve animal testing to the extent that a clinical trial for the treatment of patients and thus the resulting marketing can be prepared [Spath 2009; Stebani 2007c; polyMaterials 2008].

Associated participants were:

- Project director: Experimental Surgery and Regenerative Medicine, Surgical Clinic of LMU Munich
- Ear–Nose–Throat clinic and outpatient clinic, TU München
- Department of Pharmaceutical Technology, University of Regensburg
- Friedrich-Baur-Forschungsinstitut für Biomaterialien gGmbH (FBI) at the University of Bayreuth
- Hightech-Forschungs-Zentrum, TU München
- polyMaterials AG, Kaufbeuren
- PreSens – Precision Sensing GmbH, Regensburg
- Tutogen Medical GmbH, Neunkirchen
- KL Technik GmbH, Krailing (RP service provider).

With a focus on tissue engineering of cartilage tissue to reconstruct a pinna (Figure 18) Blunk and Göpferich [2004] from the Department of Pharmaceutical Technology, University of Regensburg (Germany) as well as polyMaterials and R. Staudenmaier from the Ear–Nose–Throat Clinic of the TU München and his outpatient clinic were involved [Stebani 2006].

Prof. Staudenmayer is an award-winning specialist in Otorhinolaryngology (the study of diseases of the ear, nose, and throat) with a focus on plastic surgery. He is a renowned expert on rhinoplasty (plastic surgery performed on the nose) as for the function of the inner nose. Since 2010 Dr. Staudenmaier is a professor at the Technical University of Munich.

In summer 2010 the agency of Economic Development of the town of Leverkusen (Wirtschafts-förderung Leverkusen) and CHEMPARK helped founding the network Innovative Materials in Leverkusen with a representative of polyMaterials' Leverkusen site as its Speaker. The aim was, through networking and cooperation, to help innovative ideas to break through and to develop them quickly and efficiently into marketable products. The network appeared in the public in 2010 with a common pavilion during the International Fair Plastic and Rubber 2010 (K 2010) [Leverkusen 2010]. The roots of the Netzwerk Innovative Werkstoffe e.V. was the CHEMPARK Start-Up Initiative (mentioned above) [Leverkusen 2010; Knauer 2010].

polyMaterials is also a member of the "National Platform for Electromobility", which was established in May 2010 on the instigation of the German Chancellor Angela Merkel. The platform's goal is to become the leading international market for electromobility by 2020. polyMaterials AG is one of six chemical companies that participate in the platform [BIOPRO 2011].

During K 2010 polyMaterials and Rough Coating Design (RCD) from Düsseldorf met to discuss production of novel crosslinkers which are used *inter alia* in environmentally friendly powder coatings, in order to reduce the curing temperature (low-temperature powder coatings) or to generate a "matt effect" in UV-based powder coatings. This resulted in a project to develop in Leverkusen a method for the industrial production from the laboratory process.

Another project aimed to combine the expertise for formulation development of new materials with a machine developer, the company ENTEX Rust & Mitschke GmbH. Also Harald Rust, CEO of ENTEX was convinced of the concept: "Our planetary roller extruder (PRE) is often compared with a twin-screw, but it can do much more. With polyMaterials we have found a partner who contributes the chemical expertise to use such extruders as a 'chemical reactor'." First results were shown to visitors of the fair. Already for 2011, the companies expected to build a corresponding production plant in Leverkusen. Thus a new era would begin for polyMaterials. [Leverkusen 2010; Knauer 2010].

> An important basis for the successful use of the PRE in the polymer production was established by the co-operation of the machine manufacturer ENTEX and polyMaterials, which exists since 2011. "In this framework the development of a procedure for the production and processing of a new polymer for a customer started. Then the aim was to release a prepolymer of solvent in a PRE and then after a thermally induced consecutive reaction to pelletize. At that time the prepolymer was still produced in a conventional batch reactor." [ENTEX 2015].

"In the meantime we made a significant step forward", explained Dr. Stebani of polyMaterials. Now also monomers can be implemented in the PRE in the technical center of polyMaterials in CHEMPARK Leverkusen whereas polymers occur due to a so-called reactive extrusion. Thus, for example, the polyaddition of multivalent isocyanate- and alcohol components provide polyurethanes [ENTEX 2015].

The continuous reaction in the PRE under precise temperature control with dwell times of up to ten minutes is well reproducible and can already be executed experimentally on a pilot scale. Polymerizations or polycondensations are conceivable as well. Stebani reported: "The PRE has already proved its worth in first fields of application for the execution of polymer-chemical reactions. Our next milestone will be, in response to customer demand, the construction of a production line for special polymers with an annual capacity of several hundred tons, the heart of which will be also a PRE."

The planetary roller extruder (PRE) of ENTEX means: Polymerizations with compounding and "reactive compounding" with high throughput with very precise temperature control and mild material processing.

From 2008 to 2011 polyMaterials worked in a large Bavarian joint project FORZEBRA with numerous partners from industry, clinical practice and research on materials for the cell-based regeneration of the musculoskeletal system in old age. The molecular causes of degenerative diseases were researched to create new models for the validation of therapeutic options in the field of regenerative medicine (FORZEBRA [Bayerische Forschungsstiftung 2012]).

From 2010 to 2012, there was cooperation of the company with LivImplant, PreSens and the Hospital of the Ludwig-Maximilian University of Munich (LMU) on a project for the optimization of thermo-reversible hydrogels for regenerative treatment of bone fractures (Smart Gels [Bayerische Forschungsstiftung 2012]).

Since February 2013 polyMaterials works in a large Bavarian joint project FORMOsA with numerous partners from industry, clinical practice and research on materials for regenerative therapies for muscular dystrophy and osteoporosis [Bayerische Forschungsstiftung 2012].

Since September 2012, polyMaterials worked with the company Aesculap AG and Aldevron GmbH as well as the Natural and Medical Sciences Institute at the University of Tübingen (NMI) and the University Clinic of Tübingen on the surface modification of vascular implants. The project "VascuTrap" was funded by the Federal Ministry of Education and Research (BMBF, project-no. 13N11679 – 13N11681). The total volume of this project was €1.289 million over three years [BMBF 2012].

Millions of patients worldwide suffer from coronary arterial diseases and in the USA alone 1.5 million bypass operations are carried out per year to treat these diseases. Many patients require synthetic bypasses, the materials of which are, however, thrombogenic leading to premature blockages. The overall goal of this VascuTrap project was to generate long-lasting synthetic blood vessel bypasses for patients suffering from coronary arterial diseases, but also as improvements for treatment of blockages in the aorta or in peripheral arteries. The idea was to coat these synthetic vessels with patient´s own endothelial progenitor cells (EPCs; "Gefäßvorläuferzellen"), *in vivo* to avoid premature blockages and thereby prolong the life-span of these synthetic vessels.

This has tremendous potential for developing more efficient forms of graft for coronary arterial diseases sufferers as the number of renewed surgical interventions will be reduced. Currently used systems have to be replaced after ca. five years.

Since 2011 polyMaterials worked with the company KL-Technik GmbH & Co. KG – Rapid Prototyping and PreSens Precision Sensing GmbH and the Universities of Würzburg (University Clinic) and Munich (Clinic and Department of Oto-Rhino-Laryngology) on a project for vascularization of adipose tissue constructs for reconstructive surgery. Project leader was Prof. Dr. Torsten Blunk [Blunk 2011].

The project made use of the research joint project ForTEPro and the project "RegImplant" which established cooperation between scientists from hospitals, basic research and industry. The results arising from the project were to provide specific perspectives for the clinical use of a soft-tissue replacement and a more advanced marketing.

Through tissue engineering adipose living transplants for reconstructive surgery were developed. The adequate blood supply to the new tissue plays a decisive role for the success of therapy. In reconstructive and plastic surgery there is an ever growing demand for suitable transplants to treat soft tissue defects successfully (for example, after tumor resection in breast cancer).

The research project was the development of novel approaches for vascularization of adipose tissue constructs which is a prerequisite for clinical application. To achieve this aim innovative strategies for pre-cultivation ("Vorkultivierungsstrategien") will be combined in 3D cell culture with optimized transplantation techniques for vascular supply.

polyMaterials participated also in EU-projects, for instance, one under the heading 2020Horizon. Here, with 10 participants from various European countries, the focus was, in particular, on carbon nanotubes (CNTs) and an "initial training network for the tailored supply-chain development of the mechanical and electrical properties of CNT-filled composites." German participants included The Fraunhofer Society, Bayer Technology Services GmbH and polyMaterials [2020HORIZON 2009].

The project duration was from 2009-10-01 to 2014-03-31 with a total cost of €3,477,181 (EU contribution: €3,477,181). The EU contribution to polyMaterials was €89,032.9.

The EU was directing intensive research efforts into nanotechnology. Carbon nanotubes (CNTs), with the electrical conductivity of copper and an E-modulus ten times greater than steel, were seen as one of the most promising developments, enabling the creation of materials with revolutionary characteristics. According to the EU the commercial potential is huge, but only a fraction of the possible applications have reached the market. Correspondingly collaboration is promoted between academia and industry, so that processes developed on a laboratory scale can be scaled up for industrial application.

Correspondingly the Marie Curie initial training network CONTACT aimed to overcome recognized limitations in the state of the art, including the production methods of CNTs, the adjustment of CNT surface properties and the production of CNT dispersions in thermosets and thermoplastics.

However, in the mid of 2013 Bayer MaterialScience (BMS) announced to exit the CNT business and close its production plant. Key applications were considered to be conductive plastics and structural composites. According to the CEO of Bayer MaterialScience (BMS) "It has been found, however, that the potential areas of application that once seemed promising from a technical standpoint are currently either very fragmented or have few overlaps with the company's core products and their application spectrum." BMS invested at least $30 million in its *multi-walled carbon nanotube* ramp up at its headquarter factory site in Leverkusen, Germany [Smock 2013].

And one year later, after concluding its research work on carbon nanotubes (CNT) and graphenes, Bayer MaterialScience was divesting itself of fundamental intellectual property in this field. The company FutureCarbon GmbH, based in Bayreuth and one of the partners from the Inno.CNT development competence network [Runge:179], as a leading provider of carbon-based composites will acquire the bulk of the corresponding patents from the past ten years [SpecialChem 2014].

On the other hand, the use of *single-walled carbon nanotubes* as one of the components seems to be more successful for polymer composites [OCSiAl]. Already according to a 2004 report from Business Communications Company (Norwalk, CT), the total worldwide market for polymer nanocomposites reached 11,100 tons, valued at $90.8 million in 2003, while growth of 18.4 percent per annum forecast through to 2008 would more than double the size of the market in five years [Editors 2005].

According to a recent MARKETSandMARKETS [2015] study the polymer nanocomposites market in terms of value is expected to reach above $5,100 million by 2020, growing at a significant CAGR from 2014 to 2019.

Nanocomposites can be classified on the basis of product type, such as carbon nanotube, graphene, metal oxide, nanofiber, nanoclay and others. According to [OCSiAl] currently the share of nanocomposites produced by using carbon nanotubes does not exceed 10 percent. However, in the next 5 years the consumption of carbon nanotubes for the production of nanocomposite materials will significantly increase in volume.

Following this last line polyMaterials seems to follow these developments as seen from a patent application (patent No. 1 in Table 7 (Appendix) and a recent scientific publication [Oliveira et al. 2016] which deals with long-range networks of dispersed and interconnected multi-walled carbon nanotubes in polystyrene nanocomposites prepared by melt-blending strategies based on melt extrusion and injection molding.

Over all, contract research (Figure 30) may appear as a reasonable kind of *cooperation* or collaborative innovation [Stebani 2008b], in particular, if there is the “customer as the innovator” [Runge 2015c] with the following features:

- Very clear position (customer – contractor), simple IP-sharing rules
- Business model as an experienced innovation partner
- No interface problems: access to all relevant resources in-house
- Industrial partner: no complication from obligation to publish results in bridging function between academic research and industrial application
- Customers benefit from results (patents); polyMaterials benefits from financial support.

According to Maier and Schieker [2010] *ideal R&D joint projects* have the following characteristics:

- Interdisciplinary issues often arise by "moving targets": the importance of individual aspects can often be assessed correctly only during work
- Interdisciplinary joint efforts enable the successful use of even the most complex topics
- Flexibility of partners allows the successful tracking of "moving targets"
- Suggestions may not be allowed to be just postponed because they are currently not a core issue
- Science and industry both benefit from a close interaction.

They easily open the options to follow a “translational research” approach. In translational research basic research gives input to a development, but considerations of practical problems inform what questions basic scientists should look at. Ideally, it goes back and forth.

Hence, exploiting synergies through networking and cooperation may help innovative ideas to break through and to develop them quickly and efficiently into marketable products. And related public funds and grants may help financing R&D of research-based startups or following own projects with which no revenue can be generated so far.

polyMaterials is now a member of the Cluster Neue Werkstoffe (CNW; Cluster New Materials) organized and managed by Bayern Innovativ GmbH, which is the Bavarian information and communication platform for advanced materials [Bayern-Innovativ].

The Impact of the Great Recession and Slow Recovery

In 2009 effects of the Great Recession hit polyMaterials seriously and this started already in the last quarter (Q4) of 2008 [Stebani 2014]:

- In Q4 of 2008 polyMaterials encountered a record slump in sales of 70 percent.
- After Q4 of 2008 polyMaterials encountered a serious decline of research projects in the labs and simultaneously a difficult set up of the new areas Technikum/compounds.

The effect of the Great Recession can be seen, for instance, by a chart of the Polymer Group showing that the amount of produced compounds decreased from 170 ktons per year in 2008 to 142 ktons per year in 2009 [Polymer-Gruppe].

Irrespectively of a tough business situation polyMaterials as an R&D service provider succeeded in achieving an average growth per year of 8 percent for the period 2009-2014. In 2010 it became again operatively positive with 29 employees (7 chemists with a doctorate) [Stebani 2010].

And the sales office in the US (Polymaterials Corp. Greensboro, North Carolina) still seems to be active (with Michael Hunt being responsible for developing new clients for research & development and toll manufacturing services; November 2008 – Present (7 years 6 months)) [LinkedIn].

Apart from the economic troubles there were also issues with acceptance of service providers for innovation. An investigation in 2007 [Stebani 2007c] of the relevance of external sources for innovation, such as networks or service providers, indicated that these are *used* to a low extent or not at all by 66 percent (Figure 33).

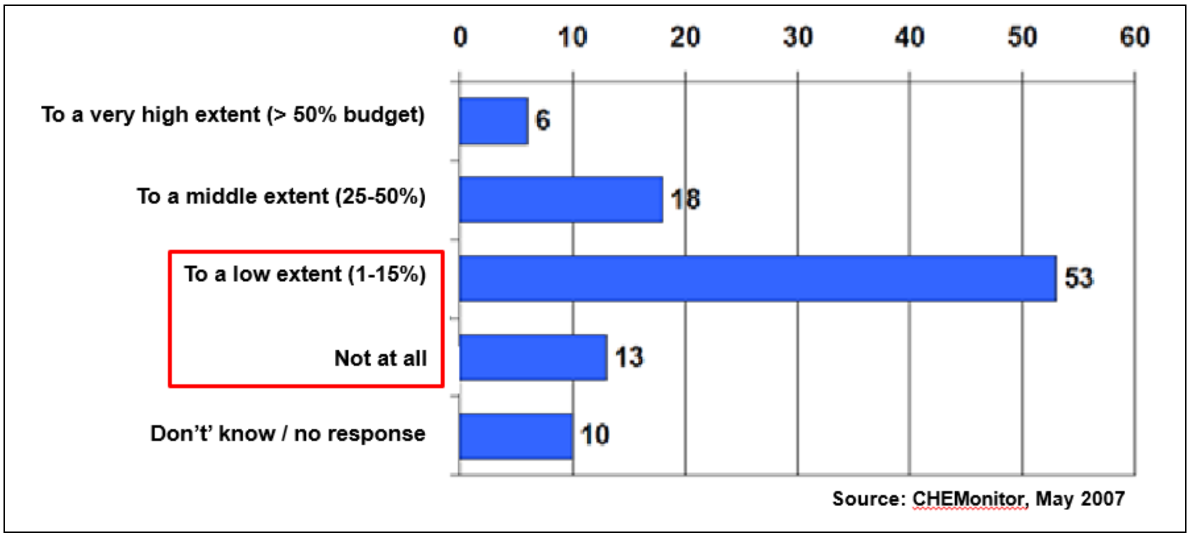
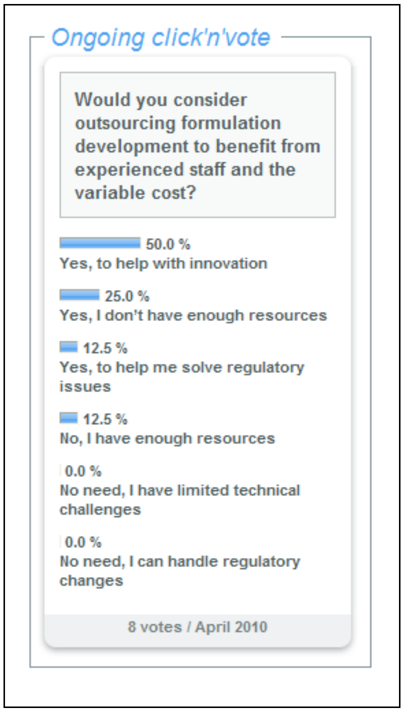


Figure 33: To which extent do companies use external sources for innovation, such as networks or service providers? [Stebani 2007c]

This is quite different, if such an investigation focuses on *consideration of using* rather than *actually using* external sources for innovation (formulation development or resin/binder development). The results of such a study would reflect reasons for consideration.



The entry into this topic was an ongoing click'n'vote with six predetermined answers for the Specialchem4coatings community. Later 1st Source Research was exploring the matter further in concert with SpecialChem4Coatings.

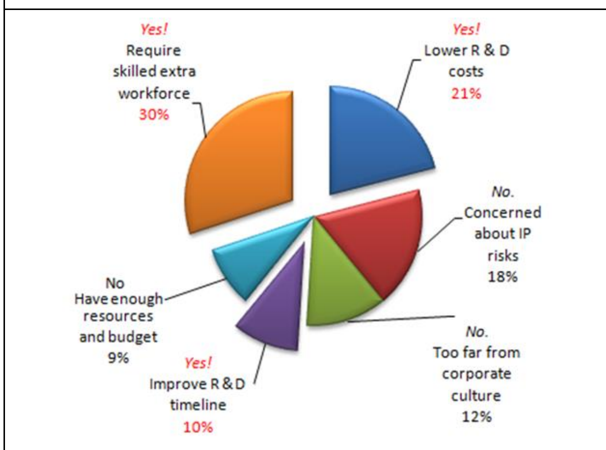
Formulation development was the first aspect of outsourcing that was investigated. But also a second aspect of outsourcing, the needs for resin/binder development, was tackled.

The results (Figure 34, left chart) indicate that nearly 70 percent of individuals surveyed would consider outsourcing support in formulation development. However, this does not tell how many of these, after fully assessing the outsourcing option, would really demand the service.

In a similar way (right chart) new resin/binder development was approached. The results indicate that over 60 percent of respondents indicated consideration of such a service.

(Source of below charts in Figure 34: 1ST Source Research: http://1stsourceresearch.com/about/ (last access 11/23/2014)).

"Would you consider outsourcing formulation development to benefit from experienced staff and variable cost?"	"Would you consider outsourcing new resin/binder development?"



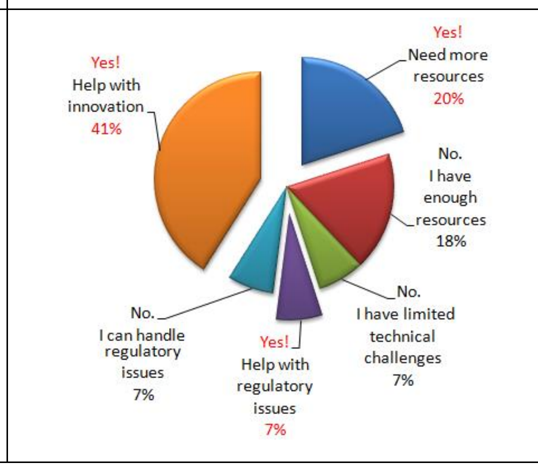


Figure 34: Considering outsourcing formulation development or resin/binder development.

polyMaterials continued to be focused on Germany for its sales and large globally operating firms. The structure of polyMaterials' customers and sales distribution in 2010 are given in Table 3. There are three areas which contribute equally (a quarter) to the sales of polyMaterials to cover 80 percent. But, relative to the pre-recession time the contribution of the medical (technology) industry increased largely at the expense of automotive suppliers and became equal to the chemical and automotive industry (cf. Figure 20).

Considering the tremendous activities of polyMaterials in the medical area through joint projects and cooperation described above the increase in sales in that field is a reflection of succeeding in R&D to be transformed into marketable products.

Table 3: Characterizing customers of polyMaterials in 2009 [Stebani 2010].

Sales Distribution by Industry	Customer Distribution by Region	Customer Characteristics
Medical – 27% Chemistry – 26% Automotive – 26% Automotive Suppliers – 7% Other – 14 %	Germany – 75% EU – 14% US – 11%	80%: Globally operating large firms, e.g. Bayer, BASF, Evonik Industries (Degussa), Fresenius Medical Care, GM 20%: Innovative mid-sized firms (e.g. plastics users)

In today's market, where the focus is on new formulations rather than entirely new plastics, and where recipes are becoming increasingly complex, there is a real need for a faster development technique .

Based on marketable technology polyMaterials re-designed its HTS/HTC system (Compound R&D with "Navi") that can speed up the formulation development up to a factor of 20, while supplying results close to the German DIN-standard [Stebani 2011; 2010a].

High throughput compounding (HTC) then meant also: Development and visualization of the recipe-property correlation at high speed as the basis of an efficient compound R&D [Stebani 2011]. Savings of more than ninety percent per compound were envisioned focusing on material, energy and time [Stebani 2011].

The high throughput screening, combinatorial experimentation and mathematical Design of Experiments (DoE) for planning and the development of polymer *compounds and blends* emerged as polyMaterials' "X-Plorator® Technology". Very complex experimental plans can be handled with it, and often predictive mathematical models can be created for systems of thermoplastic compounds and blends.

> Specifically this machine-based concept of high-throughput compounding (HTC) combines the production of a DIN-standard test block using an integrated compounding and injection molding process, followed by the thorough testing of the material and data evaluation using DoE (design of experiments) software. The new compounding method, jointly developed by polyMaterials AG, Engel Austria GmbH and other suppliers, now makes it possible to *assess between 300 to 500 different plastics formulations using material quantities of just one kg over a period of one to two weeks* [BIOPRO 2011].

More insights into the role of outsourcing compounding to related service providers was presented by Biron [2011] in a rather broad context.

Combinatorial chemistry is a technique that has revolutionized many industries including chemical synthesis, pharmaceuticals and biotechnology. But this idea of trying various combinations of materials to create large arrays of new materials was only now making notable inroads into the compounding industry [Anscombe 2009].

Gathered from the SpecialChem4Polymers Community with representatives from four market sectors accounting for more than 50 percent a click'n'vote approach (65 responses) gave some indications about "challenge when introducing new additive or compounding technology" [Biron

2011]. The four market sectors were Automotive/Transportation, Electric and Electronics (E&E) and Wiring, Packaging and Building & Construction.

The answer was clear. More than 75 percent of voters pointed out particularly three issues linked to the adopted strategy governing [Biron 2011]:

- Long lead time needed for the change – 35 percent
- Lack of resources to support the change – 25 percent
- Insufficient evaluation of needs – 18 percent
- Unsatisfactory improvements – 13.8 percent
- Lack of reach of the true stakeholders – 8 percent.

The most important issue relating to the lead time of changes is inherent to the *complexity of chemistry, processing and use of plastics*. Biron [2011] lists ways to reduce lead time: Use of sophisticated tools reducing the first step and the duration of each loop, wholly or partly outsourcing, co-development and co-innovation with linked sub-contractors, suppliers and customers.

For a firm needing compounding in the first step it is necessary to make the most of in-house and external knowledge bases keeping in mind the actual context and to fairly define the requirements. Experiments, analysis, and testing are expensive and time consuming.

To enhance their effectiveness and reduce their cost it is necessary to use smart strategies and suitable tools to reduce trials and analyze the results obtaining the maximum of benefits for a minimum of labor and cost. Tools described and assessed by Biron [2011] would include: Design of experiments (DoE), statistical analysis, mapping, modelling, simulation, virtual testing etc. Earlier detection of inefficiency or failure with more sophisticated methods saves time and money.

Lack of resources to support the change can be partly compensated for by partnership with suppliers of additives and machinery, customers or sub-contractors in the framework of co-development or co-innovation. Biron [2011] cited, for instance, that compounding extruder producer Coperion Werner & Pfleiderer (WPF has developed a new ETAA process (Extrusion of Thermosets for Automotive Applications) in a project with Daimler. Thermosetting materials are compounded and extruded in a co-rotating twin-screw extruder and pressed into molded parts in one direct process.

Another example of aiming to combine the expertise for formulation development of new materials with a machine developer was the project of polyMaterials with the company ENTEX Rust & Mitschke GmbH described above. The roller extruder of ENTEX is often compared with a twin-screw extruder, but it can do more. polyMaterials acted as a partner who contributes the chemical expertise to use such extruders as a “chemical reactor".

Dr. Maier pointed out that the main aim of combinatorial compounding is to identify trends and promising recipes, and not to obtain absolute values for mechanical properties of certain blends. polyMaterials’ system changes the recipe in a step-wise fashion, producing a fixed number of test pieces using one recipe, followed by a purging step where the test pieces are discarded. A fixed number of test pieces are then produced using the new recipe. These test pieces are then fed into tensile strength and impact testing machines [Anscombe 2009].

Between 2009 [Anscombe 2009] and 2014 [Maplestone 2014] the HTC approach became more and more known to potential customers through promotion in a relevant journal (Compounding World) and more and more accepted as a generally valuable tool for blending and compounding, in particular, vis-à-vis the twin-screw extruder technology and conventional injection molding.

Dr. Maier explained: “Combinatorial screening entered the polymer world some 10 years ago, but most institutes have used it only for miniaturized samples. We wanted it to work with standard test pieces in standard tests, just as you do in conventional product development. It was clear to us that we needed to base our system on injection molding to work on the mixing aspect that would enable us to generate a melt that would have the same morphologies and physical properties that you would normally obtain using a twin-screw extruder and conventional injection molding." Early work to establish the validity of the system involved fairly conventional polymer blends [Maplestone 2014].

> "We have always found that we can make materials with the same physical properties as obtained using a twin-screw extruder with an error of 5-10%," Dr. Maier said.

Up to eight components can be mixed together for any one test run. Dr. Maier said that, assuming that 10 test samples are required per test, polyMaterials can process up to 40 different compositions a day. "We can handle relatively complex systems in a very easy way," Dr. Maier said.

Dr. Maier admitted: "A series of 100 different compounds will be in the range of €30,000-€35,000, depending on the number of test bars or other samples per compound, how many different measurement methods will be used, whether or not there is the need for producing masterbatches (MBs), and whether there is a DoE or combinatorial plan already available, and what kind of evaluation the client desires (just graphical representation or creation of a predictive model."

"While the individual compound including measurements may not be that much cheaper than doing it the conventional way, the strength of our X-Plorator lies in the possibility to run a large number of compounds in a short time," Maier concluded [Maplestone 2014]. Figure 35 illustrates the process steps and characteristics of the X-Plorator approach.

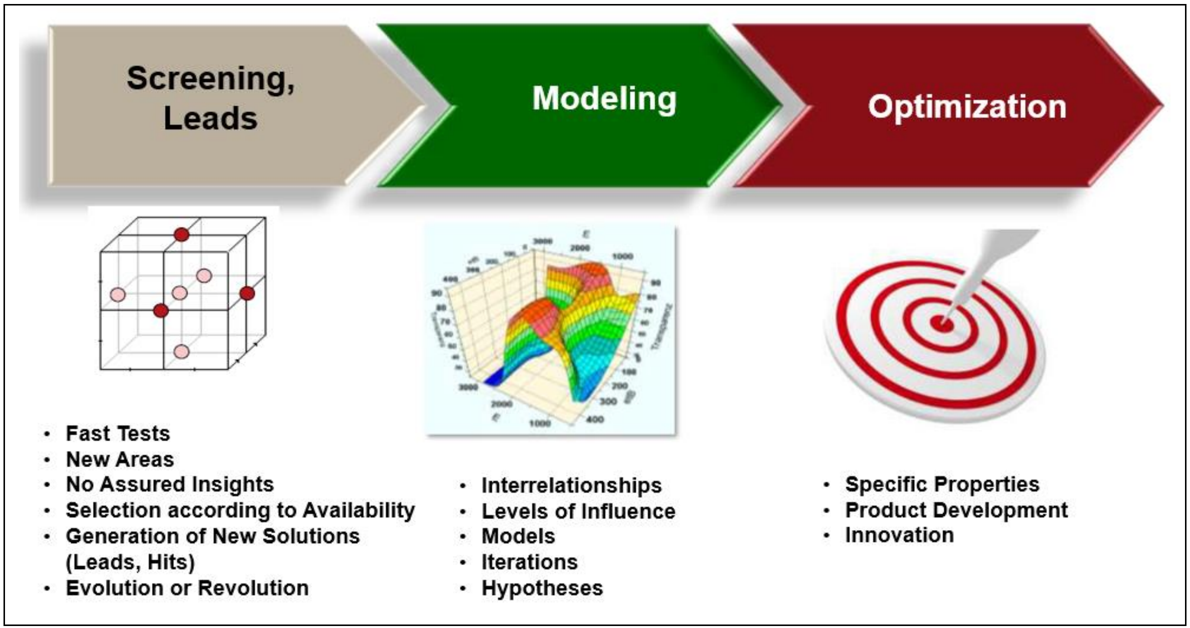


Figure 35: Steps and characteristics of the HTC X-Plorator approach [Stebani 2012].

Advantages of process-innovation through X-Plorator technology compared with common approaches are [Stebani 2014]:

- A fast system for compound-screening, based on an injection molding machine; combination with DoE
- Consumption of material is only ca. 0.75 kg per compound instead of conventionally 15 kg; change of material in ca. 10-15 minutes

- Current throughput is ca. 40-50 different compounds in 10h instead of <10 conventionally; upgradable to ca. 600 compounds per week; current focus: thermoplastics
- Raw materials used directly or as a masterbatch via 8 gravimetric dosing systems; glass fibers or fillers up to a proportion of 60-70%
- Compound-screening typically in fields of ca. 60-100 compounds, duration of ca. 2-4 days including tests.

References to the establishment of the HTC technology with customers were expressed by representatives of German big companies BASF and Evonik Industries [Stebani 2012:24]:

- "One can assume that HTS methods are established as the standard method for plastic compound manufacturers under this enormous increase in efficiency." (Dr. Arnold Schneller, BASF Research Director Performance Polymers)
- "We therefore envision a great potential in the plastics manufacturing industry for HTC to obtain a permanent place in the development of polymer compounds." (Dr. Georg Oenbrink, Evonik Innovation Management Chemicals + Creavis).

Additional references to the HTC methods are by Bayer MaterialScience (BMS), DSM (Netherlands) and Topas COC (Japan, with former sites of Hoechst-Celanese in Frankfurt/M.)

Polyamides with various structures and components and related properties play important roles for the automotive industry and electric and electronics (E&E) and wiring industry which means relevant customers of polyMaterials [Kunststoffe].

Based on increased interests in blends or compounding involving polyamides around 2010/2011 polyMaterials oriented itself towards establishing a polyamide platform as an opportunity (polyamide innovations by synthesis and compounds) reflected by a presentation of Dr. Stebani [2012]. The opportunity was the envisioned new possibilities for PA-developments and production on a low level due to

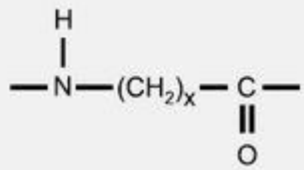
- knowing more than others regarding compound R&D based on HTC (high throughput compounding) and
- complexity as an advantage for innovation (higher blends with HTC).

Concerning compounding, for instance, polyMaterials experimented to optimize flame-retardant polyamide compounds [Maplestone 2014].

Structures and related nomenclature of polyamides are outlined in Figure 36.

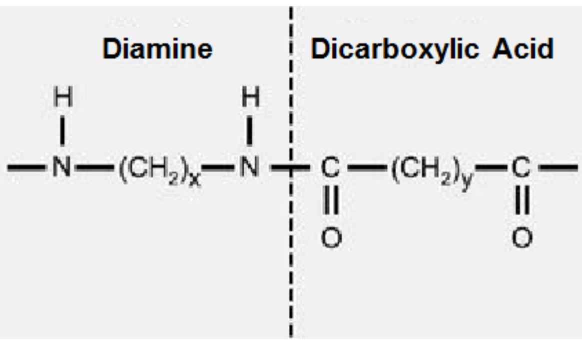
The polyamide chemistry and materials started ca. eighty years ago with PA 66 (Nylon® of DuPont) [Runge 2006:414-418] and PA 6 (Perlon® of I.G. Farben – BASF) [Runge 2006:415-417]. It is interesting that DuPont already noted that PA 510 should exhibit properties superior to PA 66 [Runge:1123-1124].

Over the last decades a lot of PA-variations (PA xy) were developed and entered the market as "high-performance plastics" [Stebani 2012:8]. The scope of PA variants is rather large [Stebani 2012:8,11]. Designer-PAs are generally high-value specialties.



PA 6:	x = 5	(5 + 1 = 6)
PA 11:	x =10	(10 + 1 = 11)
PA 12:	x =11	(11 + 1 = 12)

Composites of polyamides usually are characterized additionally by the additive, such as DIN-PA 66 GF 30 (Glasfaser – glass fiber reinforced; GF is a term of the German standard DIN)



	Diamine	Dicarboxylic Acid	
PA 66:	x = 6	y = 4;	4+2= 6
PA 610:	x = 6	y = 8;	8+2=10
PA 612:	x = 6	y =10;	10+2=12
PA 46:	x = 4	y = 4;	4+2= 6

Partially aromatic polyamides are polyamides which contain in the polymer chain both aliphatic and aromatic elements between the amide groups. These are mainly co-polyamides, i.e. PA produced from several PA-forming monomers (precursors).
Their resulting properties are determined by the nature of the aromatics component (terephthalic acid (T) or isophthalic acid (I)), and determined by their proportion in the polymer to the aliphatic moiety.

Aromatic polyamides, also known as aramids, are long chain synthetic polyamides in which the amide groups are connected directly to aromatic rings (benzene structure) and not to -CH2-groups in the polymer chain.

Figure 36: Structures and nomenclature for aliphatic and aromatic polyamides [Kunststoffe].

Starting around 2005 [Runge 2006:563-596] and accelerating after ca. 2010 the chemical industry and specifically the plastics and polymers segments encountered developments towards biodegradable and fully or partially produced by biobased (biogenic) raw materials – towards bioplastics. Pure biobased chemicals behave as “drop-in chemicals”, which means they have same properties as conventional petro-oil based chemicals [Runge:951-1050,1112-1133] – to ultimately provide “drop-in biobased polymers”.

More recently polyMaterials has also looked at blends based on biopolymers, such as polylactic acid (PLA) [Mapleston 2014]. But, concerning “green” PAs, the cost of producing biobased PAs relative to petro-oil PA 6 or PA 66 are tremendous [Stebani 2012:12].

Partially biobased plastics refer often to blends of petrochemical based polymers with fully biobased polymers, such as polylactic acid (PLA) [Runge 2006:129, 245-246,586-597] or poly(hydroxyl-alkanoates) (PHAs) [Runge 2006:585,870] or using biobased polyalcohols and petroleum-derived aromatic acids to produce polyesters or use biobased additives.

> Based on political initiatives and demand by customers the plastics industry is currently subjected to a significant driver: The trend towards specifically biodegradable and biobased plastics as “green” polymer chemistry as well as recyclability, often by design.

For the transition ("cross-over") from petro-oil based polymers to biobased polymers a typical example was DuPont's Sorona® 3GT [Runge 2006:583].

DuPont followed generally crossover strategies, not just only for Sorona. DuPont's Sorona 3GT is a copolymer first designed to be made from corn-derived 1,3-propanediol (alcohol) and petroleum-derived terephthalic acid (Sorona: poly-trimethylene terephthalate – PTT polyester). But the first step of the *crossover strategy* was to use petroleum-derived propanediol (PDO) to produce some 10,000 metric tons of Sorona to learn and establish the production process. The second step was using biobased PDO and finally biobased terephthalic acid had to be used.

Crossover strategies involving renewables does not only refer to replacing oil-based monomeric chemicals by structurally identical biobased chemicals, but also replacing oil-based monomers by functionally "identical" biobased chemicals.

Currently there is activity to provide an affordable industrial sugar stream for the large-scale production of *bio-based para-xylene*. Para-xylene is a basic raw material used in the manufacture of purified terephthalic acid (PTA), an important chemical in the production of plastic bottles and fibers made from polyethylene terephthalate (PET).

Recently, there were unexpected impacts of the low oil prices and a less favorable political framework on the biobased economy: Biobased drop-in chemical commodities fade more and more from the spotlight.

On the other hand, special biobased fine chemicals, solvents and materials for end products are more attractive than ever. Due to their new functionalities and properties, they are not in direct competition with conventional petrochemical products. This will enable them to conquer the market without the need for strong support simply because they have a lot to offer – to the industry and to the consumer.

Sustainability has an increasing impact on the product and raw-material purchasing decisions of consumers and brand owners. Worldwide substantial investments are being made in this sector with high added value and strong market growth.

And there emerges, for instance, a starch and polyols (polyalcohols) industry, which is pursuing a strategy of sustainable innovation that consists in designing and developing from plant-based resources, products, solutions and technologies reconciling the environmental, economic and societal issues. And there also emerges an industrial sugar segment [Runge:1118-1119,1129] using this as a raw material or intermediate for producing chemicals and polymers.

Recently, Bayer MaterialScience (now called Covestro AG as an independent company) was showcasing a milestone in this field: Pentamethylene diisocyanate (PDI) is a new isocyanate 70 percent of whose carbon content comes from biomass. It is an eco-friendly hardener component for waterborne polyurethane dispersions (PUD) for textile coatings [Runge 2015c].

Covestro has developed a technology to raise the content of renewable resources in PUDs up to 65 percent. This makes new levels of sustainability possible for PU synthetic materials (footwear, garment, accessories…). It is now possible to produce coated textiles with high performance and low content of fossil-based raw materials in each layer. The key benefits are: 43% – 65% renewable carbon content can be used in every layer of the production of synthetic materials or coated textiles, drop-in of existing Impranil® PUD types (Impranil®eco), with low reformulation efforts.

Stebani [2012:6,7] provides some information about the current status of the plastics industry differentiating plastics listed by the acronyms [6] according to petrochemical plastics and (partially) biobased plastics and their characters as high-performance plastics, engineering (technical) plastics and mass products. Accordingly, bio-PAs account currently for 5 percent of bioplastics. Also the relation of price (€/kg) *versus* sales (quantity/volume: kilo tons per year) is given [Stebani 2012:20].

As the basis of molecular design and marketable PAs the focus has to be on properties and Stebani (2012:8,9,10] shows thermal data (Tm *versus* Tg) [6], tensile strength and e-module (modulus of elasticity) *versus* Tg and extent to absorb water and resistance towards hydrocarbon or polar solvents.

Stebani [2012:19] provides also the historical development of new polymers in terms of polymers based on new monomeric units and polymers based on well-known polymeric units and polymeric components (blends).

Rather than focusing essentially on compounds after 2009 polyMaterials also addressed polymer blends, not just binary blends, but also ternary and higher blends referring to ca. 100 thermoplastic polymers with technical significance. There are roughly 5,000 binary blends in 50,000 compositions – very well studied for 50 years – but ca. 5,000,000 ternary and quaternary blends in 10^9 compositions – essentially unknown [Stebani 2012:21].

Solving a multi-parameter problem for such new applications and formulation fields experience-based development concepts will encounter limits of resources. And against this orientation frequently heard concerns were [Stebani 2012:28]:

1. "What can we get out of it? We know of the binary blends, which is thus compatible with what; what should be different there in ternary and higher blends?"
2. "Even if there were anything to find, browsing millions of combinations in billions of compositions, that's absurd. No one can find there anything within a conceivable time."

As an answer to such doubts Stebani [2012:16,17] presented some findings of PA-related HTC-based results of its recipe design, for instance, high modulus blockcopolymers of PA showing molecular reinforcement by poly(para-phenylene) (PPP). The thermoplastic materials have high modulus even without fiber content. This is a platform of new polymeric materials with excellent mechanical properties, for which a customer (giant automotive supplier Robert Bosch GmbH) filed a patent application (Table 7).

There are also results presented that the compounding with the HTC-system of PA 12 with glass fibers (to get PA 12 GF 15, 30, 50) achieves mechanical properties which are demanded by specifications for these properties by commercial products [Stebani 2012:27]. And Stebani presents many additional results achieved by polyMaterials' recipe design, sometimes unusual behavior of blends for which a patent application was envisioned.

As a summary of more than a dozen years of existence [Stebani 2014]:

- polyMaterials achieved a balanced portfolio of research, development, and compounding.
- The customer base was expanded from approximately 15 projects per year with about 20 customers to approximately 80 projects per year with about 40 customers, of which approximately 50 percent were medium-sized industrial customers.
- The next stage was envisioned to cover contract production/compounding.

Quantification of polyMaterials' development over time from foundation until 2013/2014 will be discussed essentially in terms of revenues and number of employees.

Key Metrics

The company's development in terms of number of employees is reflected by data extracted from various sources and particularly for the period 2006-2014 from the (German) Electronic Federal Announcements [EB] (Table 4). Numbers of employees by [EB] refer to average numbers across the year.

During its early phase the firm achieved rather fast a number of employees of more than 10-12 as a first threshold which often is associated with problems and related re-organization of young firms. Similarly also the next related threshold of 25-30 employees was also achieved rather fast apparently without much trouble ("10 – 25 – 150" rule-of-thumb, [Runge:656-658]).

Revenue data (Table 4) for 2002-2007 were estimated on the basis of reported sales for 2006 and later productivities. Particularly productivity of €100,000 per employee in 2002 was used to estimate related revenue of ca. €1.5 million for 2002.

Stebani [2007c] reported that *until the end of 2007 polyMaterials' sales increased linearly over time*. Then using 2006 revenue data allowed to derive approximate revenue data until 2007. These are given in parentheses in Table 4. It is not clear (for the author) whether the revenue data contain public subsidies or grants for the many projects in which polyMaterials was participating.

However, in the last quarter of 2008, in line with typical effects of the Great Recession (Dec 2007 – June 2009 in the US), polyMaterials suffered from a dramatic sales slump of ca. 70 percent. This was associated with a strong decrease of research projects in the lab and resulted in a difficult setup of the new fields Technikum/Compounds. Only in 2010 polyMaterials became again operatively positive, but on a level with only 29 employees (7 chemists) [Stebani 2014].

Actually, the negative effects of the Great Recession show up as a slump in numbers of employees 2009/2010: The corresponding sales slump may have occurred in 2009. And as a response polyMaterials decreased the number of employees: by ca. 30 percent from 2009 to 2010.

As described above, Dr. Stebani, during his presentation at the KIT in Karlsruhe [Stebani 2011], explained that no employee was fired; they did not replace positions of employees who left the firm.

A *recovery* occurred in the period 2009-2014 with an *average growth rate of eight percent* for this time span [Stebani 2014].

polyMaterials appears as a research-based startup (RBSU). At its pre-recession peak of development 2007/2008, early in 2007, it had 35 employees in two locations (29 KF, 6 LEV). It covered 11 chemists with a doctoral degree and 18 chemical lab technicians, technical employees (TAs, "technische Angestellte"), (chemical) craft masters and chemically skilled workers [Stebani 2007a]. On the other hand, Stebani [2007b] reported that in addition to Dr. Maier (CTO) and Dr. Stebani (CEO) there were 8 chemists with a doctoral degree, 20 TAs and 6 persons involved in administration.

Correspondingly, in 2007 polyMaterials with 36 employees had 8 employees in Management & Administration, 6 in "Production" and ca. 16-22 employees in R&D (Figure 31).

In the mid of 2008 just before the impacts of the Great Recession were felt Stebani [2008b] reported 40 employees, 30 in KF with 9 chemists with a doctoral degree and 10 employees in LEV [Stebani 2008b].

In 2014 Dr. Stebani reported that polyMaterials had 35 employees (probably including himself and Dr. Maier), roughly in line with the data in Table 4.

Table 4: Developments of polyMaterials's revenue and number of employees (estimated numbers in parentheses)**.**

Year	**Revenue (€, million)**	**Number of Employees**	**Productivity (€ per Employee)**	**References and Remarks**
1999		3		Year of foundation, in August
2000		5		[Stebani 2014]
2001				
2002	(1.50)	15	(100,000)	[BJU 2002]; estimated value
2003	(1.78)			
2004	(2.06)			
2005	(2.36)			
2006	$3.3 1) – ca. €2.64	25 2) 33 4)	105,600	[Hoovers 2007]; [EB]; [ABC]: when the firm had 32 employees revenue was €2.50 mil.
2007	(2.92)	35, 36 2)		[EB], in Jan. 2007 35 employees [Stebani 2007a]
2008		38, 38 3)		[EB; Stebani 2011; Colvin 2008]
2009		38 3)		[EB]
2010	2.060	27 3), ca. 32	82,480	Firmenwissen; [EB], [Stebani 2010]
2011	2.227	27 3)		Firmenwissen; [EB]
2012	2.364	29 3)		Firmenwissen; [EB]
2013	2.700	30 3)	90,000	Firmenwissen; EB]
2014	2.590	30 3), 35	86,000	Firmenwissen; [EB], [Stebani 2014]
2015	3.3	36		J. Stebani, personal communication; [Stebani 2016]

1) In 2006 1 euro was ca. 1.25 dollars; 2) apart from three executive directors [EB]; 3) apart from two executive directors [EB]; 4) Anonymus [2006] reported 33 employees for October 2006.

In 2008 the original share capital of €50,000 ("Grundkapital", minimum for AG; the capital onto which the liability of shareholders for the liabilities of the corporation against creditors is limited) was considerably increased to €217,000.

Looking at the critical years 2008 and 2009 in the balance sheet data (Table 5) one sees distinct decreases of value for the items "Current assets, "Retained earnings, reserves, equity portions" or related items reflecting losses by more negative numbers, such as "Related loss carryforward" or the Equity Ratio. These emerge even more distinct if comparing corresponding items for 2007 and 2010.

Silent participations in 2010 were €1,533,875 and in 2014 these were €935,000 (reduced from €1,533,875 in 2007 and also in 2013).

Table 5: Balance sheet components of polyMaterials comprising the period of the Great Recession **(**€) [EB].

Balance Components	2007	2008	2009	2010
Equity (Eigenkapital)	0.00	0.00	0.00	0.00
Not covered by equity loss (Nicht durch Eigenkapital gedeckter Fehlbetrag)	1,228,235	2,022,871	2,536,086	2,741,155
Share capital (Grundkapital)	50,000	217,000	217,000	217,000
Related profit/loss carryforward (davon Gewinnvortrag/-verlust)	--1,268,837	–1,278,235	–2,239,871	–2,753,086
Retained earnings, reserves, equity portions (Rücklagen, Rückstellungen, Reserven) a)	72,053 62,752 134,805	64,462 3,500 67,962	25,500 3,500 29,000	24,600 0,00 24,600
Total assets (Bilanzsumme)	2,223,096	2,692,953	3,219,044	3,306,843
Current Assets (Umlaufvermögen)	583,401	222,018	169,795	141,049
Fixed Assets (Anlagevermögen)	401,940	434,523	477,168	401,793
Equity Ratio (Eigenkapitalquote)	–55.25%	–75.12%	–78.78%	–82.89%

a) Special items with an equity portion (Sonderposten mit Rücklageanteil),
Special items for grants and subsidies (Sonderposten für Zuschüsse und Zulagen),
Accruals (Rückstellungen).

polyMaterials as a stock company (AG) – which is not often found for NTBFs – is subjected to special reporting requirements in the balance sheet. Therefore, it seems useful to outline this situation for the context of entrepreneurship in some detail.

Equity (on the "Passiva" side of the balance sheet) can be depleted by losses and moreover can be negative. For stock companies (in Germany) in this case on the assets side (! – "Aktiva") of the balance sheet the item "Not covered by equity loss" ("Nicht durch Eigenkapital gedeckter Fehlbetrag") has to be given. Equity (generally on the "Passiva" side) will not be given by a negative number, but the equity will be reported in total with €0.0 and the related item "Not covered by equity loss" is required to appear as the last entry on the assets side.

A negative equity ratio, hence, will be calculated by dividing the item "Not covered by equity loss" by the balance total. Leveraged borrowing, for instance, can contribute to negative shareholder equity.

Notably for 2014 the item "Not covered by equity loss" decreased by about €1 million to ca. €1.9 million relative to ca. €3.0 million in 2013 and 2012.

This means there is an "indebtedness according to balance" ("Überschuldung in der Bilanz"). But negative shareholder equity most often comes from the accounting methods used to deal with accumulated losses from prior years. These losses generally are viewed as liabilities carried forward until future cancellation. Oftentimes, the losses exist on paper only, which makes it possible for a company to maintain operations, despite the continued posting of substantial losses.

In polyMaterials' reporting [EB] one continuously reads related comments provided by authorized accounting consultants:

> According to the current insolvency law a legally defined situation of indebtedness and thus insolvency law based indebtedness is not to be applied to polyMaterials since it depends solely on the likelihood of continuation of the company's activities.
>
> There is a positive continuation forecast, confirmed by opinion of authorized accounting consultants. Furthermore, the company has hidden reserves in the form of patents, intellectual property rights and assets.
>
> Tangible assets alone are hedged by a contents insurance on the sum insured in the amount of €2,701 million against the dangers of fire, burglary, tap water, storm and hail. The electronic system is hedged separately by an electronic insurance against unforeseeable damage and destruction.

Vision/Mission, Business Model and Risks

polyMaterials started in 2000 based on the idea to bring a discrete portfolio of research and development services to market which were until then only in-house activities – focusing on materials and polymers.

The underlying *operational model* is *contract research services* for the polymer and plastics industry – specialized in high tech innovations – for innovative materials from global players to innovative small and medium-sized enterprises (SMEs) [Runge:19].

As cited by Dr. Stebani [2010] ca. 70 percent of all technical innovation of the Western industrialized countries depend directly or indirectly on the used materials. All the materials-based industry segments in Germany with around 5 million employees achieve around one trillion euros in sales.

> "A trend we are seeing is that our customers are to an increasing extent focusing on the adaptation of materials, which is why they contract us," said Stebani going on to add that "polyMaterials helps clients to apply innovative and optimized existing formulations. In the field of biopolymers, one of the things we are working on to give you an example, is the polymerization of biogenic building blocks and the screening of new blends and compounds with our superior HTC technology." [BIOPRO 2011]

polyMaterials continuously scaled up its business model concerning covering more components of the supply chain (Figure 4) and technically with regard to continuous improvement of its HTS/HTC system to speed up the compounding and blending process as well as production concerning quantities to be produced and technology (injection molding and extrusion processes).

Ten years later, polyMaterials was not only able to provide its customers *individual, customized R&D services* but to offer support for a *complete innovation process chain*, from idea to R&D to production of plastics materials.

polyMaterials *mission* is to *accelerate innovation processes* considerably, *to enable material-based innovations*, and to deliver those materials *as marketable products*. The motto "*Turning Ideas into Materials*" describes this process best: to realize customers' wishes, ideas, and requirements [Stebani 2010b].

Currently on LinkedIn polyMaterials AG has established itself as *a holistic service provider* in the field of polymer materials. Its approach towards its research topics is summed up by the slogan "Simply superior".

“By intelligently combining familiar facts, we create new, innovative ideas and facilitate their later implementation as marketable products, paving the way for superior technologies based on optimally adapted polymer materials. In addition to customer projects from nearly any branch of industry we have two proprietary projects”:

> High Throughput Compounding – Keeping tabs on time: polyMaterials utilizes its further advanced HTS/HTC method to rapidly optimize existing formulations and develop new ones.
>
> Biomedical Polymers – Polymers for health: polyMaterials is developing a new platform for materials aimed at healing damaged cartilage, bones and tissue.

The medical market is attractive because it appears to be *recession-resistant*.

polyMaterials’ related *core competency* is starting from request (application) to elaborate problem solving focused on market on the basis of commercially available educts or raw materials or known principles and possibilities of polymer chemistry [Stebani 2007c]. Additionally, due to its broad *experiences*, it guarantees quick familiarization and handling of interdisciplinary polymer chemistry projects [Stebani 2007a].

Developing and producing materials is focused on the specific needs of each individual client, who then has *exclusive use of such materials*. And this includes both the data and information obtained during the development processes as well as the specifically produced polymer [BIOPRO 2011] and also related intellectual properties, such as patents.

From its start the company was involved in a wide cross section of industrial sectors (chemical, automotive, medical etc.) and a variety of research. Smaller companies like this were seen to filling gaps in the innovation process for larger companies as they focused on their core competencies [Maier 2007b]**.**

> polyMaterials’ achieves its revenues by medical technology (own projects, cooperative developments) by ca. one third and ca. two thirds by services to the chemical and automotive industry including automotive suppliers (Table 3).

For its own projects, for instance, related to biomedical polymers requiring investment in material science, polyMaterials often encounters a fundamental disadvantage (Figure 37): The actual materials manufacturer participates only marginally on the later, often high value added to the component or system, respectively, although with him the highest proportion of R&D costs are incurred. Furthermore, the market will ask for only small quantities of material, particularly for functional materials (Figure 6) [Stebani 2007b].

In Figure 37 the problematic of advanced developments of functional or nano materials, similar to technology-push approaches [Runge:120-121,395-396], are illustrated.

polyMaterials AG works on innovations in the development and production of biomedical materials, together with numerous partners from university hospitals, research institutions and industry (Figure 17, Figure 18; cf. also text on “networking”).

To be developed materials can be used for the three-dimensional cultivation of cells. These materials are biocompatible and bioresorbable, release fewer acids than polylactic acid and can be flexibly adapted to the requirements of product properties. “The three-dimensional shape can be made to measure to replace the missing tissue,” said Dr. Stebani explaining that cells grown on the scaffold take on the shape required for each individual patient [BIOPRO 2011].

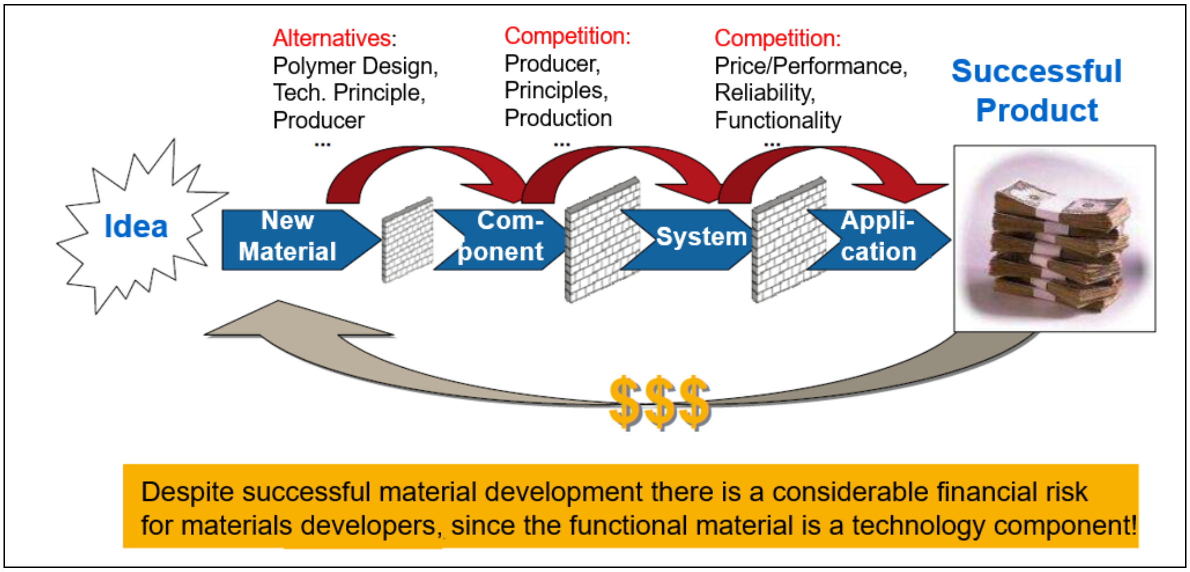


Figure 37: Financial risks associated with advanced developments of functional materials [Stebani 2007b; 2010].

The 3D data sets are generated from a patient's computed tomography scan (imaging by sections or sectioning, through the use of any kind of penetrating wave), which are then used to produce the required tissue shape using a silicone injection mold produced with rapid prototyping. "We now have a broad range of different material compositions with different material properties available," said Stebani. This complete formulation platform consisting of polymeric components made from different formulations also enables the company to adapt the materials' properties to specific tissues. [BIOPRO 2011].

Numerous experiments have shown that the materials are well tolerated by tissue and that they have not led to any inflammatory reactions. The materials are already being tested for application in orthopedics, for use in cartilage or intervertebral discs, for example, or in the field of trauma surgery where they can be used for tissue construction [BIOPRO 2011].

> As outlined the material innovations of the 21st century require completely different process chains, other infrastructures and other business concepts than the plastics of the 20th century. There is a great need for innovative materials for technical as well as economic reasons.

"However, many companies lack the resources and the infrastructure required to *turn basic research ideas into marketable products*. polyMaterials AG's structured service portfolio is designed to support its clients in finding solutions for material problems and implementing innovative ideas." [BIOPRO 2011]

Stebani said that very many *big companies are experiencing gaps between ideas and the internal implementation of ideas into products*. Contract researchers and producers such as polyMaterials AG can close this gap and are able to take projects from basic research to market entry. "We are rather like a new, independent transfer platform between research institutes and industry," said Stebani explaining the company's goal to develop materials that correspond to clients' requirements and enable their cost-efficient industrial implementation." [BIOPRO 2011]

"CEO Dr. Stebani believes that polyMaterials AG has a considerable advantage over bigger companies in terms of speed and flexibility, as it has less administration and is focused on special materials on the semi-industrial scale." [BIOPRO 2011]

Using a "neutral" polymer platform as given in Figure 38 represents a *Unique Selling Proposition* (USP; "Alleinstellungsmerkmal") comprising additionally the following aspects: Industrial research as a service, complete process chain from the lab via analytics to production (Figure 30), speediness and flexibility and a clear IP policy [Stebani 2007c].

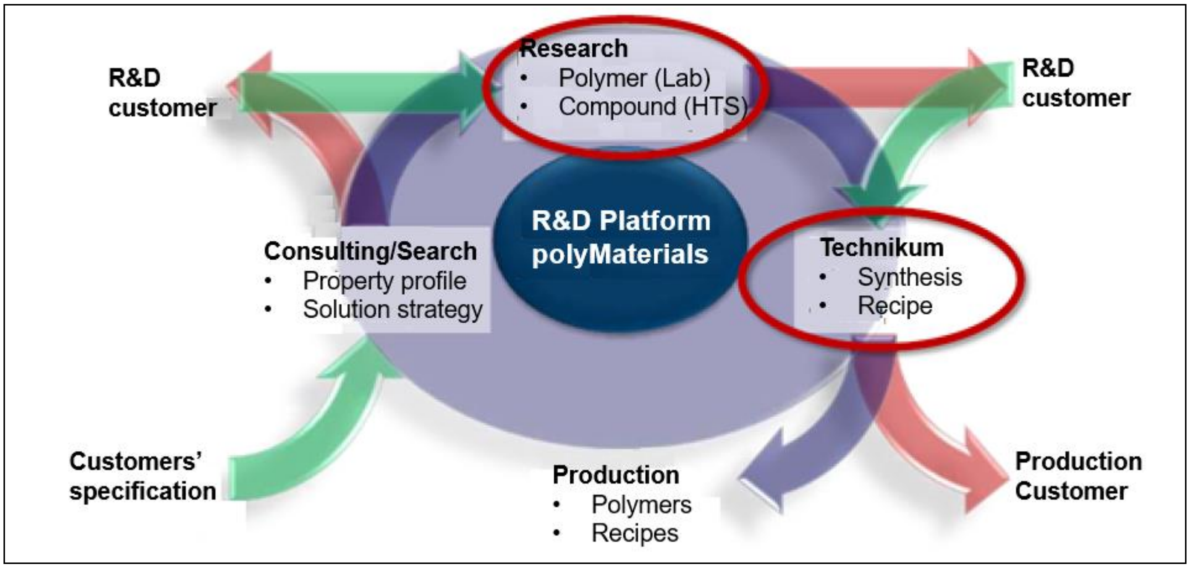


Figure 38: A "neutral" R&D polymer platform of polyMaterials in the context of customer relationships [Stebani 2012].

This approach allows alliances to be structured as "deep collaboration": Two-way sharing of technology and intellectual property, along with joint technology development, to provide a single unified offering to the market.

Through many projects polyMaterial has already proven the ability to successfully collaborate and develop and transfer to the industry new process technologies that work at larger plants.

Re-thinking the innovation process chain in the context of polyMaterials' actual and future roles (Figure 29, Figure 30, Figure 38) led to differentiating invention (reflected by R&D and lab work in industry or academia) and innovation in terms of potential players (Figure 39) and polyMaterials as an innovation partner.

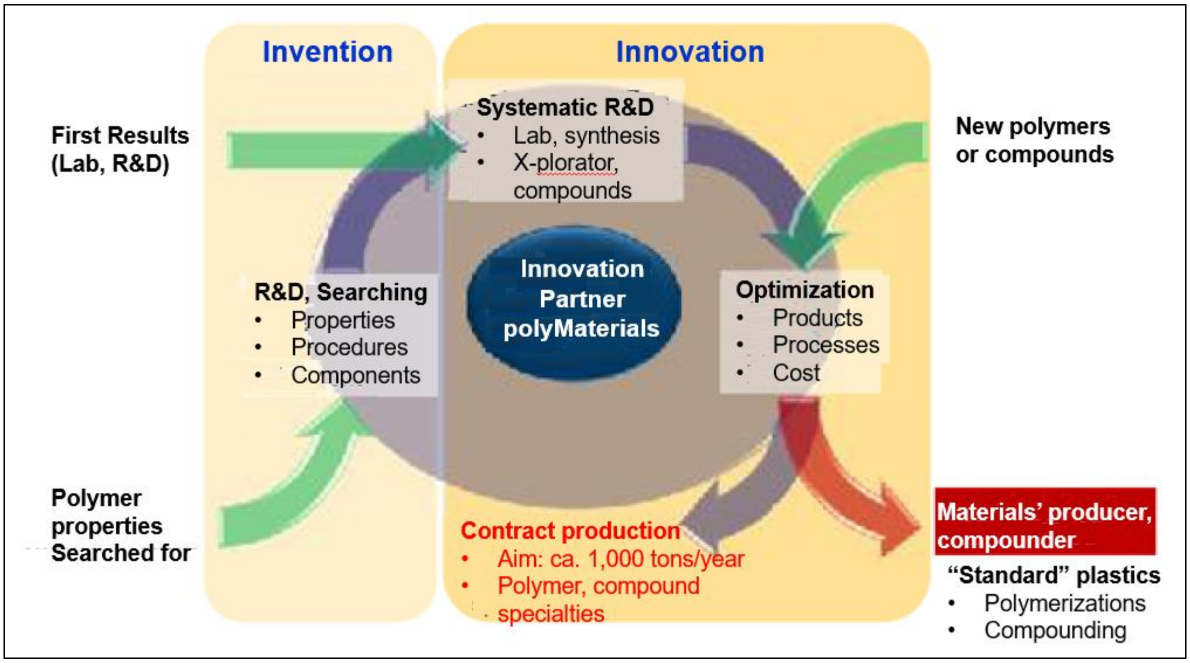


Figure 39: polyMaterials offerings comprising steps from invention to innovation [Stebani 2014].

Invention here does not only mean business idea and industrial research or research in universities and public research institutes (Figure 27, Figure 29, Figure 30) but reflects also polyMaterials' own application oriented research efforts concerning new polymers or compounds and subsequent activities addressing materials' producers or compounders or alternatively contract manufacturing by polyMaterials on a semi-industrial level.

Over time developments of the business model of polyMaterials followed targets addressing complements or missing parts of its offerings regarding supply chain components, innovation process steps, quantity of production, technology (injection molding – extrusion – 3D-printing, but also RP, combinatorics – HTS – HTC), associated with generating and expanding resources (labs, teams, plants, networks).

Specifically there seems to be also an orientation towards polymer nanocomposites using carbon nanotubes [2020HORIZON 2009; Oliveira et al. 2016]. Nanocomposites have recently gained fast momentum in high strength-to-weight ratio applications. Approximate practices used in the past are no longer enough today to reach higher performance targets at lower cost. This calls for revisiting formulations (nanofiller selection, loadings/processing parameters) for high value applications.

Key periods of the development of polyMaterials' business model were observed at

2003/2004: Figure 19, Figure 20, Table 1;
2007/2008: Figure 21, Figure 22, Figure 23, Figure 27, Figure 29, Figure 30, Figure 31, Table 2, Table 3;
2010-2011: Figure 35, Figure 38, Figure 39.

In particular, for polyMaterials it is of outmost importance to track and assess new technologies of relevance for its production processes of low volumes or small series of functional polymers (Figure 29, Figure 30, Figure 37) for components used by other industries.

Generative manufacturing processes (for example, 3D printing) are increasingly used for rapid manufacturing, that means used for the preparation of individual pieces and small series. For the application of rapid manufacturing in medical technology adjustments are needed in both the material used and in the field of process technology.

The distinct entry of polyMaterials into 3D technology was reflected by its offering a new job for the end of 2015 (chemist or chemical engineer with Dr./PhD) to focus on:

Scale up of thermoplastic compound recipes using an extruder,
Compound development for 3D printing methods, particularly FDM [polyMaterials – Jobs].

Fused Deposition Modeling (FDM) is one of the techniques used for 3D printing. It is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. It is also sometimes called Plastic Jet Printing (PJP).

3D printing is already strong for metal, for plastics it is on the rise. The jump into small series will occur essentially or even only with customized materials. Relatedly in 2014 Dr. Stebani provided already a presentation entitled “3D-Druck – Materialien in einer neuen Dimension” (3D printing – Materials in a new dimension) during a WIP-Kunststoffe e. V. (Wissens- und Innovations-Netzwerk Polymertechnik) seminar or symposium. His outline emphasized and tackled

- Already for Rapid Prototyping (RP), even more for small series, targeted reproducible properties are important.
- What qualities can 3D printers already reflect? What in particular is it about the mechanical characteristics and tribological ones – and about surface properties?
- Which additives can already be used?

Small series and customization or even personalization of plastic components is important for medical technology (Figure 18). For instance, there was a publicly financed project (BMWi) of the University of Rostock and the firm Voxeljet Technology GmbH (Friedberg, Germany, near Augsburg) entitled “3D-Druckverfahren zur Herstellung von Medizinprodukten” (3D printing process for the preparation of medical devices) for the period 10/2008 – 09/2010. The goal of the project was to develop a 3D printing process for processing a biocompatible plastic that can be used for the production of medical devices (for example, hearing aid shells) [Polzin 2010]. Voxeljet Technology was founded in 1999 as a GmbH, listed on the New York Stock Exchange since its IPO in the year 2013 and has currently ca. 250 employees (according to Wikipedia).

3D printing has the potential to fundamentally change the way medical devices are prototyped and tested, or more generally rapid prototyping for regenerative medicine [Pomager 2015; Baudis 2016].

One fundamental question in this context is whether 3D printing will replace traditional manufacturing of parts through injection molding, or other mass manufacturing means. Whether it is an important manufacturing strategy will ultimately depend on what is the 3D printing *versus* injection molding cost-per-unit breakeven. And that means: At what volumes is at advantageous to 3D print parts? [Lubin 2015; Alec 2014].

But specifically for the medical area, which is highly constraint by governmental regulations, Pomager [2015] pointed out that “today’s 3D printing technology can carry a product only so far into the development process, primarily due to material constraints. Following a design freeze, it is preferable to build functional prototypes using parent materials — the specified materials intended to be used in the final product — to enable accurate verification and validation testing (as required by the FDA, the US Food and Drug Administration). In many cases, parent materials are incompatible with the current generation of 3D printing technology. Plus, 3D printing cannot always deliver the fidelity or surface finish necessary to satisfy regulatory or internal testing requirements.”

As a result, device makers usually turn (back) to traditional manufacturing methods like injection molding (IM) to create their functional prototypes. A hybrid prototyping process has begun to emerge, offering medical device developers the best of both worlds – the speed and economy of 3D printing combined with the material and accuracy advantages of IM, a 3D IM process [Pomager 2015].

Concerning 3D printing of plastics, for instance, the US firm Stratasys Ltd. Is notable. [7] Stratasys Ltd. is a manufacturer of 3D printers and 3D production systems for office-based rapid prototyping and direct digital manufacturing solutions. Engineers use Stratasys systems to model complex geometries in a wide range of thermoplastic materials, including: ABS, polyphenylsulfone (PPSF) and polycarbonate (PC). Stratasys is an enterprise with $696.0 million sales (2015) and 2,800 employees.

Regarding regenerative medicine currently there are reports and discussions on cartilage from the 3D printer and more generally 3D printed organs from regenerative living cells – from kidneys to hands, 3D printers are churning out made-to-order bones and rudimentary organs [Schwan 2016].

Current *technical core competencies* of polyMaterials include (Figure 29, Figure 30, Figure 38, Figure 39) [Stebani 2014; 2010]:

- Functional polymers and polymerization
  Fuel cell membranes, (proton/hydroxide ion conductors), dielectrics for polymer electronics, plastic electronics, holographic data storage, polymer electrolytes for Li-cells, shape memory polymers;
  polybenzamidazole, polyimides, polyketones, polysulfones, liquid crystal polymers (LCPs), poly(para-phenylenes), polyamides, polyesters, polycarbonates, polylactides, poly(meth)-acrylates and its co-polymers (PMMA/PS/PVAc-Copolymers) [Stebani 2012]),
- Medical polymers
  Polyurethanes for tissue engineering, coatings materials, thermo-reversible gels …
- Polymeric recipe components, HTC, compounds/recipes (polymers, additives);
  Compatibility agents, water-soluble polymers, thickeners for lacquers, cosmetics, laundry detergents …
- Polymerizations, polycondensations.
  In solution/emulsion/suspension, radicalic/ionic/ring-opening, "in batch", but also reactive extrusion by a new aggregate in polymer chemistry, the planetary roller extruder (PRE).

Operational core competencies refer to its broad experiences in polymer and compound chemistry, which guarantees quick familiarization and handling of interdisciplinary polymer chemistry projects [Stebani 2007a].

A structured representation status of polyMaterials' *business model* is given in the Appendix (Table 6). Some more specifications are given below [Bayern Innovativ].

Innovation

- Biodegradable backbone polymers for millimeter-precise components for medical tissue regeneration
- Monomer and polymer synthesis in laboratory and industrial scale
- Highly efficient high-throughput compounding for detecting optimal plastic blends and compounds

Technology/Research

- Wide methodological expertise in research, development and production of polymer materials

- Fastest process and technology for R&D of plastic blends and compounds
- Polymers, blends and compounds from biogenic monomers

Products/Services

- Search, feasibility studies, consultancy in the field of polymer materials
- Scale up and process development of monomer and polymer synthesis.

In 2016 polyMaterials re-focused its strategy for further development [Stebani 2016]:

- Reduction of activities in the medical area
- Contract manufacturing/contract compounding on the level >1,000 tons/year
- Own products (3D print materials).

Concerning *customer relationships* the company has advanced to become a *one-stop service provider and partner* for research and innovation in the field of polymer materials. Projects are carried out in close cooperation with the experts of the clients or its cooperation partners.

Dr. Stebani is heavily active in promoting polyMaterials and marketing its services in terms of presentations to many different audiences from various industries and applied research as well as to members of the many networks polyMaterials is a member of.

Efforts so far (in Germany) targeting *marketing and customer relationships* comprise:
Gaining visibility:

- The Web (home page, YouTube contributions)
- Public attention exclusively in the business world is achieved by participating in related industry's fairs, exhibitions and conferences, for instance, the annual Compounding World Forum and Compounding World Congress
- Providing courses/lectures through seminars, workshops or symposia on polyMaterials' technologies or offering of new technologies implemented by polyMaterials
- Attention among researchers from public research organizations and industry may be gained by participation in competence networks and related events of the network
- Reviews and other contributions in (German or US) scientific and technical journals and magazines; (, for instance, contributions to the Compounding World Magazine)
- Winning various awards and prizes alone or with cooperation partners.

Customer Contacts:

- Sales and after-sales services by highly qualified scientific/technical personnel
- Personal contacts, customer visits
- Customization of products
- Test measurements
- Common projects.

For *scalability of polyMaterials' business model* one has to differentiate between product orientation and service orientation.

Product-oriented business model [Stebani 2014]:

- The basis is usually a new class of material or processing materials (ionic liquids, nano… e.g. nanocoatings, CNT, graphene, bio…) in the context of publicly financed programs or initiatives
- Necessary: Setting up market experience, R&D processes, plants, organization, additional locations/representations to exploit more markets => VC-financing, advisors, support concepts …

- Scale up: Small quantities => large quantities; exact volume depending on price (or depending on margin), expansion by new application, widening the product range.

Service-oriented business model [Stebani 2014]:

- The basis is fundamental experience with R&D projects and an orientation towards problem-solving
- Setting up resources (labs, teams, plants, networks) through projects
- Extremely broad spectrum of topics, building a tremendous amount of experience
- Scale up by two steps
  - More projects, different services, result: all resources (technologies, employees) for material R&D and production
  - Exploiting the various contacts to customers and the experience now for “own” materials with an image as a materials’ specialist.

During an SKZ seminar [SKZ], referring to the complexity of compounding and “Methods of compounding-R&D in the 21st century”, Dr. Stebani promoted compounding-R&D with the “X-Plorator technology” referring essentially to speed and the slogan “Experience is good – knowledge is better!” (Erfahrung ist gut – Wissen ist besser!).

But this reflects an opinion concerning the focus for multi-parameter issues on know-how as the necessity for technological breakthroughs ((Figure 40).

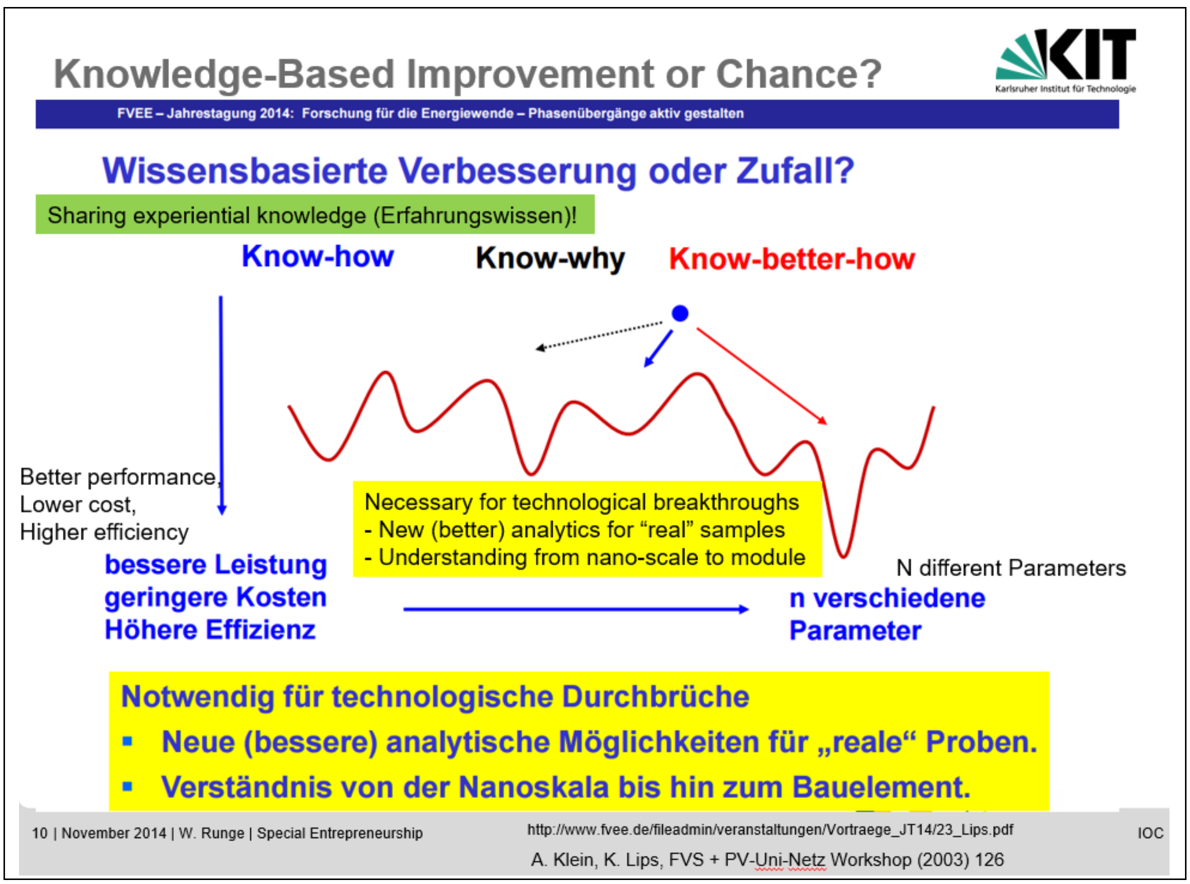
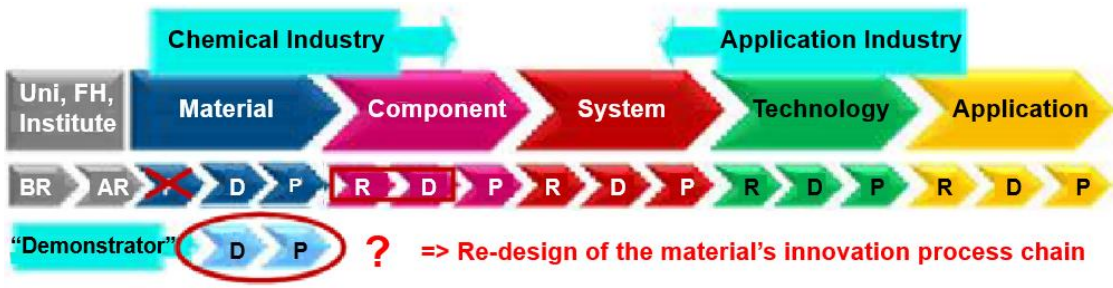


Figure 40: Improvements for technology breakthroughs of n parameter issues by knowing-better-how (translations into English added) [Lips 2014].

And concerning materials' innovation starting in one industry and ending in another one an open question about the underlying process chain appeared (Figure 41) – in an again distinctly changing chemical industry.

Stebani [2014] pointed out an issue of the *process chain of materials' innovation*, whether a re-design of the process chain would not be better off with a demonstration phase after research (BR, AR, Figure 41). In this regard the process chain exhibits a similarity to the staged Research, Demonstration & Development (RD&D) approach [Runge 2006:550, 580, 620,855-856] which recently became relevant for innovation in the biofuels area [Runge:1052-1053].



Product	Price (€/kg)	Bulk (tons/y)	R&D-Focus	Model	Example
Material	> 1	> 1,000,000	Process	Chemistry	Thermoplastics
System	> 100	> 10,000	Chemistry	Hybrid	Films, 'Semi-Prod'
Function	> 1,000	> 10 ?	Physics, …	Technology	FC, LiB, OLED

BR: Basic research, **AR**: Applied research, **R**: Research, **D**: Development,
P: Product/Prototype – **Institute**: Publicly financed R&D institutes (e.g. FhG, MPI, …);
"Semiprod": Semi-finished product ("Halbzeug")**;**
FC: Fuel cell, **LiB**: Lithium battery, **OLED**: Organic light emitting diode

Figure 41: The process chain and economics of starting in the chemical industry and ending in providing functional materials for components and systems for an application industry [Stebani 2014].

In 2015/2016 *the chemical industry encountered further significant re-structuring* characterized by many M&A (Mergers & Acquisitions) activities. The current numbers of M&A is high relative to those of previous years [Tullo 2015; Schneider et al. 2016].

For instance, a deal in 2016 under which Dutch AkzoNobel was taking over BASF's global industrial coatings operations would be the first of a number of initiatives among coating businesses to re-organize their activities. And then BASF consolidated its coatings business further: BASF signed an agreement to acquire automotive refinish coatings assets of Guangdong Yinfan Chemistry to boost its automotive refinish coatings business in China and Asia Pacific.

The (2015) year's biggest chemistry headlines included a *merger mania* epitomized by the stunning combination of Dow Chemical and DuPont. Nelson Peltz, the activist investor who has been hectoring DuPont to break apart, appeared to be a deal backer. "Generally speaking, activists are attracted to companies when they see underperformance relative to the peer group," said a partner at the consulting firm Pricewaterhouse-Coopers. "Their hypothesis is that a lack of portfolio coherence is an important cause for such underperformance." [Tullo 2015].

"Activist investors" go for shares of a stock company to capture a position of the Board or CXO management to achieve a position to execute larger changes of the company to increase the value of the shareholders.

Air Products & Chemicals (sales of $10.4 billion in fiscal 2014), for example, was the last industrial gas company with a substantial chemical business planned to spin off its Materials Technologies business as Versum Materials.

The year's biggest spin-off was Covestro AG, Bayer's former Bayer MaterialScience unit and polyurethane and polycarbonate business, which generated $15.5 billion in sales in 2014. Bayer's managers decided on their own to get rid of the underperforming unit to focus on pharmaceuticals and crop protection. The German firm took a similar step in 2004 when it spun off its industrial chemicals business as Lanxess. This may have consequences for the many relationships of polyMaterials with BMS and Bayer AG.

Not only producers from the chemical and pharmaceutical industry are involved, but also distributors, not only large/big firms, but also contract manufacturer for the pharmaceutical industry [Schneider et al. 2016; Runge 2015a].

Intellectual Properties

Concerning intellectual property rights (IPRs) there seems to be just one IP related to *trademarks*: X-Plorator® as a wordmark.

For patents one must differentiate those which are owned by polyMaterials or polyMaterials' employees, respectively, and those owned by customers of service. In the last case polyMaterials' employees may appear as co-inventors.

Primary search was in "Expert Mode" in the DEPATISnet database which allows deleting patent family members and keeping only the basic (family) patent or patent application.

Selected data of the representatives of patent or patent application families for both these kinds until 2013 as obtained from the German DEPATISnet patent database are given in Table 7 (Appendix, no. 1-7 for polyMaterials; patent assignee, PA= polyMaterials).

Database search for customers involving polyMaterials looked for Dr. Jürgen Stebani or Dr. Maier excluding polyMaterials as the patent assignee (Table 7, a – f). For instance, the search for Dr. Maier as co-jnventor (IN) and deleting family members provided 24 hits – (IN=((Maier(l)Gerhard) AND München) NOT PA=(polymaterials)).

The related inventions provided insights into the technical expertise of the persons, technical fields protected by patents of polyMaterials and various customers for whom polyMaterials provided services (a – f), such as Aesculap AG and TETEC Tissue Engineering Technologies AG, Robert Bosch GmbH, GM Global Technology Operations LLC and Xetos AG.

Some patents of Dr. Maier before foundation of polyMaterials reflect developments of expertise in certain areas which later became explicit competencies of the company, such as:

- With Infineon Technologies AG: Polybenzoxazole precursors
- With Hoechst AG: New polyimide(s) for use as membranes – prepared from long chain aromatic indane and ether group contg. di:amine(s) and standard tetra:carboxylic …; Heteroaromatic polyethers
- With Ticona GmbH: Polyetherketones and polyethersulfones based on phenylindane and their use for optical devices.

These patents can also be used as a documentation of related competencies or experiences as a partner in publicly financed (joint projects) or cooperation with other firms.

Competition

When considering *competition by companies* one can refer to different levels in line with regional distributions of polyMaterials' customers. That means the focus is on German *competitors*; there is little significance for European firms and probably less regarding firms in the US.

On the other hand there is *competitive process technology*, such as injection molding *versus* 3D printing, particularly when considering small scale products or even personalized products in the medical arena.

In today's engineering plastics and materials markets the focus is on new formulations rather than entirely new plastics. But as recipes are becoming increasingly complex, there is a real need for a faster development technique. For scale up of compounds and blends the focus is on

- Achieving greater process efficiency, yield and throughput
- Decreasing the costs and number of steps involved and probably
- Eliminating unsafe and non-green processes and materials or covering biodegradability and/or recyclability.

One of the main reasons why the compounding industry is a few years behind other industries in adopting a combinatorial approach to product development is that the compounding industry is interested in the physical properties of the polymer blends. Testing hundreds of samples quickly, ideally online, is a huge challenge [Anscombe 2009].

Regarding polyMaterials, after years of continuous developments, the period between 2007 and 2009 provided a first state of technology using combinatorial and HTS principles to increase the speed of compound development and related cost decreases [Stebani et al. 2007; Anscombe 2009].

A detailed description of polyMaterials' approach to developing compounds is given in the previous text and Stebani et al. [2007] presented characteristics of other competitive technologies.

- Typical ranges of applications of different concepts for developing recipes: Differentiation by test method and targets of development (Figure 42).

All these approaches have been further developed – polyMaterials now offers its HTC/X-Plorator technology. Specifically the "*X-Plorator technology*" is promoted for compounding-R&D.

The German Polymer Institute (DKI, Deutsches Kunststoffinstitut) in Darmstadt, Germany, together with the Dutch Polymer Institute (DPI) designed a combinatorial compounding line that integrates as many as 10 different on-line tests [Stebani et al. 2007; Anscombe 2009]. "Our system uses a melt divider to divide the melt into three streams." "With the first melt flow we perform tests on the melt, such as viscosity. The second melt flow is pelletized and these pellets can be used for off-line testing, such as injection molding. The third melt flow is fed into a flat film line and this is where most of the testing takes place."

The film first passes through a non-destructive testing station where various different kinds of spectroscopy can be used to test a wide range of film properties, such as color, clarity, degradation, crystallinity and particle size distribution. These tests can be carried out on the moving film without damaging it. However, mechanical tests require a stationary piece of film in order to perform the test. These tests can be performed continuously and on-line.

The researchers will have a minute or so to perform the mechanical tests. These include lateral and longitudinal tensile strength as well as tear strength. The system is also able to monitor the degassing process inside the extruder by using an FTIR spectrometer at the degassing vent.

The combinatorial compounding line at DKI is able to change recipes continuously. For example, one additive can be ramped up from 0 to 2 percent while another additive could be ramped down from 5 to 0 percent, giving a gradient of different properties over a length of film.

The DKI combinatorial process splits the output from a compounding extruder into three streams: One for testing the melt, one that is fed into a flat film line, and one that is pelletized [Anscombe 2009].

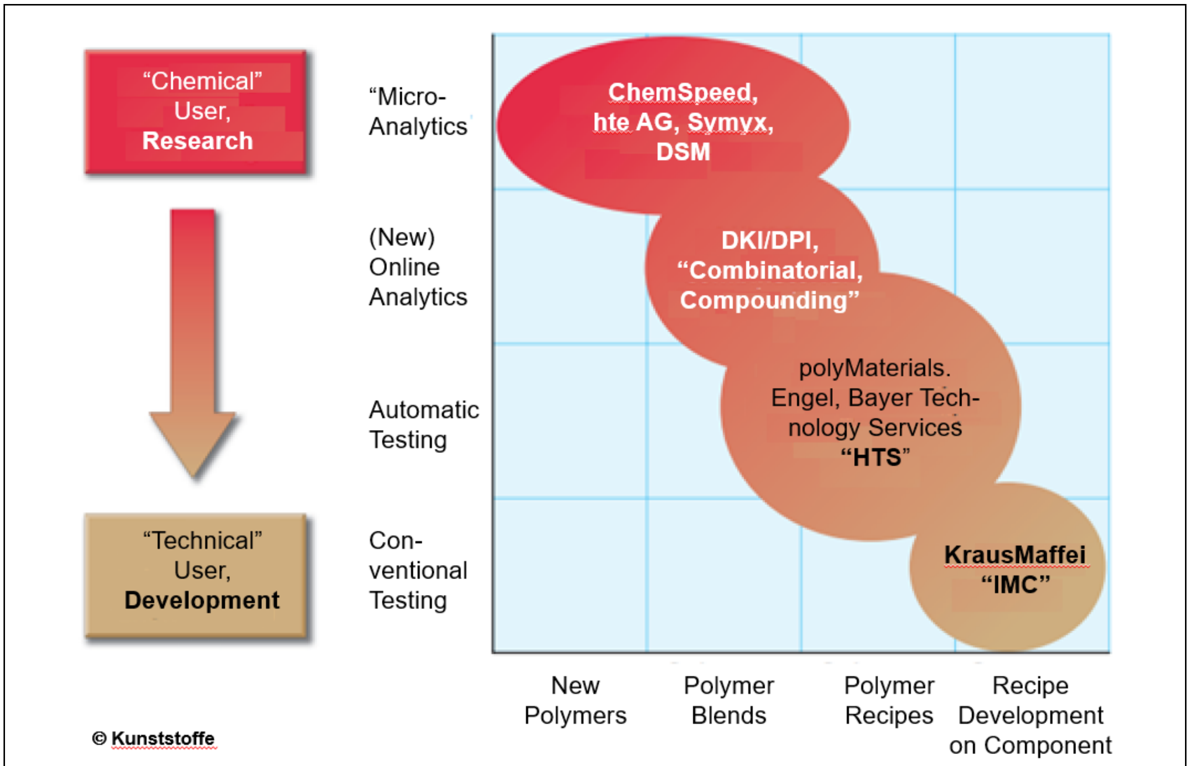


Figure 42: Typical ranges of applications of different concepts for developing recipes – Differentiation by test method and targets of development [Stebani et al. 2007].

The KrausMaffei IMC (Injection Molding Compounder) links the continuous extrusion process with a discontinuous injection molding process: Extruding and injection molding in one working step. The IMC concept unites a closely intermeshing twin-screw extruder for processing with a plunger injection system and a closing unit of a conventional injection molding machine. The combination of a continuously operating machine unit with a cyclically working machine unit is done by integration of a melt-cache [KrausMaffei].

Many dedicated (independent) compounders exist all over the world potentially competing with polyMaterials in the areas of compound development and production on a contract basis or as a toll manufacturer or even as a supplier of "standard" compounds or/and blends.

Most of them, however, are characterized by focusing on a limited number of targeted types of polymers or plastics to be compounded. There is offered a number of groups of compounds with given performance features. And only for relatively few cases requests for customized compounds are followed. Their approach is: Mix properly your plastics with a structured method to process your compound and usually produce them on a large scale.

The focus is usually on engineering plastics rather than functional materials, structural polymers *versus* functional polymers (Figure 6, Figure 37), and since recently also on nanocomposites. Moreover, their orientation is often based on their experience with plastics offered to a small number of mostly large or big firms which represent already their major customers.

Many focus on PVC (polyvinyl chloride), the polyethylene/polypropylene (PE/PP) or PA 6- und PA 66-compounds and are large independent firms or firms of groups (holdings) with much more than 100 employees which exist already for more than 20 years.

Usually these firms also address firms of the chemical and automotive industry including the suppliers of automotive industry, the E&E industry and medical technology/regenerative medicine.

Names of relevant companies can be identified by more or less regular presentations of the column "Compounder of the Month" in the Compounding World magazine or search Google for “research development toll compounding” to get a long list of companies. But only few of them exhibit a competitive threat due to their orientation on specific engineering plastics which are not of interest for polyMaterials.

According to Freedonia’s [2010] US industry study of thermoplastic compounding by independents, which is also indicative for Europe, there are needs for higher performance compounds. There are unique advantages offered by independent compounders, such as rapid product development and delivery.

Demand for independently compounded engineering plastics will be driven by growing needs for *custom tailored formulations with higher performance ranges*. Best growth opportunities were seen for thermoplastic elastomers (TPEs) and polypropylene (PP). PP is widely used as a base resin due to its ability to carry heavy filler loadings, such as glass fibers, flame retardants or colorants.

Leading engineering resins are acrylonitrile-butadiene-styrene (ABS), polycarbonate (PC) and nylon (PA xy or PA x) based on their widespread use in electrical and electronic and motor vehicle parts and components. Independently compounded polyvinyl chloride (PVC) demand will expand at a below average pace due to environmental and health concerns.

Motor vehicles were expected to be the fastest growing market; automotive is making more frequent product changes to their vehicles in order to differentiate them from competitors to garner additional market share.

There are high performance requirements of motor vehicle components and the need for close customer liaison (high levels of customization and technical support). Independents can offer a broader range, thus enabling component producers to use the most appropriate resin for a given application rather than just what is made by the resin manufacturer [Freedonia 2010].

Global consumption of nanocomposites is expected to grow in unit terms from nearly 225,060 metric tons in 2014 to nearly 584,984 metric tons in 2019, a compound annual growth rate (CAGR) of 21.1 percent for the period of 2014 to 2019 [BCC 2014].

In particular, nanocomposites find also applications in the biomedical area via 3D conductive scaffolds prepared by employing a biocompatible conductive polymer. Bone healing can be significantly expedited by applying electrical stimuli in the injured region. Therefore, a three-dimensional (3D) conductive tissue engineering scaffold for large bone defects that can locally deliver the electrical stimuli is highly desired [Shahini et al. 2014].

Furthermore, there are also preliminary investigations into the potential of poly(para-phenylene) (PPP) as a biomaterial in orthopedic load-bearing applications. Relative to other polymers used for load-bearing biomedical applications, PPP displays promising mechanical properties that remain stable in aqueous solution [Frick et al. 2014].

The following outline will address some few independent compounders which indicate certain new directions which, in addition to "common compounding", may affect polyMaterials' current or future business orientation by additionally offering "green compounding"/biomedical compounding.

The Feddersen Group, now related to the K.D. Feddersen Foundation, is a group of companies focusing on foreign trade, distribution and marketing of chemicals, engineering plastics, stainless steel, as well as plastic production and mechanical engineering.

The privately owned (K.D. Feddersen Foundation) company is involved in compounding since 1988. Actually Karl Detlef Feddersen established K.D. Feddersen & Co. in Hamburg (Germany) in 1949 specializing in the distribution of chemical products. And in 1955 K.D. Feddersen & Co. started to trade with plastics. In 1958 after the passing of Karl Detlef Feddersen the K.D. Feddersen Foundation became the sole owner of the Feddersen Group. Already in 1968 K.D. Feddersen & Co. KG signed a distribution contract with the then German chemical giant HOECHST AG.

Since being founded in 1985, K.D. Feddersen Holding GmbH owns all companies belonging to the Feddersen Group. The 1988 acquisition of AKRO-PLASTIC GmbH, manufacturer of engineering plastics, based in Niederzissen, Germany, was the entry into plastics manufacturing. The Group has expanded globally into various business areas including being a twin-screw extruder manufacturer [K.D. Federsen; Compounding World 2014].

The Feddersen Group today is globally positioned within a broad range of industries. There are over 600 employees around the world working for the Group. Ca. 330 employees are engaged in compounding, creating in 2013 sales of €60 million [Compounding World 2014].

Specifically there are the group members

- AF-COLOR GmbH – Manufacturing high-grade technical masterbatches. It runs research and distribution facilities. It distributes high-quality color masterbatches as well as additive concentrates and carbon black concentrates to customers all over the world.
- AKRO-PLASTIC GmbH – Specialist for innovative and application-oriented plastic compounds, toll compounding, specializing in refining standard and technical plastics, and producing more than 100,000 tons of plastic compounds annually. Selected products comprise partially aromatic PA, PA 610, PA flame-retardant, PA high impact, PA/PP blends, PA/ABS-, PA/PBT blends, PEEK and LGF products.
- PolyComp –Is concerned modifying engineering plastics on a toll compounding and license production basis (a member of the Feddersen Group since 2013). Processing expertise covers a very broad range of technical polymer types, such as polyolefins, polyamides, polyesters, polycarbonates, ABS and PMMA. [6] These resins can additionally be modified, for instance, with fillers such as talc, glass reinforcement, elastomer for impact modification or different additives. Pigments can be added to produce colored compounds. To provide the maximum compound process flexibility, different extrusion technologies are used.

In 2014 the Feddersen Group acquired the Bio-Plastic portfolio from Metabolix Inc. (Cambridge, Massachusetts) and used it to establish BIO-FED as a branch of AKRO-PLASTIC GmbH. BIO-FED focuses on development, compounding and marketing of *biodegradable and/or biobased plastics*. Its specialists can provide customized technical solutions for specific application. Metabolix is a manufacturer of biobased polyesters, polyhydroxyalkanoates (PHAs) [BIO-FED].

The product range, developed and successfully launched by Metabolix under the brand name "Mvera", will henceforth be marketed and further developed by AKRO-PLASTIC GmbH through its BIO-FED branch located on the BioCampus Cologne (Germany). Security of supply for customers and the transfer of all required technologies and IP to AKRO-PLASTIC have been mutually assured through contract negotiations [BIO-FED].

M·VERA® film grade products are used for the manufacture of retail bags, organic and garden waste collection bags, industrial can liners, mulch film, etc. M·VERA® injection molding grade products cover a range of semi-crystalline, biodegradable polyester grades, with good processing performance on conventional injection molding machines. The series can be used as a biodegradable alternative for PP, PE, PS or ABS components. They benefit from biodegradability as a performance factor. Moreover, the two companies intend to continue working together in the future in the area of PHA products and blends [BIO-FED].

TechnoCompound GmbH (Bad Sobernheim/Germany) which is also active in bio-compounds belongs to the German Polymer-Gruppe ("Polymer Group"), an independent family business.

Polymer Group emerged from Polymer-Chemie GmbH and is an international, independent group of companies with extensive know-how in the production of highly filled plastic compounds and metal powder compounds. It claims to be one of Europe's leading compounders. Since 2008 the Polymer Group is present in North America, with the independent subsidiary Polymer Chemistry Inc. [Polymer-Gruppe].

The Polymer Group achieved 53 percent of its sales by compounding polypropylen (PP), which is used for parts in automotive construction. With PVC (polyvinyl chloride), which is mainly used in the construction industry, it generated 24 percent of sales. Polyethylene (PE) as the third most important source of revenue contributed 21 percent, which is used for packaging and raw material for consumer products. Founded in 1973 Polymer Group had about 420 employees in five Bad Sobernheimer works in 2013 and achieved sales of €130 million [Krupp 2014]. In 2015 Polymer Group had 480 employees [Plasticker 2016].

The group member Polyblends is involved in toll compounding of polyolefins and technical polymers, specifically polyolefin-chalk compounds [TechnoCompound].

In 2005 outsourcing the segment "Technical Compounds" of Polymer-Chemie GmbH into the legally independent TechnoCompound GmbH started with 50 experienced employees who could utilize efficient production plants for more than 20,000 tons/year and made revenues of more than €20 million. The company's strengths are a high degree of flexibility in developing customized solutions and developing innovative new products that meet changing or increasing demands, such as the new compounds with long glass fiber reinforced polypropylene (PP) or PET as the matrix material. Obtained through injection moldings up to 20 mm long rod-like granulates provide not only high strength by a high absorption capacity and high impact resistance [KONSENS 2005].

TechnoCompound showed significant growth. Sales in 2007 amounted to around €30 million [Plastverarbeiter]. Sales in 2011 was €46.9 million. Total capacity was 45,000 tons/year [Plasticker 2012]. In 2014 TechnoCompound had 60 employees, sales of €48 million and a capacity of 50,000 tons/year. The firm serves the automotive industry by 80 percent. Non-automotive applications, such as consumer goods (power tools) or goods for the construction industry show an ever stronger growth [TechnoCompound – Kompetenzen].

TechnoCompound GmbH (independent subsidiary of Polymer Holding since 2005) in 2008 established its product segment "Engineering Plastics". TechnoCompound's portfolio of functionally modified plastics ranges from commodities through technical compounds to thermoplastic elastomers. There are four business orientations [TechnoCompound]:

- Polyolefins-Compounds
- Long glass fiber (LGF)-Compounds
- Engineering Compounds
- Bio-Compounds.

Through the Engineering Plastics segment TechnoCompound offers a variety of interesting material groups, such as PA, PET, PBT and TPE [6] and common blends. Concerning temperature and mechanical requirements apart from common fillers and reinforcing materials also typical additives are used.

LGFs rod granulates are based on PP, PA and PET. Polypropylene (PP) with long fiber reinforcement can replace polyamide (PA) with short fibers.

The Bio-Compounds segment of TechnoCompound introduced in 2015 a product range Biobatch Compounds. In product development for film applications in addition to fulfilling biodegradability and compostability (according DIN EN 13432 as well as ASTM D6400 of DIN CERTCO) the emphasis is on using preferentially bio-based sources of raw materials.

More explicit with regard to its offerings and business basics is the small firm Advanced Compounding Rudolstadt GmbH [ACR]. ACR develops and produces high-quality granules of natural fiber compounds (NFC) for processing by injection molding, extrusion, extrusion blow molding and rotational molding. The product range include various PP and PE standard mixtures and customized special granules named Polywood. Different types of wood fibers are used.

Furthermore, it provides consulting concerning all aspects of using natural fiber compounds, starting with the development of materials via modification of processing plants to the technical implementation of the customers' production processes.

In 2015 ACR had 10 employees and a production line capacity of ca. 19.000 t/a.

Polywood products exhibit different properties depending on the proportion of fibers and polymers, may even have antibacterial properties and include:

- Concerning the polymer matrix polyolefins, ABS, PS, TPE and partially polyamide
- Replacement potential of technical plastics, such as PP/chalk, PP/glass fibers, ABS, but also PA 6, PA 6/glass fiber (long fibers).

A further case study on the compounder BADA AG (Bühl/Germany) [Runge 2016b] will provide more actual or potential competitors of polyMaterials.

The activities of polyMaterials in the *medical area* suggest to look into this area with regard to the role of plastics – with the consequence to operate in a governmentally *regulated environment*.

The role of plastics in the medical device (and pharma) industry continues to expand, driving demand for polymer compounds produced in *cleanroom environments* to limit the presence of submicron sized particles and modifying inadequate environmental conditions, such as pollutants, dust, airborne microbes, aerosol particles and chemical vapors [Holmes 2016].

The cleanroom has become essential in the electronic, high-tech semiconductor and aerospace industries as well as for medical device technologies and in the pharmaceutical sector [Runge 2015a] where clean, safe and contaminant- free products are imperative – expanding also the need for plastics compounding to cleanroom conditions to meet corresponding stringent requirements.

There are a number of key regulatory and technical requirements and operational essentials for a cleanroom compounding extruder. In particular, it is essential that cleanroom personnel assigned to the extruder are garmented in a complete coverall, hood, gloves and face mask as necessary, and employees are formally trained in cleanroom operations. The key requirement when installing or operating a clean compounding extruder is company mind-set [Runge 2015a; Holmes 2016].

The device company is required to follow the quality systems designated by the US FDA (Food and Drug Administration) or related European agencies (European Medicines Agency – EMA). Compounding of drugs and polymers must be done according to current Good Manufacturing Practices (cGMP) under the FDA's quality system for manufacturing pharmaceuticals [Runge 2015a].

For instance, specialist producer of biomedical polymers and compounds Foster Corp. operates three facilities in the US – two for the manufacture of engineered polymer materials for medical device technologies and one for compounding materials for pharmaceutical and combination products. Notable applications include polymer compounding for implantable medical devices, compounding of drugs and polymers for combination products, and pharmaceutical extrusion of drugs and polymers [Holmes 2016].

Biomedical polymer compounds are rather expensive. Several polymers used for implanted medical devices cost $1,000 per pound ($2,200 per kg) or more [Holmes 2016].

It is recommended that compounding extruders should be sized to maximize the yield when processing these expensive materials. Twin-screw extruders are a good choice as they allow for maximum mixing and temperature control within a short screw length. Extruder sizes used for compounding biomedical polymers are generally smaller than those used for compounding traditional healthcare or non-healthcare materials [Holmes 2016].

In 2015, the globally operating Swedish firm Hexpol TPE (Thermoplastic Elastomers) announced the start-up of a new medical line and expansion of its technical center at its Elasto Sweden operation at Åmål (the company claims it was the first European TPE compounder to gain ISO 13485 certification for development, manufacturing, marketing and sales of TPE compounds for medical devices). It will produce the company's Mediprene grades [Holmes 2016].

Additionally, there is a startup Innovative Polymer Compounds Ltd. (IPC) in Ireland (Dublin) which runs a compounding facility encompassing all of the features a customer would require of a 100K cleanroom. IPC has been founded as a sister company of the National Chemical Company Ltd. Ireland (NCC) focusing on polymer compounds which also set up a UK subsidiary NatChemCo UK Ltd. to specifically serve the UK market.

NCC is a privately owned chemical distributor which was formed in 1969 to service the chemical demands of the Irish Industry. It became the largest chemical distributor in Ireland. Its core focus is the supply of bulk and packed chemicals into the pharmaceutical and fine chemical industry, and polymers including compounds into the plastics industry. The company has several exclusive Distribution Agreements with a range of major European chemical producers [NCC].

NCC was formed in 1969 by the late Denis Looney, father of the current MD Alan Looney. It transformed its business in the 1990s from its traditional industrial market base. NCC has four divisions, Pharmaceutical, Food, Technical Polymers and Industrial [NCC].

It supplies to a range of sectors including pharmaceutical, cosmetic, construction, food, medical, plastics, textiles, electronic and engineering. NCC has a global reach in sourcing new products. After 47 years in business, NCC has affiliate partners throughout Europe, China, Japan, India, South Africa, North and South America [The Irish Times 2016].

The Company has earned recognition for excellence by winning a Global Supplier of the Year Award from a major pharmaceutical multi-national and being designated a Deloitte Best Managed Company for the last three years. With Innovative Polymer Compounds Ltd it operates a joint venture manufacturing unit [NCC].

NCC's Polymers division offers a wide range of polymers and additives into the *medical device* and *industrial sectors*, with services including material sourcing, materials stockholding, material selection, and compounding through sister company Innovative Polymer Compounds (IPC). IPC is a high quality white room compounding facility working with designers, molders and extruders in developing compounding solutions servicing medical and other high specification and regulated markets [NCC].

Compounding solutions through IPC address contract R&D. Product categories include

- Polyamides
- Vinyl Compounds
- Thermoplastic Elastomers (TPEs)
- Pebax
- Polyolefins
- Additives
- High Performance/Technical Polymers
- Engineering Polymers.

With 31 employees in 2014 NCC had €35.5 million turnover and €1.7 million profit (CEO/Managing Director is Alan Looney who is also in charge of IPC) [The Irish Times 2016].

Innovative Polymer Compounds Ltd. (IPC)

According to [Solocheck] Innovative Polymer Compounds Ltd. (IPC) was founded in March 2007 and has two shareholders. It lists Alan Vincent Looney as a company's director who is also the Managing Director of the NCC Company. IPC is located in the Midlands Gateway Business Park, Kilbeggan (Co Westmeath Ireland) – close to Ireland's major Medical Device Manufacturers [NCC 2015].

Currently it is reported that IPC was founded in 2008 [Sparrow 2014; NCC 2015], specifically in September 2008 [Compounding World 2013]. In 2013 it had a capacity of 350 tons and seven employees [Compounding World 2013]. On its current Web site seven persons are listed as its team – Henrik Bjoerk given as a Director and Partner [IPC – Contact]. H. Bjoerk is introduced as a co-founder of IPC by KTI [2012].

On foundation IPC relied on the resources of CRANN, a research institute within Dublin's Trinity College (the Centre for Research on Adaptive Nanostructures and Nanodevices) which is one of the largest research institutes in Trinity College Dublin, and on CCAN (Collaborative Centre for Applied Nanotechnology), a public body that helps Irish companies leverage nano-enabled innovation to develop material [Sparrow 2014].

CCAN is an industry-led, collaborative, applied research center enabling its member companies and research providers to work together to develop nanotechnology-enabled products and solutions for the I&CT and biomedical industries.

IPC's mission is [IPC – Mission]:

> To be the most innovative, respected, responsive and quality driven supplier of medical polymer compounds and R&D support to the medical device community worldwide based upon our 4C formula – Compliance, Commitment, Capability and Capacity.

IPC has completely transparent Certificates of Conformity (COC) and Certificates of Analysis (COA) and is a certified ISO 13485 and a Class 100K standard cleanroom polymer compounder. It performs its own color matching using a base range of FDA approved pigments which achieves tighter and more consistent color tolerances as well as short lead times for colored compounds to various (Pantone, Munsell or RAL) color standards [IPC; Qmed; ENTERPRISE IRELAND 2015].

Providing polymer compounds solely for the Medical Device Industry IPC is dedicated exclusively to medical device designers and medical device manufacturers. It works with medical device designers, molders and extruders from concept, through R&D and the development phase and all the way to production. IPC compounds are then used when the design is transferred to production.

For distribution it can rely on its parent company NCC.

IPC's *Value Proposition* has the focus on short lead-times – from 3 working days, small lot orders of 5 kg – but offering also large lots of 5,000 kg. The ability to produce small lots are in support of medical R&D activities. Furthermore, delivering will mean the highest levels of material consistency and quality backed up with outstanding customer support [IPC; ENTERPRISE IRELAND 2015].

IPC is experienced in a wide range of compounding additives including radio-opaque (radiopaque) additives, anti-microbial additives, lubricous additives, in-house color matched colors and strand pelletized, micro bead pelletized and nanocomposite materials [NCC 2015; IPC; Qmed; ENTERPRISE IRELAND 2015].

Facilities for compounding, set up in 2008 and certified to ISO 9001, include a twin screw extruder and related units and [NCC 2015]:

- Cleanroom facilities – Class 100K standard, not certified
- Full material test laboratory
- Color matching laboratory.

IPC processes a wide range of polymers for medical applications including: PEBAX, TPU, PA 11/PA 12, PPSU, PEKK, PEEK, PLA, PLA/ PHA, ABS / PC ABS, PP, PE, PC. *Geographies served* cover Europe, The Middle East and The Far East: Ireland, UK, France, Holland, Belgium, Germany, Switzerland, Poland, Finland, Italy, Spain, Turkey, Israel, China, South Korea. The *key clients* are major OEMs and first and second tier suppliers to the Medical Device Sector. Concerning *key partners* IPC works in partnership with materials suppliers and include universities and designers to develop new material choices, focusing on future needs and applications of the medical device sector. Working with research bodies and universities is across Europe on FP7 and 2020 funded projects [ENTERPRISE IRELAND 2015; NCC 2015].

Polymers with which the company is most familiar include Arkema's Rilsan, Pebax and Kynar, Lubrizol and BASF TPU's (thermoplastic polyurethanes), EMS' Grilamid range, DuPont's Surlyn, Evonik's Vestamid and Solvay's Solef and Hylar PVDF (polyvinylidene difluoride).

Rather early IPC and Trinity College developed strong research ties after collaborating on three pieces of research under Enterprise Ireland's Innovation Vouchers program, with IPC benefitting from the innovation capability of Trinity researchers [EuroNanoForum 2013].

When Trinity began discussions with Medtronic on a collaborative project that would require the participation of a materials supplier, Trinity introduced IPC to Medtronic and then two collaborative projects were conducted with CCAN funding [KTI 2012].

According to Wikipedia Medtronic Plc is a medical device company headquartered in Dublin, Ireland. Their operational headquarters is in Fridley, Minnesota. Medtronic is the world's largest standalone medical technology development company (ca. 85,000 employees, $28 billion in 2014).

Henrik Bjoerk, co-founder and Director of IPC, stated: “CCAN makes it easy for us to collaborate with large medical device companies and leading research institutes like the CRANN Institute. Within CCAN the whole development process from project definition, to execution and subsequent IP licensing is streamlined and efficient. It is exactly what industry needs.” [Nanowerk 2014].

In developing the PEBASlide technology, IPC combined its own expertise with that of other CCAN member companies and the outstanding polymer science expertise of Dr. Ramesh Babu’s group at the CRANN Institute in Trinity College Dublin [Nanowerk 2014].

The success of the two projects with Medtronic resulted in IPC investing in and joining the Science Foundation Ireland (SFI)-funded AMBER Centre of large firms and SMEs [Sullivan and Babu 2013], hosted at Trinity [KTI 2012].

The two projects were named: SIRNANO and NanoSlide [Sullivan and Babu 2013; CCAN].

Henrik Bjoerk, co-founder of IPC, stated: “For fast growing Irish companies such as IPC to develop and deliver new products, it is essential that we can quickly and easily access the expertise needed from a wide network of development partners.” [KTI 2012]

The medical device company sought radiopaque polymers for *in vivo* imaging – to replace precious metal marker bands in catheters. But there were tight specifications – polymer properties, composition, strength flexibility, manufacturability etc. [EuroNanoForum 2013].

The SIRNANO (Selective Incorporation of Nanoparticles for Radiopaque Medical Grade Polymers) project involved a CCAN funded feasibility study of CRANN and the two industry partners, IPC and Medtronic.

Concerning the compounding trial,

- During the project the most successful polymers brought to production trial
- Worked with IPC to ensure successful up scaling – challenge to compound highly loaded polymers
- Measure and verify mass fraction of additive in composite
- Extrusion trial by Medtronic
- Radiopacity similar to gold marker band.

Achievements and benefits for Innovative Polymer Compounds (IPC) were [EuroNanoForum 2013]:

- SIRNANO team assembled – Project delivery in less than 18 months
- IPC now
    - Has a new product line
    - Export sales to new customers
    - New R&D relationship with Medtronic.

The NanoSlide project (Nano-additives for Low Friction Medical Grade Polymers) had the same three partners as SIRNANO [Sullivan and Babu 2013].

Low-durometer polymers often are used to manufacture catheters and medical tubing (for instance, stents). They afford flexibility to the physician who is navigating the device through the vasculature while minimizing patient trauma. However, the material's inherent friction can lead to manufacturing and packaging issues and create complications in the final application. Through the NanoSlide project a material based on a medical-grade polyether block amide from Arkema, Pebax MED, that improves lubricity and adds functionality, could be developed [Sparrow 2014].

NanoSlide had to overcome several challenges [Sullivan and Babu 2013]:

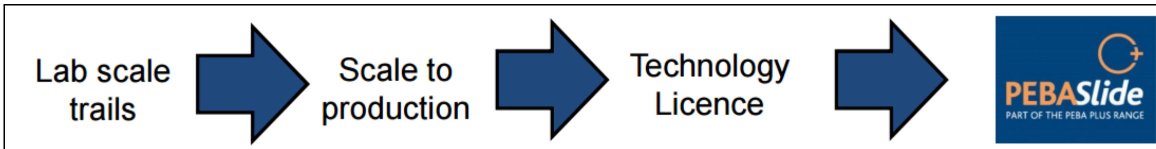
- Potential advantages over existing technologies, such as hydrophilic coatings – non swelling, non-migrating, inherent in polymer with no potential for detachment.

Pebax is a widely used polymer in the medical device industry. Concerning additives, after review of current solutions, few publications existed on Pebax incorporating friction reducing additives measured essentially by COF (Coefficient of Friction). But water absorption and dimensional stability in water at body temperature is also important.

"Materials with a low Shore hardness tend to have tackiness issues," said David Howard, IPC Marketing Director. "We tweaked the formulation of Pebax in terms of lubricity and, to some extent, conductivity." This was achieved by adding a nano- additive to the material, called PEBASlide, that resulted in a measurable improvement in the coefficient of friction [Sparrow 2014].

The combination of a hydrophilic polymer with nano-additive was found to deliver a combined effect; most promising candidates were compounded with IPC. The final compound was PEBAX 4033 hydrophilic polymer plus nano-additive.

The IPC PEBASlide™ product line is a direct result of a technology license signed with CCAN – the Collaborative Centre for Applied Nanotechnology. The licensed technology allows IPC to enhance the properties of PEBAX [Nanowerk 2014].



[Sullivan and Babu 2013]

David Howard, Sales Director at IPC, commented on the reaction to the product launch. "The PEBASlide launch created significant interest for IPC at the Medtech Europe show and we are already preparing and shipping PEBASlide batches for evaluation by customers." [Nanowerk 2014].

And Dr. Alan Hynes, Executive Director of CCAN commented "This technology license and product launch further enhances IPC's reputation in the medical device industry as an innovative adopter of advanced technologies and a partner of choice for larger companies seeking specialist polymer solutions for their medical devices." [Nanowerk 2014]

IPC also participated in European medical technology projects, the European Union's Seventh Framework Programme (EU FP7) [Bio-PolyTec 2013]. The project [Bio-PolyTec 2013] with total cost of €1,015,391.2 and EU contribution of €787,595.95 provided €156,199.75 to IPC. The project's goal was outlined as follows:

The manufacture of bioresorbable medical devices for temporary implantation inside the human body is growing into a high-value industry with many benefits over traditional devices. Bioresorbable devices do not need a removal operation, reducing patient trauma and significant healthcare costs. Due to the ability to add antibacterial or antibiotic drugs and to control the release rate at the implant site such devices can reduce the number of post-operative complications.

The seven project partners (and one coordinator) are from the UK, Finland, Germany and Ireland. They include academics and polymer processing and biomaterials experts at two universities and staff in three manufacturing firms.

The main obstacle to wider use of the material has been high processing costs. Now Bio-PolyTec was developing monitoring and control techniques which will speed up processing methods and slash high rates of wastage of the costly material. Joe Molloy, Technical Director IPC, said, ability to monitor and control the dispersion of additives in a polymer is an important technological development [MPN 2014].

Joe Molloy continued: “Consistently dispersed additives are key for performance in medical implants, but it can be expensive and time-consuming to achieve. With the real-time dispersion measurement instrument that the Bio-PolyTec project aims to develop, Innovative Polymer Compounds (IPC) will much more effectively be able to measure product consistency, which enables implants to be developed faster and with improved performance. This adds another competitive advantage to Innovative Polymer Compounds’ (IPC) repertoire.”

Although the material is expensive, ranging from €2k-5k per kilo, it is being used increasingly in implants. Processing methods are complex and slow and entail long and expensive trial and error tests which result in typical “scrap” rates of 25-30 percent. According to Dr McAfee: “In many cases this is prohibitive to successful commercialization of devices. In Bio-PolyTec we will develop novel instrumentation and control technology to rapidly optimize process set-up and reduce scrap rates to a target 5%.” [MPN 2014]

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TechnoCompound: *Web.*
Company. http://www.technocompound.com/,
http://www.technocompound.com/unternehmen/historie/,
Products. http://www.technocompound.com/produkte-anwendungen/,
http://www.technocompound.com/fileadmin/media/downloads/publikationen/TechnoCompound_de.pdf, http://www.polymim.de/uploads/media/Praesentation_Polymer-Gruppe_2010_01_dt_01.pdf,
Competencies – Kompetenzen. http://www.technocompound.com/unternehmen/kompetenzen/,
Biobatch. http://www.technocompound.com/produkte-anwendungen/biobatch/,
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Notes

1. *Injection Molding* (Spritzgießen): https://en.wikipedia.org/wiki/Injection_moulding.
Injection molding is a manufacturing process for producing parts by injecting material into a mold. Injection molding can be performed with a host of materials, including metals (for which the process is called diecasting), glasses, elastomers, confections, and most commonly thermoplastic and thermosetting polymers. Material for the part is fed into a heated barrel, mixed,

and forced into a mold cavity, where it cools and hardens to the configuration of the cavity. Injection molding is the most common modern method of manufacturing plastic parts; it is ideal for producing high volumes of the same object.

2. *Extrusion*: https://en.wikipedia.org/wiki/Extrusion.
Extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed through a die (a certain manufacturing tool) of the desired cross-section. The two main advantages of this process over other manufacturing processes are its ability to create very complex cross-sections, and to work with materials that are brittle, because the material only encounters compressive and shear stresses. It also forms parts with an excellent surface finish.
The extrusion process can be done with the material hot or cold. Commonly extruded materials include metals, polymers, ceramics, concrete, play dough, and foodstuffs. The products of extrusion are generally called "extrudates".

3. *Twin screw extruder*: http://www.polymerprocessing.com/operations/tscrew/index.html.
(Zweischneckenextruder) Twin screw extrusion is used extensively for mixing, compounding, or reacting polymeric materials. The flexibility of twin screw extrusion equipment allows this operation to be designed specifically for the formulation being processed. For example, the two screws may be co-rotating or counter-rotating, intermeshing or nonintermeshing. In addition, the configurations of the screws themselves may be varied using forward conveying elements, reverse conveying elements, kneading blocks and other designs in order to achieve particular mixing characteristics.
It enables the continuous production of highly homogeneous and finely structured products, using bio-sourced or synthetic raw materials. It is used to produce a wide range of food & feed products, cellulose pulps, (bio-sourced) plastics and chemicals.
Pictures: http://www.clextral.com/technologies-and-lines/technologies-et-procedes/twin-screw-extrusion-technology/,

4. *Product Design Workbench*: http://www.systems-biology.com/products/custom.html.
The product design workbench is an integrated software-platform to support the industrial product design process and comprises the following methods: a) evolutionary algorithms modules to handle optimization problems in high-dimensional and discrete parameter spaces as well as for the identification of suitable initial values for fine tuning; b) modules for data-based modeling, i.e. based on specific artificial neural networks and structured hybrid models (a combination of neural networks and rigorous models); c) modules for the design of experiments specifically for data-based models; d) an integrated database with interfaces to external data sources for data import and export; e) an inquiry module to find exactly those experiments which are relevant for a specific product design problem.

5. *Silent participation*: http://www.mzs-law.com/financial-professionals/financing-of-companies/silent-participations.html.
It is a financing method an investor (so called silent partner) participates in the commercial business of another person by providing a capital deposit and in return receiving a participation in the profits of the company.
One advantage is that the silent partnership will generally not be discernible for outsiders. There is no requirement of enrolling the silent partnership in the register of corporations and its status cannot be recognized from the company’s trade name. This is only different for silent participations in stock corporations.
Another advantage is that the parties are very flexible in the contractual design of the participation. The company’s financing can therefore be fitted to the individual needs of the investor and the company seeking capital. For example the silent partner can participate in the losses of the company, or such a participation in the company’s losses can be ruled out by the contract.

6. *Plastics Acronyms/Abbreviations*: http://www.professionalplastics.com/de/ACRONYMS.html (last access 3/23/2016);

Classification of polymers: Thermal data as important differentiators of polymers. *Amorphous polymers*, such as acrylic and polycarbonate, have a glass-transition temperature, Tg, but do not have a specific melting point, Tm. *Partly crystalline polymers*, such as polyethylene and nylons, contract sharply at their melting points during cooling.
https://www3.nd.edu/~manufact/MPEM_pdf_files/Ch10.pdf (last access 3/23/2016).

7. *Stratasys Ltd.* https://en.wikipedia.org/wiki/Stratasys (last access 5/7/2016).
Stratasys, Ltd. is a manufacturer of 3D printers and 3D production systems for office-based rapid prototyping and direct digital manufacturing solutions. Engineers use Stratasys systems to model complex geometries in a wide range of thermoplastic materials, including: ABS, polyphenylsulfone (PPSF) and polycarbonate (PC).
Stratasys was founded in 1989 by S. Scott Crump and his wife Lisa Crump. Scott Crump owns the patented fused deposition modeling (FDM) technology. In 2003, Stratasys fused deposition modeling (FDM) was the best-selling rapid prototyping technology. Via several acquisitions and mergers Stratasys became a $ 696.0 million (2015) enterprise with 2,800 employees. Stratasys manufactures in-office prototyping and direct digital manufacturing systems for automotive, aerospace, industrial, recreational, electronic, medical and consumer product OEMs.

Appendix

Table 6: Business Model Canvas (Template by Alexander Osterwalder).

<table>
<tr>
<td rowspan="2">Key Partners
Scientific Advisory Board
Cooperation partners for dedicated own projects (process and medical technology)
Partners in publicly financed joint projects (companies, universities, research institutes)
Business contacts in many various scientific and technical networks and associations</td>
<td>Key Activities
Industrial R&D, covering the whole process chain from search/idea generation via R&D in the lab and analytics to production compounding of materials [Stebani 2010]; consulting</td>
<td rowspan="2">Value Proposition(s)
Contract R&D; (co-)polymers, compounds, polymerization processes; IP to customers. Synthesis and low volume production of chemicals, monomers and polymers (CRO/CMO)
Perspective: contract manufacturing specialty polymers up to 1,000 tons per year [Stebani 2014]
Customer and application-specific polymer design [Stebani 2012]. Industrial R&D service: Complete process chain from the lab via analytics to production
Own R&D projects (experience!) providing polymers and materials with sales potentials in high-tech areas, e.g. high-performance materials in energy, IT, medical technology.</td>
<td>Customer Relationship
Customer-orientation fundamental as a service provider
Broad experiences guarantees quick familiarization and handling of interdisciplinary, polymer chemistry projects of customers
Projects in close cooperation with the experts of the clients or its cooperation partners
Confidentiality and reliability, flexibility and speed of service</td>
<td rowspan="2">Customer Segments
Chemical industry (large/big firms), firms of the automotive, automotive suppliers and. medical technology; OEMs
Medium-sized firms (compounders, users/appliers) Stebani 2014]
Various real or potential customers are cooperation partners of polyMaterials in publicly financed joint projects</td>
</tr>
<tr>
<td>Key Resources
Highly educated/experienced employees
KF (Headquarters): R&D labs, Analytics/Testing, compounding, “X-Plorator” technology (HTS/HTC for compound R&D)
LEV: (Chempark): Technikum for syntheses, batch polymerization (e.g. polyester, poly(meth)acrylates, polyamides, co-polymers, special polymers); injection molding, extruder for polymer work (planetary roller extruder)</td>
<td>Channels
Direct contacts with customers for specifications of projects and implementations
Customer-visits
Common distribution modes; direct selling (?)</td>
</tr>
<tr>
<td colspan="3">Cost Structure
Cost for personnel: 60+ percent – 7-9 PhD scientists and 2 CXOs with high salaries and fringes of a total of 30-35 people, many technically educated employees;
PhDs will additionally generate high travel cost to visit customers for projects and attend conferences, fairs, etc. and workshops/seminars
Other major cost items: maintenance of infrastructure, power and process/waste water</td>
<td colspan="2">Revenue Streams
Service projects (CRO, CMO),
Own R&D projects (mostly cooperative projects),
Publicly financed joint projects (minor financial contributions)</td>
</tr>
</table>

Table 7: Some data of the representatives of patent or patent application families involving polyMaterials AG until 2013 as obtained from the German DEPATISnet patent database.

Number [1)] – Patent Publication Number	Applica-tion Date	Inventor	Patent Assignee/Owner	Title
1 EP000002835375A1 <1>	2013-08-09	Escarcega Bobadilla Martha Verónica, ES; Kleij Arjan Willem, ES; Maier Gerhard, DE; Zelada Guillen Gustavo Adolfo, DE	Fundació Inst Catal d' Investigació Química, ES; Institució Catalana de Recerca i Estudis Avançats, ES; Polymaterials AG, DE	[DE] Bis-salphen-Verbindungen und kohlenstoffhaltige Verbundstoffe damit [EN] Bis-salphen compounds and carbonaceous material composites comprising them
2 DE102012223416A1 <11>	2012-12-17	Moll, Uta, 85622, Feldkirchen, DE; Schieker, Matthias, 81929, München, DE; Wiese, Hinrich, Dr., 86925, Fuchstal, DE	Schieker, Matthias, Prof. Dr. med., 81929, München, DE; polyMaterials AG, 87600, Kaufbeuren, DE	[DE] Kettenverlängerte Poloxamere, daraus gebildete thermoreversible Hydrogele mit biologischen Materialien, und medizinische Anwendungen derselben [EN] Chain-extending poloxamers, thermoreversible hydrogels formed by them which include biological materials, and medicinal applications of same
3 DE102005013790B4 <6>	2005-03-24	Gärtner, Robert, Dr., 87656 Germaringen, DE; Maier, Gerhard, Dr., 80807 München, DE; Stebani, Jürgen, Dr., 87600 Kaufbeuren, DE	Polymaterials AG, 87600 Kaufbeuren, DE	[DE] Polymerelektrolyt, Verwendung des Polymerelektrolyten und elektrochemische Vorrichtung, die den Polymerelektrolyten umfasst [EN] Polymer electrolyte the use thereof and an electrochemical device containing said polymer electrolyte
4 DE102004046172B4 <17>	2004-09-23	Maier, Gerhard, Dr., 80807 München, DE; Wiese, Hinrich, Dr., 86899 Landsberg, DE	Polymaterials AG, 87600 Kaufbeuren, DE	[DE] Offenporiger Polyurethanschaum ohne Hautbildung, Formulierung zu seiner Herstellung und Verwendung desselben [EN] Open-pored polyurethane foam without skin formation, formulation for the production thereof and use thereof as a carrier material for cell and tissue cultures or medicaments
5 US020050017412A1	2004-08-31	Maier Gerhard, DE; Rehmet Roland, DE; Schneider Christian, DE; Stebani Jurgen, DE	Maier Gerhard, DE; Rehmet Roland, DE; Schneider Christian, DE; Stebani Jurgen, DE	[EN] Methods and devices for producing homogeneous mixtures and for producing and testing molded bodies
6 DE000010252564A1 <8>	2002-11-12	Maier, Gerhard, Dr., 80807 München, DE; Wiese, Hinrich, Dr., 87600 Kaufbeuren, DE	Polymaterials AG, 87600 Kaufbeuren, DE	[DE] Kombination aus Baumaterial und Badflüssigkeit zur Verwendung in Rapid-Prototyping-Verfahren [EN] A combination of building material (BM) and bath liquid useful for direct printing of visual aid
7 DE000010141459C2 <11>	2001-08-23	Maier, Gerhard, Dr., 80807 München, DE; Rehmet, Roland, Dr., 87600 Kaufbeuren, DE; Schneider, Christian, 91054 Erlangen, DE; Stebani, Jürgen, Dr., 87600 Kaufbeuren, DE	Polymaterials AG, 87600 Kaufbeuren, DE	[DE] Verfahren und Vorrichtung zur Herstellung und Prüfung von Formkörpern [EN] Methods and devices for producing homogenous mixtures and for producing and testing molded bodies

Some patents or patent applications of customers of polyMaterials' services				
a DE102011002530A1	2011-11-01	Bohnsack, Claudia, 22043, Hamburg, DE; Fritz, Jürgen, Dr., 72144, Dußlingen, DE; Gaissmaier, Christoph, Dr., 72127, Kusterdingen, DE; Maier, Gerhard, Dr., 80807, München, DE; Mollenhauer, Jürgen, Dr., 72764, Reutlingen, DE; Stebani, Jürgen, Dr., 87600, Kaufbeuren, DE; Wiese, Dirk Hinrich, Dr., 86899, Landsberg, DE	Aesculap AG, 78532, Tuttlingen, DE; TETEC Tissue Engineering Technologies AG, 72770, Reutlingen, DE	[DE] Medizinisches Produkt und Verfahren zu seiner Herstellung, insbesondere zur regenerativen Behandlung von Knorpelschäden [EN] Medical product and method for producing same, in particular for the regenerative treatment of cartilage damage
b DE102009027983A1	2009-07-24	Gerhard, Maier, 80807 München, DE; Herz, Hans-Georg, 87616 Marktoberdorf, DE; Koelle, Philipp, 30451 Hannover, D	Robert Bosch GmbH, 70469 Stuttgart, DE	[DE] Copolymer aus einem Polyphenylen und einer flexiblen Kettenkomponente [EN] Copolymer made of a polyphenylene and a flexible chain component
c DE102009027982A1	2009-07-24	Herz, Hans-Georg, 87616 Marktoberdorf, DE; Koelle, Philipp, 30451 Hannover, DE; Maier, Gerhard, 80807 München, DE	Robert Bosch GmbH, 70469 Stuttgart, DE	[DE] Sternpolymer [EN] Star polymer
d DE102007034753B4	2007-07-25	Gross, Markus, 87600, Kaufbeuren, DE; Maier, Gerhard, 80807, München, DE	GM Global Technology Operations LLC (n. d. Ges. d. Staates Delaware), Mich., Detroit, US	[DE] Fluorierte Polymerblöcke für PEM-Anwendungen [EN] Fluorinated polymer blocks for PEM applications
e DE102007034752B4	2007-07-25	Gross, Markus, 87600, Kaufbeuren, DE; Maier, Gerhard, 80807, München, DE	GM Global Technology Operations LLC (n. d. Ges. d. Staates Delaware), Mich., Detroit, US	[DE] Polymerblöcke für PEM-Anwendungen [EN] Polymer blocks for PEM applications
f DE000010153028A1	2001-10-26	Groß, Markus, Dr., 87600 Kaufbeuren, DE; Maier, Gerhard, Dr., 87600 Kaufbeuren, DE; Stebani, Jürgen, Dr., 87600 Kaufbeuren, DE	Xetos AG, 82064 Straßlach-Dingharting, DE	[DE] Holographisches Aufzeichnungsmaterial und Verfahren zur Bildung eines lichtbeständigen Hologramms [EN] Holographic recording material and method for creating a light-resistant hologram

1) Numbers in <> means number of patents in the patent family.

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Critical reading of this case and helpful discussions with polyMaterials co-founder Dr. Jürgen Stebani during several occasions are gratefully acknowledged.

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