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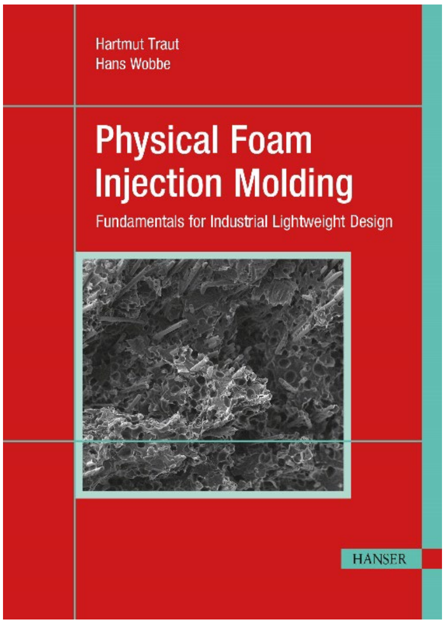

Sample Pages

Physical Foam Injection Molding

Hartmut Traut und Hans Wobbe

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Preface

The industrial injection molding process is dominated by compact injection molding, despite the wide variety of special processes available. Of these, one process, the foaming of plastics, is coming into focus due to its potential as a driving force of the lightweight design megatrend.

This involves the chemical and physical foaming of plastics. The latter, physical foaming, is of greater importance in the range of applications today. However, this was not always the case. Based on a patent from MIT (Massachusetts Institute of Technology), physical foaming became widespread only since the late 1990s / early 2000s through the global manufacturers of injection molding machines. The interested machine manufacturers concluded contracts with the patent holder – Trexel Inc., USA – and started marketing the technology. Both main authors of this book remember these beginnings well, as they both were involved in contract signings.

Today, physical foam injection molding is on the threshold of becoming another standard process alongside the established compact injection molding process. The focus of our considerations is therefore on answers to the questions that have so far stood in the way of this goal: Why has physical foam injection molding not become more widely accepted, even though there are already so many outstanding example applications that speak in favor of this technology?

As with the introduction of all new innovative technologies, investments are also necessary for foam injection molding. However, we are not thinking here of the necessary machine equipment for production. We would rather leave the monetary evaluation of comparing the manufacturing costs using compact injection molding with those using the foam molding process to the businessperson.

We are thinking of investments in the training of product designers responsible for the part design suitable for foam injection molding, investments that are necessary to create appropriate guidelines and standards, and investments to register and publish specific material data. If you ask the universities responsible for research and training about this, the answer is always: *"The process has been developed, what are you waiting for? Now the ball is in the industry's court!"* With the questions formulated above, we are obviously in an unresolved "gray area" between engineering science and industry. But isn't engineering science closely intertwined with industry, and should they not seek dialogue with each other? This is obviously less the case with our topic.

We as authors have therefore initiated Guideline 2021 ("Thermoplastic foam injection moulding") at the VDI (The Association of German Engineers), which was published in May 2023, and with this book we also want to make a contribution to the design guidelines that have been missing up to now. The last missing area of material data sheets is also discussed. Frankly, however, this is the last missing link to the breakthrough of foam injection molding as a second standard process, since few impulses for solving the problem come from the material manufacturers who are actually responsible. In concrete terms, this means that there is a lack of material data without which no part designer can make detailed calculations. Molders who consistently and uncompromisingly enter the technology of foam injection molding must therefore currently invest their own work with regard to the material question. However, a competitive advantage will be the reward.

This book, with its broad presentation of all important topics, is intended not only as an important guide for the beginner, but also as an aid to the advanced user of foam injection molding in dealing with current problems.

The main authors would like to express their special thanks to the other co-authors on their individual contributions, for their willingness to cooperate and for their perseverance and patience during the long development phase of this book project. In particular, we would like to take this opportunity to thank Mr. Roger Kaufmann, who actively supported us with his pure expert knowledge of the important areas of process simulation application and mold design and development. Furthermore, the authors are deeply indebted to the staff of Carl Hanser Verlag for their helpfulness and generous support in coordinating the work at the publishing house. Another big thank you goes to Ms. Angelika Wobbe, who not only had to hold the threads together, but also took over the careful review and correction of the book chapters and is also responsible for the translation into English.

Hartmut Traut, Siegen, Germany
Hans Wobbe, Hitzacker (Elbe), Germany

Spring 2024

Foreword

What is holding back new technology adoption? Often our personal aversion to risk. The reasons for this may be laziness on the one hand, and on the other hand the application of the familiar, the good old habits. Often, it is simply ignorance. The ignorance regarding opportunities and risks as well as the uncertainty in evaluating them correctly in order to dare to implement. To dare and not to hesitate in order to release beneficial potentials. It is often the same when it comes to using physical foam injection molding technology: "Isn't it all voodoo?" – Which brings us back to uncertainty, and thus to risk aversion.

But then, it is not that simple. Good solid engineering of products, tools, machines and processes is based not only on the depth of technical knowledge, but also on engineering common sense. In other words, on the valuable wealth of experience of a technical expert, but also on the gut feeling of the specialist. The skillful combination of both is a guarantee for the development of efficient and economical production processes, which are then used to manufacture high-quality products that meet the requirements.

And this is exactly where the work of the authors Traut and Wobbe comes in. The aim of this book is to enlighten, to create trust, and to enable users to go risk-consciously into the implementation. The technology of physical foam injection molding has been around for a good 20 years. At the beginning, it was heavily regulated due to existing patents by the Trexel Company, which meant that the spread of MuCell® on shop floors was correspondingly restrained. Due to this obstacle, the process could only slowly establish itself in the world of plastics. In addition, in the early years, attention was often focused on the general upgrading of the process technology, its implementation possibilities and performance diversity. Now that the process is in place, one might think, it is time to move on to production. However, as is well known, the industrialization of a process technology already begins with product development. You could also say that the process follows the product with its requirements and specifications, and not the reverse. It always makes sense to first clarify the *"what"* and the *"for what"* before one can think about the *"how"* and the *"by what means"*. Classic, but proven – unfortunately not always put into practice. But that is another topic ...

In order to be able to successfully implement the promising advantages of physical foam injection molding, such as weight reduction, minimization of shrinkage and warpage, and cycle time reduction – to name but a few – it is necessary to take into account and, above all, to realize the special process engineering features early in the product development stage. The classic doctrine of material- or process-oriented design for compact injection molding applies only to a limited extent, or is no longer necessary in the depth of its consequence. In this case, this can be very advantageous, especially with regard to wall thickness variations, sink marks and geometric dimensional accuracy. In short, it must – or rather "may" – be designed differently. The same has an effect on the mold design and thus on the mold construction. Here, too, there are special features to be taken into account so that the process can ultimately be successfully applied.

Product, mold and injection molding machine: an inseparable triad that must be harmoniously coordinated to ensure process capability around the clock if necessary. All these topics are discussed, explained and usefully reflected upon in the book, based on the professional competence that the entire team of authors has built up and acquired over many years. Reading this book, it soon becomes obvious that the practical implementation of what is described has a very high priority. Basic knowledge and solution approaches are considered holistically. Advantages and disadvantages are presented and discussed.

At this point, one can only wonder why it has taken so long for such a standard work to be made available to the industry. The "thirst for knowledge" is there – finally, it is satisfied.

Thomas Seul, Schmalkalden, Germany

Spring 2024

The Authors

Hans Wobbe

Dr.-Ing. Hans Wobbe switched from compounding to injection molding after holding several management positions in plastics compounding, including head of development at Werner & Pfleiderer GmbH in Stuttgart, Germany.

The combination of both technologies was first developed as a production-ready system for the market under his responsibility as Managing Director Technology at KraussMaffei Kunststofftechnik GmbH, Munich. During his time as Managing Director Technology/Production of the Austrian company Engel Holding GmbH, a special focus was on the development of a complete product range of fully electric injection molding machines. In production, the expansion and construction of new plants was also stepped up, particularly in Asia (South Korea and Shanghai/China).

In 2010, as an independent management consultant, he founded the partnership Wobbe Bürkle Partner together with Dr.-Ing. Erwin Bürkle, which today operates under the name Wobbe & Partner. Since 2016, he has been a member of the strategy board at Yizumi Precision Machinery in China.

In 2014, he was appointed as Foreign Expert in China by the “State Administration of Foreign Experts Affairs” (SAFEA) and has been “Member of 1000 Thousand Plan” since then.

Hartmut Traut

After completing his vocational training as an industrial sales representative and graduating from a technical secondary school, Dr. Hartmut Traut completed his first degree in business administration. He completed his second degree, in teaching/secondary level II with a vocational specialization, in 1982 and then completed his doctorate as Dr. phil.

In 1987 he founded the company Centro Kontrollsysteme GmbH, Germany, which to this day develops and manufactures control and sorting systems for the packaging industry, and was its CEO.

After selling the company in 1994, he worked for 8 years as Sales and Marketing Director at Thermo Detection, responsible for Europe, Middle East and Africa. Products included chemical and optical detection systems for the food and beverage industry.

He then served as Trexel's Business Director for Europe for 19 years, most recently as Vice President International Relations. He helped build Europe into Trexel's largest market. The partnerships he established had a major impact on the company's global growth. In recognition of his many years of service and his role in the development of Trexel, the company has awarded him the honorary title of "Vice President Emeritus".

Glossary of Abbreviations

Abbreviation	Definition
AiF	Arbeitsgemeinschaft industrieller Forschungsvereinigungen (German Research Association)
Al	Aluminum
ASA	Acrylonitrile–styrene–acrylate
BLM	Boundary-layer mesh
DIN	Deutsche Industrie Norm (German industry standard)
FEM	Finite element method
Fraunhofer ICT	Fraunhofer Institute for Chemical Technology, Pfinztal, Germany
GKV	Gesamtverband der kunststoffverarbeitenden Industrie (General Association of the Plastics Processing Industry), Berlin, Germany
HDPE	High-density polyethylene
HP process	High-pressure process
IKV	Institute for Plastics Processing, Aachen, Germany
IML	In-mold labeling
IP	Instrument panel
ISO	International Standards Organization
LDPE	Low-density polyethylene
LGF	Long glass fibers
LLDPE	Linear low-density polyethylene

Abbreviation	Definition
LP process	Low-pressure process
MFI	Melt flow index
MFR	Melt flow rate
MIT	Massachusetts Institute of Technology, Boston, USA
OEM	Original equipment manufacturer
PBT	Polybutylene terephthalate
PET	Polyethylene terephthalate
PiAE	Plastics in Automotive Engineering; VDI Congress
PP	Polypropylene
pvT	Pressure–volume–temperature behavior
SEM	Scanning electron microscope
SCF	Supercritical fluid
SPC	Storage programmable control
TFIM	Thermoplastic foam injection molding (*see* TSG)
TPE	Thermoplastic elastomer
TPU	Thermoplastic polyurethane
TSG	Thermoplastic foam injection molding
UN	United Nations
VCI	Verband der chemischen Industrie (German Chemical Industry Association), Frankfurt am Main, Germany
VDI	Verein Deutscher Ingenieure (The Association of German Engineers), Düsseldorf, Germany

Contents

Introduction

Hartmut Traut and Hans Wobbe

It is as a result of the lightweight design megatrend that foam injection molding has developed into the most important special process alongside conventional compact injection molding. However, the actual development of thermoplastic molded parts by injection molding began already in the 1950s. Experienced machine operators reduced sink marks on the molded parts by adding small amounts of baking powder to the granules. This was the beginning of chemical foaming, but with the focus on eliminating sink marks – the production of complete foamed molded parts was not yet envisaged at that time.

Before we continue with the text, a quick note on terminology: The authors have chosen to use the abbreviation "TSG" for "thermoplastic foam injection molding" throughout this book; this corresponds to the German term for the method, but is quite widely used, partly because it is the standard abbreviation applied by the VDI (Association of German Engineers). However, readers may find the abbreviation "TFIM" is sometimes used in other sources.

Thermoplastic foam injection molding (TSG) then received a major boost in the 1990s from the work carried out at MIT (Massachusetts Institute of Technology) in Boston on microcellular plastic foams using direct gassing". Compared to the chemical blowing agents used until then, direct gassing involves inert gases such as nitrogen or carbon dioxide. It is therefore also referred to as physical foaming. Here, for example, the nitrogen is metered under pressure into the plasticizing area, where the polymer is already fully melted. It plays a special role here that the gas is mixed into the molten plastic in a supercritical state. Thus, a single-phase mixture can be achieved, and with excellent homogeneity.

After some time, which was also characterized by start-up difficulties, the "special TSG process" then established itself as a largely "normal" processing method. In addition, the initiators often come directly from the molders, who are aware not only of the material savings but also of the advantages in the production of finished parts.

Lock housings in the passenger car sector are a very good example of this. The requirements of the finished part are characterized by tight tolerances, a surface without visible sink marks, and material savings. Without the TSG process, these are not achievable! In addition to the lightweight design mentioned at the beginning, the trend toward large-area, thin-walled components also plays into the cards of foam injection molding. Today, many of the required part dimensions in terms of warpage cannot be produced without TSG.

The well-known disadvantages of foam injection molding, i.e. a surface of the molded part that is not free of streaks, have now been solved. High-gloss surfaces can be achieved by rapidly variable mold temperature control. There are also ceramic-based coatings on the market which – applied in the cavity – produce a “variothermic effect”. Component surfaces with textures and grains can already be produced without the additional processes mentioned.

This means that there are no longer any limits to the TSG process – the way is now clear for it to become a standard process alongside compact injection molding. The relevant committees have also recognized this and have developed a standard for foamed components as a VDI guideline, which was published in May 2023 after several years of work.

1 Importance of Foam Injection Molding for Industrial Lightweight Design

As already mentioned in the introduction, the actual breakthrough of foam injection molding did not take place until the 1990s, driven by the lightweight design trend in the automotive industry. Developments at that time, such as the lock housing already cited or headlight housings, are now standard technology. Not only that, but today all these components in automotive engineering are actually foamed. Foam injection molding has replaced compact injection molding as the standard process for many components in the automotive industry! The technology curve in Figure 1.1 clearly shows the “development history”.

The abscissa of the graph in Figure 1.1 depicts the technology life status of the components over time, starting from the development status to the state of the art. The ordinate shows the corresponding manufacturing process, partly named with the material component to be processed (MuCell® with TPU), partly as a combination technology, such as MuCell® with film back injection.

The superficial explanation for the definitive breakthrough of foam injection molding is that foaming the plastic reduces the weight of the material for the same part geometry. At the same time, the manufacturer saves on the material input of the polymer during the primary shaping process. A closer, more intensive look at the process steps, as we will explain in detail in Chapter 3 *“Definition and Characteristics of Physical Foam Injection Molding”*, also reveals a considerable range of additional advantages. In many cases, it is precisely these advantages that make it easy for the user to decide whether a component should be produced by compact injection molding or whether it is better to produce it as a foamed part.

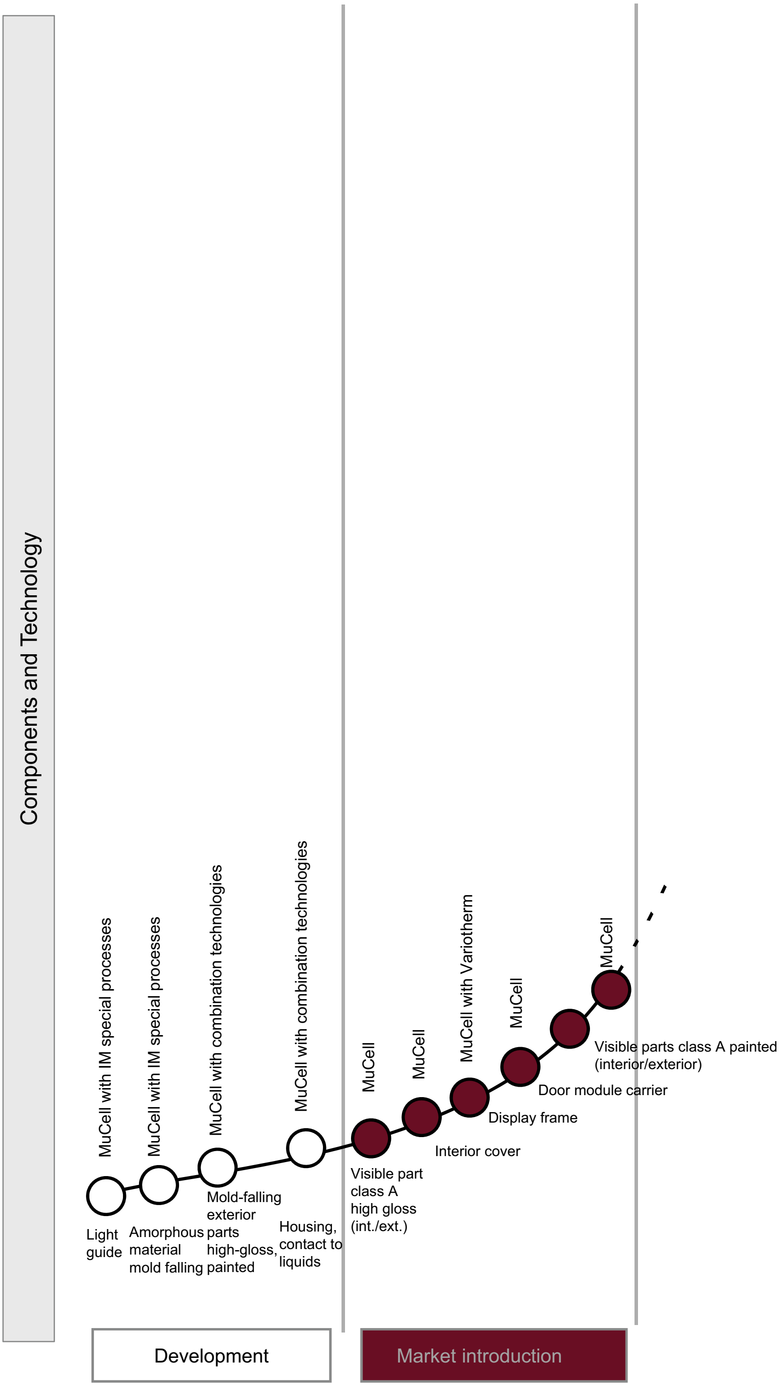
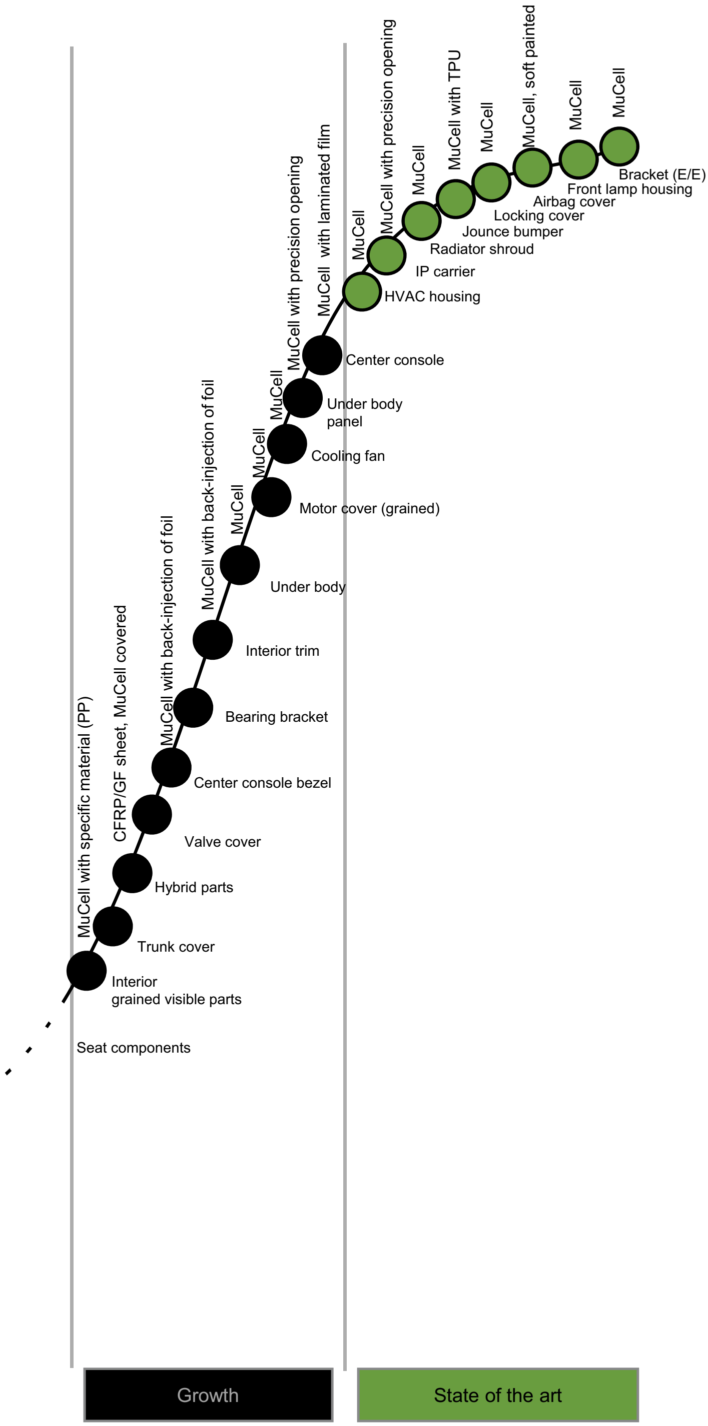


Figure 1.1 Development curve of MuCell® for automotive applications [Source: Trexel GmbH]


MuCell
Bracket (E/E)
MuCell
Front lamp housing
MuCell, soft painted
Airbag cover
MuCell
Locking cover
MuCell with TPU
Jounce bumper
MuCell
Radiator shroud
MuCell with precision opening
IP carrier
MuCell
HVAC housing
MuCell with laminated film
Center console
MuCell with precision opening
Under body panel
MuCell
Cooling fan
MuCell
Motor cover (grained)
MuCell
Under body
MuCell with back-injection of foil
Interior trim
Bearing bracket
MuCell with back-injection of foil
Center console bezel
Valve cover
CFRP/GF sheet, MuCell covered
Hybrid parts
Trunk cover
MuCell with specific material (PP)
Interior
grained visible parts
Seat components
Growth
State of the art

These advantages of the TSG process are, in addition to the weight savings already mentioned:

- A reduction in sink marks (usually to zero).
- Hardly perceptible warpage of the components.
- Production increases due to cycle time reduction.
- Possibility of thin-walled lightweight design (see in detail Chapter 4 *"Design Guidelines for Foamed Components"*).

Figure 1.2 gives an exemplary overview of this, based on four reference parts from the automotive industry. To explain Figure 1.2, let us take the "oil pan" as seen in the third row: Here, the second column in the figure indicates the reference data in each case, i.e. the part weight, the equipment investment including tooling, the productivity, the resulting part costs, and the mechanical part properties required for the critical points. The reference is, of course, the classically compact injection molded part.

In the third column "Injection Molding with MuCell®", the first results can now be discussed comparatively:

- The component weight decreases, corresponding to the degree of foaming.
- The investment increases concerning the injection molding machine. A gas dosing station is also required.
- Productivity increases significantly, mainly due to faster production cycles.
- The costs related to the component decrease, since the reduced material input and the increased productivity offset the higher equipment investment.
- The necessary mechanical properties at the critical points of the component remain intact.

It becomes even more interesting for every user as soon as the component design has been carried out as a lightweight design in compliance with the TSG design guidelines (for details, see Chapter 4). For this purpose, we will now discuss the representation in the fourth column of Figure 1.2 “Injection Molding + MuCell® + Lightweight Design”:

- The component weight of the oil pan is further reduced by approx. –10%. This is due to the lightweight design suitable for the TSG process.
- The equipment investment increases slightly, also compared to the third column, because the tooling costs for such a component are slightly higher. Otherwise, there are no changes to what has already been stated.
- Productivity continues to increase! We achieve shorter cooling times due to thinner components as well as even faster cycles of the production line.
- The costs related to the component are reduced once again, now by a good 10% in total.
- There is no change in the mechanical properties of the critical areas of strength. The values are comparable with those of compact injection molding.

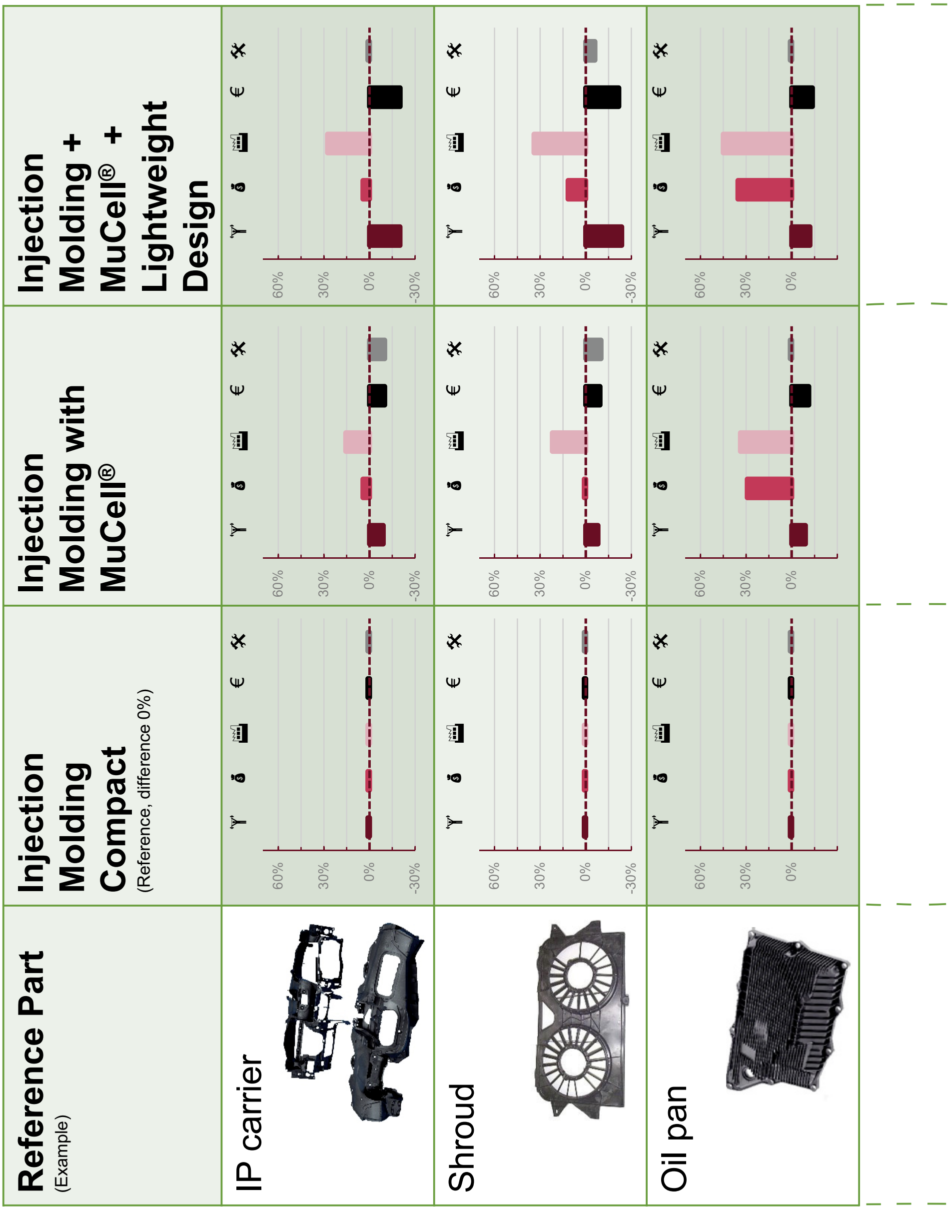
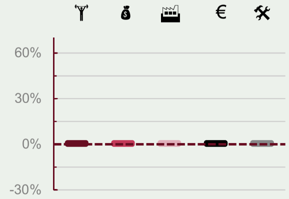
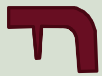
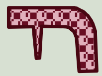
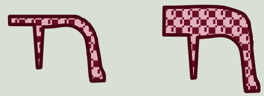


Figure 1.2 Advantages of exemplary TSG components [Source: Trexel GmbH]

Underbody (draft with mold opening stroke) 			

Remark	Molded part in conventional design:
	- Rib / Wall ratio
	- Flow length
	- Injected from thick to thin 
		Molded part in conventional design foamed with MuCell:
		- Less weight due to foamed structure
		- Production without holding pressure 
			MuCell enables free part design adapted to topographic load :
			- Lightweight design
			  - Reduced wall thickness
			  - Thick parts with lower density
			- Increase in output 

- = Weight
- = Investment
- = Productivity
- € = Part costs [1)]
- = Crucial mechanical property

[1)] Calculation based on a volume model with 300.000 cars per year

So much for the advantages of TSG components, which we experience every day in mass production. We do not wish to go into further detail here on another macroeconomic advantage that is repeatedly mentioned, namely the CO_2 footprint in production – we will discuss this issue in more detail using an example from the automotive sector in Section 9.1. However, it is clear to everyone that TSG offers considerable advantages here compared to traditional compact injection molding: Material costs decrease, production efficiency increases, and the lightweight part requires less kinetic energy in its “later life cycle”.

Let us return to Figure 1.1 in this chapter. In particular, the “Development” section should clearly show here that TSG by itself is a technology that today can be described as a standard process. In addition, however, every expert is aware that TSG in conjunction or in combination with another process offers an enormously large, yet unexploited potential for new processes.

Last but not least, we would like to point out that in most chapters of this book we list tips and suggestions in prominent type under the motto “Less is more”. In each case, the labeling begins with the symbol of a scale and points out advantages and interesting aspects of foam injection molding.

We hope that this will motivate as many readers as possible to take a closer look at this innovative process, so that further development and research will be carried out in this area in the future – because, as already mentioned above, this technology still holds some unrealized potential.

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