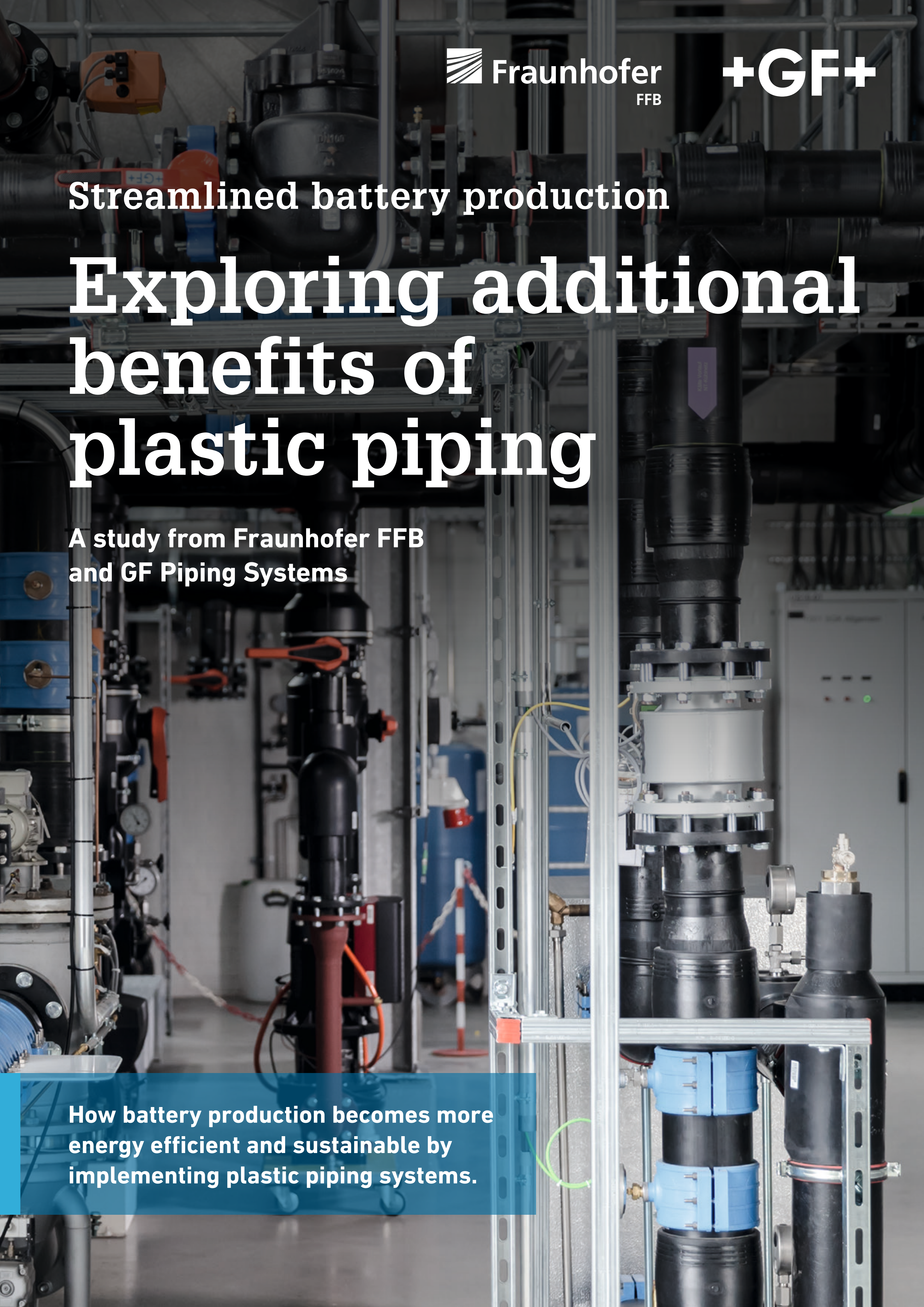


Fraunhofer FFB

+GF+

Streamlined battery production

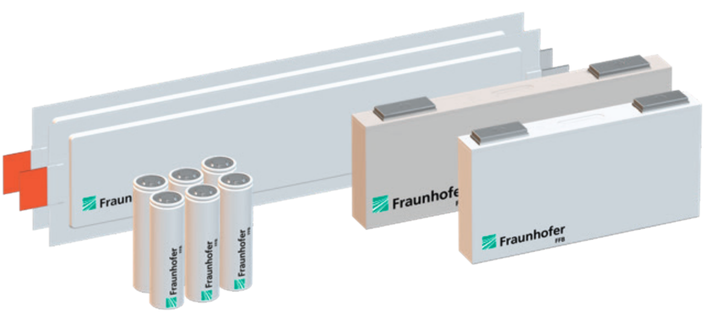
Exploring additional benefits of plastic piping

A study from Fraunhofer FFB
and GF Piping Systems

How battery production becomes more energy efficient and sustainable by implementing plastic piping systems.

Abstract

The transformation of the mobility sector has produced a significant upswing in battery cell production [1]. While the construction of new gigafactories is ongoing, economy of scale may not suffice as an approach to optimizing the industry's production capacity. Other avenues for process improvement are therefore of critical interest [3].



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The choice of piping material used for building systems and in specific applications presents one such opportunity to improve quality, lower cost, and advance sustainability. The advantages of modern plastics over traditional materials such as steel include lower cost, lighter weight, and superior chemical resistance.

The present study evaluates the advantages and limitations of plastic piping for battery production in the setting of a gigafactory operated by Fraunhofer FFB. GF Piping Systems, a leading global supplier with more than 50 years of experience, provided its expertise and indepth information about plastic piping. An analysis conducted with Fraunhofer FFB's expertise in battery cell production identified several contexts in which the use of plastic piping had a positive impact on efficiency and sustainability. Areas showing particular benefit included the heating and cooling circuits of the production plant and specific process applications such as mixing.

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Introduction

Unlocking optimization opportunities in the growing battery market

The progress of global warming requires a worldwide reduction of greenhouse gases in all sectors. Political and economic pressures for a rapid expansion of electromobility have generated an enormous increase in demand for battery cells (e.g., "The European Green Deal" [9]). To meet this demand, new mega- and gigafactories are being set up around the world. In Europe alone, new production capacities of around 1.4 TWh of battery cell capacity per year are expected by 2030, while projects with four times as much capacity were announced worldwide [2].

Even as new construction expands the industry's capacity, the larger battery cell production plants have already exploited the economies of scale [4] [5]. Other opportunities to optimize the efficiency of battery cell production are thus of great interest. All elements of factory infrastructure are receiving new scrutiny, including the critical piping systems that transport liquids and gases. While steel emerged as the standard material in the 19th century, plastic now offers an alternative with significant potential benefits.

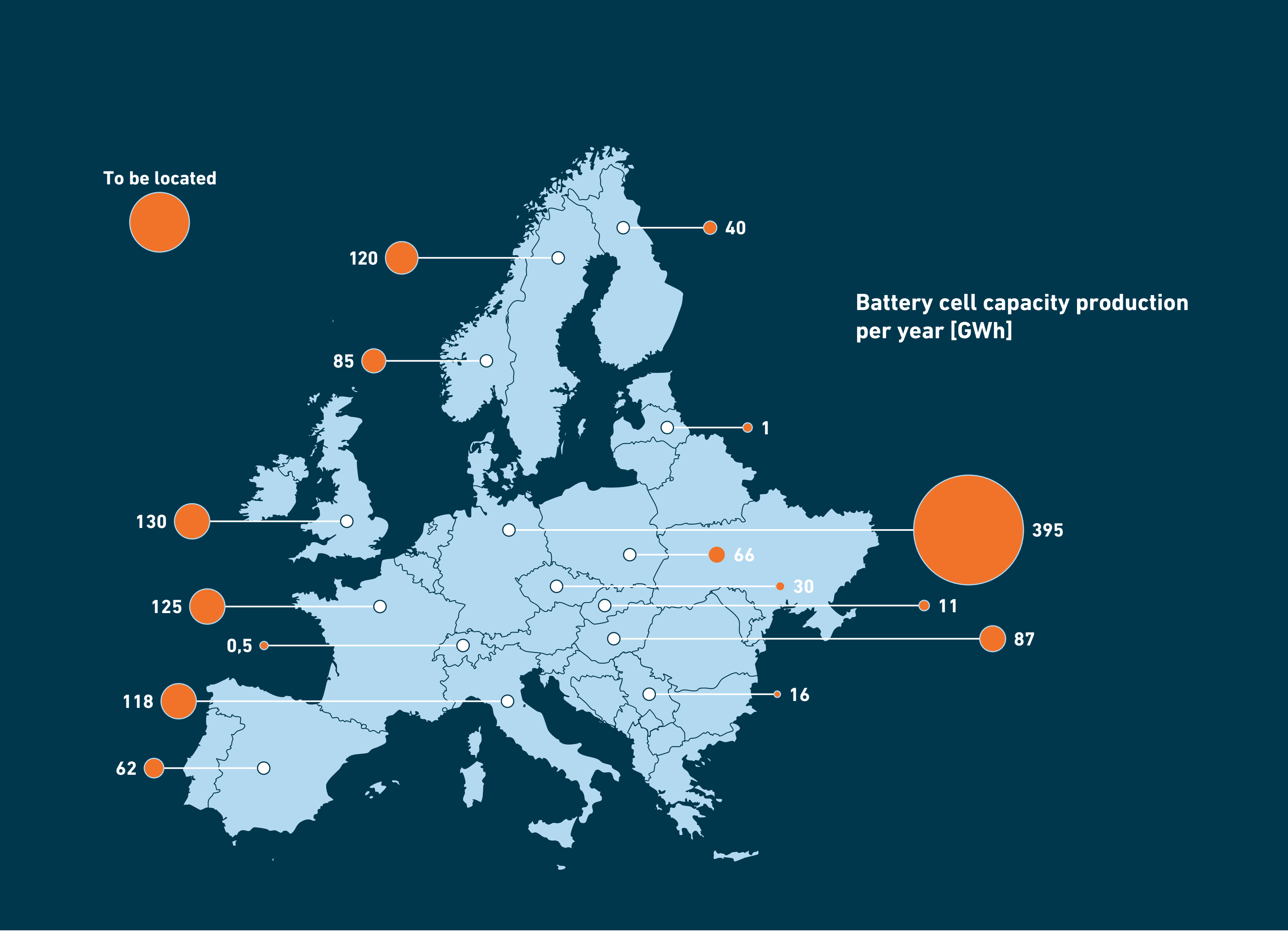

Figure 1: Announced projects for large-scale battery cell production in Europe [2]

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How plastic piping adds value to battery production

Unused potential with proven advantages

Due to the significant increase of battery cell factories in the next few years, their need for technical building systems will also increase significantly. Around 60 billion euros will be invested world-wide in technical building systems for battery cell factories in the next few years [10] [11].

One area where building and production processes meet is piping. Piping is essential in value-adding processes, both in equipment technology and at the linkage with building technology to provide heat, cold, or process media. While plastic pipes have already achieved a large market share in many areas, new applications need to be investigated [6]. Steel piping systems are still the standard in battery cell production in some applications. However, many applications are showing optimization potential by using plastic piping systems. With this background, possible applications in battery cell production were analyzed.

Potential advantages of using plastic piping systems compared to steel piping systems can be in areas such as chemical resistance, weight, handling during installation processes, service life, and energy efficiency [12] [13]. In today's solutions, sustainability often plays an essential role in decision-making. Here, plastic piping may also provide a positive added value compared to steel piping [14]. The degree to which these advantages can be realized depends on the application environment. Factors such as the chemical resistance of the medium, the process pressure, the ambient temperature, volume flow, etc., play a critical role [6].

Regarding battery cell manufacturing, some processes where piping is required are very specific. Various disciplines must work together to conduct a potential analysis to assess the potential of plastic piping systems in the environment of battery cell manufacturing for buildings and processes.

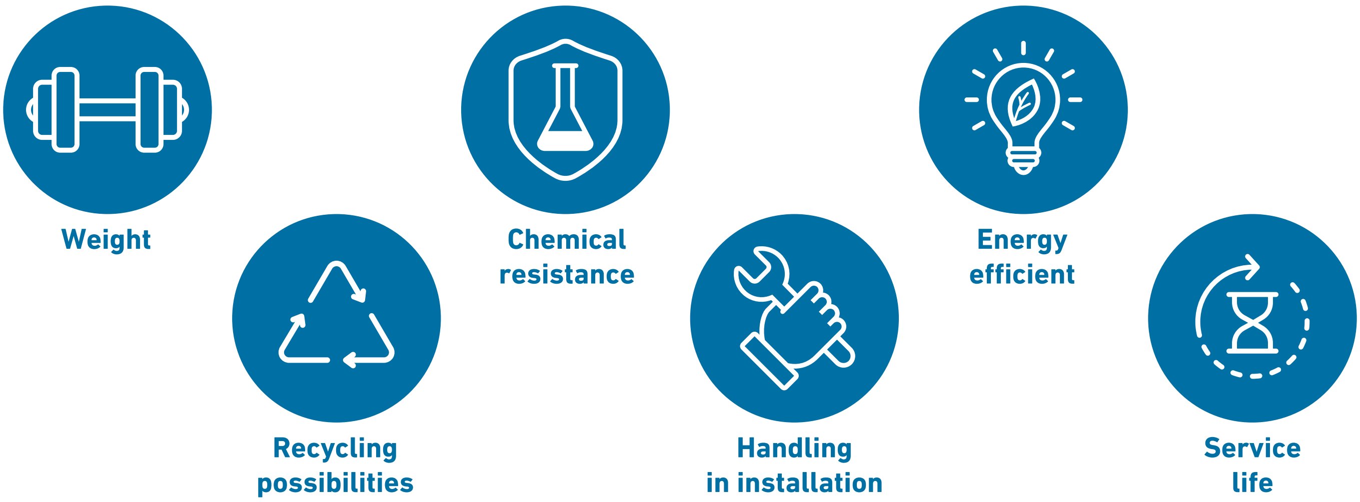

Figure 2: Potential through plastic piping

Research institute as the environment of the study

The potential analysis is performed in the environment of a research facility that mirrors a gigafactory. The Fraunhofer FFB conducts large-scale research for battery cell production. The processes and buildings used on site serve as a basis for assessing the potential of plastic piping. The Fraunhofer FFB covers all three primarily relevant cell formats (cylindrical, pouch, and prismatic) and has theoretical production capacities of 7 GWh per year in electrode production as well as three times 200 MWh per year in assembly and 600 MWh per year in cell finalization. The processes are built on 20,000 m^2 and equipped with state-of-the-art process and building technology.

The battery cell production process chain under consideration only covers the production of a cell (Process 3 in Figure 3). This analysis does not include upstream value-added processes, such as material extraction, or downstream processes, such as module assembly and recycling. However, it should be mentioned that benefits regarding the material of the piping systems are also possible in these areas and should be analyzed separately.

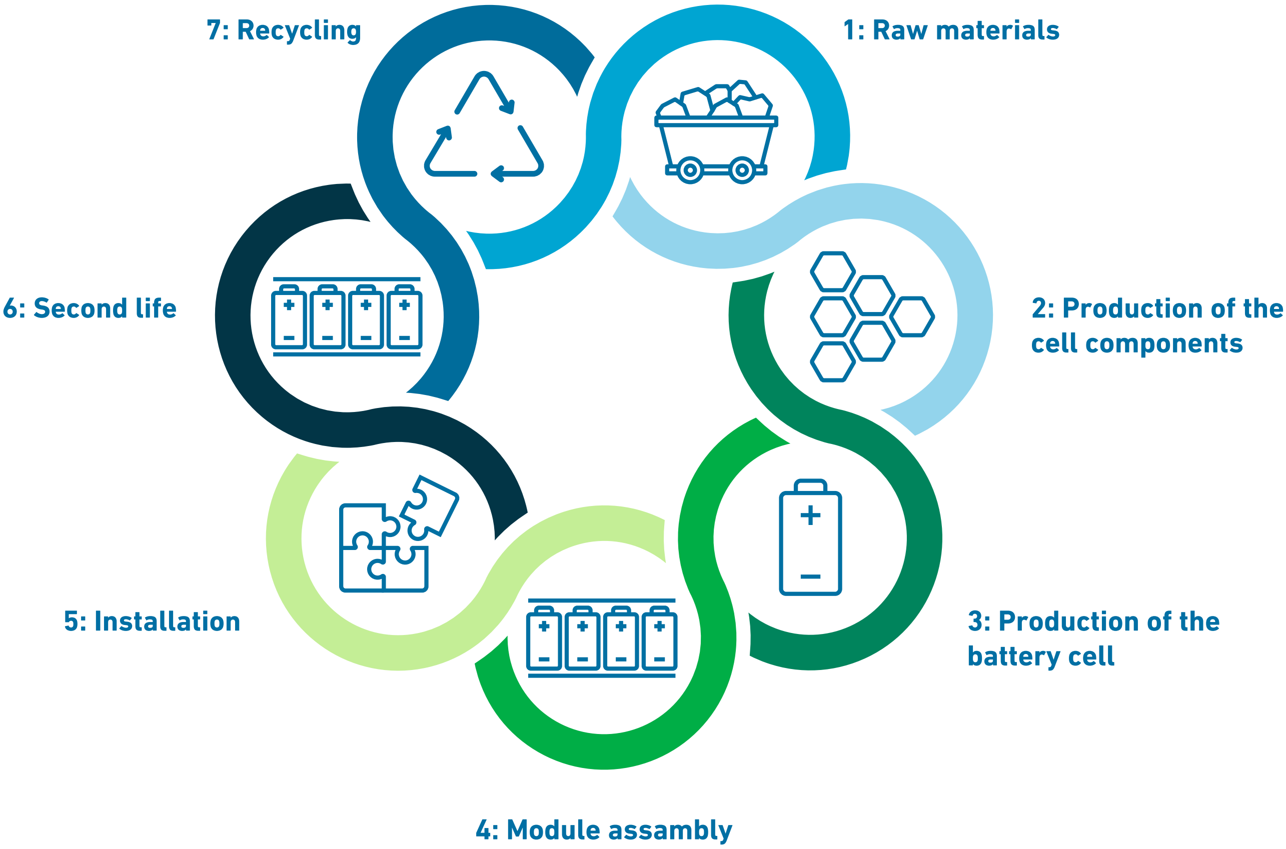

Figure 3: Battery cell value chain [1]

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Key applications for piping in battery-specific processes

To determine the demand for piping in the battery-specific processes, it is recommended to first select the processes roughly on a higher level. The considered processes are shown in Figure 4, with an evaluation of their piping amount.

This first rough estimation includes the chemical composition of the ingoing and outgoing media. Due to the chemical diversity throughout the process chain, the individual material compatibility is checked separately.

Ingoing media, which are centrally supplied (e.g., process gases, demineralized water, and solvent), and cooling and heating circuits are considered. The outgoing media include various wastewaters, exhaust gases, and solvent recovery. Due to the size of the factory and the distance between the locations of the machinery to be supplied, these piping systems can reach several kilometers in length.

The first overall assessment, therefore, provides an overview of which of the processes are to be considered in more detail. A selection of the most relevant applications for plastic pipes is then made. In particular, battery-specific applications, such as mixing and electrolyte filling, as well as applications with large amounts of piping, such as cooling and heating circuits, are considered. Pipelines that transport media with very high temperatures, as well as ventilation lines, are not examined further.

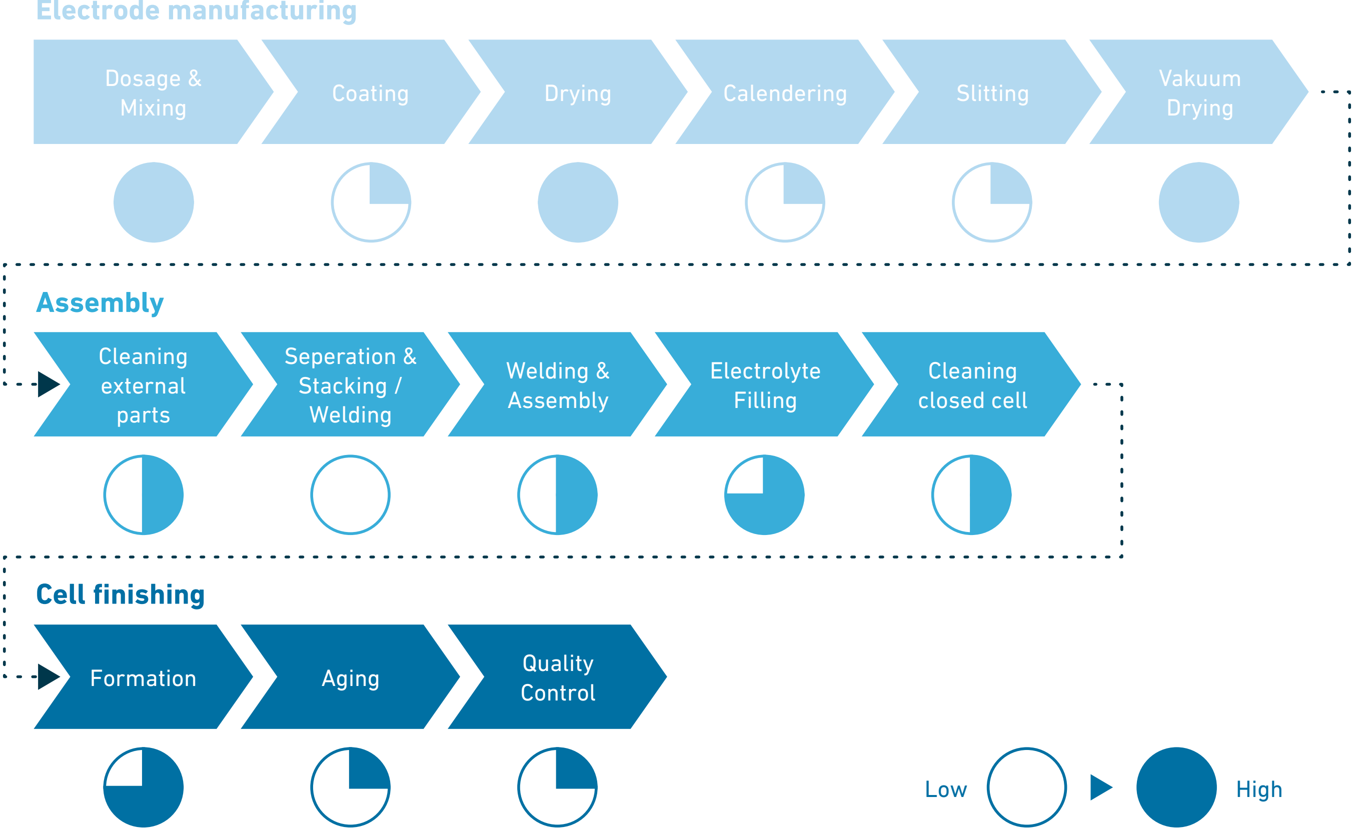

Figure 4: Overview of the quantity of necessary piping

A controlled environment demands reliable piping systems

Technical cleanliness and dry air requirements of battery cell production

Clean and dry room technology is a specific area of battery cell manufacturing critical to cell quality [15] and safety [16]. It ensures that nearly no moisture is present in the manufacturing environment of critical process steps. Process steps where ambient air could encounter the electrolyte are particularly vulnerable to moisture. When moisture enters the cell chemistry, quality degradation, and safety hazards can occur as toxic hydrofluoric acid (HF) is formed. Furthermore, surface passivation, increased gas formation, and degradation effects can occur. [16]

Due to these risks, the requirements for dry room technology for battery cell production are very high. In some cases, dew points down to -60 °C are required, equivalent to an absolute humidity of about 0.01 g / kg [17].

The complex drying process requires heating and cooling from different temperature levels, leading to a high piping demand. The drying environment is essential for many process steps, which is why they are distributed over the whole factory and additionally lengthen the necessary pipes. Figure 5 shows which manufacturing areas need to be equipped with a dry room environment. The necessary dry room technology is usually located close to the process, so the cooling and heating circuits need up to several kilometers of piping.

Given these requirements, it is necessary to look closely at the piping to determine whether plastic piping can provide advantages.

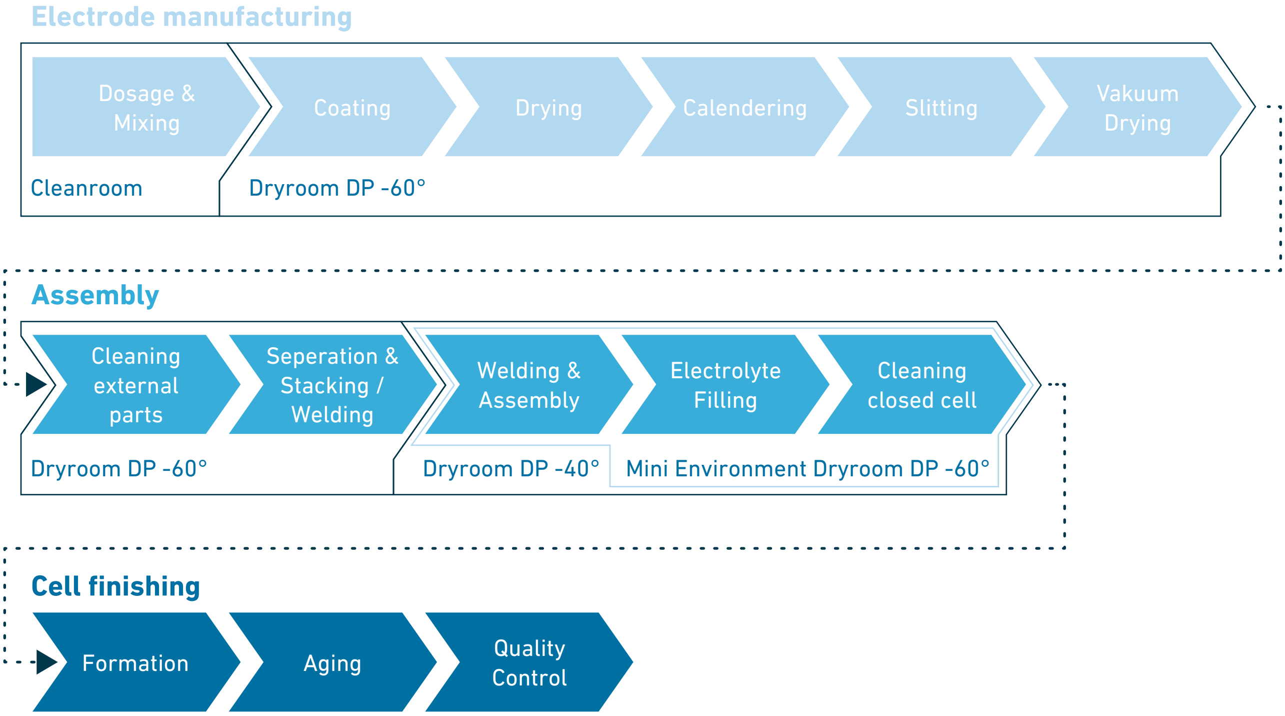

Figure 5: Humidity requirements

Evaluation model

Development of a specific evaluation methodology

Within the framework of the evaluation of piping systems, a specific evaluation methodology is applied, which is customized to the requirements of the investigation range. The use of different evaluation criteria, which can be evaluated independently of each other, is advantageous for complex applications such as piping systems in different fields of operation. A combination of the criteria can, under the circumstances, represent promising uses less accurately, although a potential can be described.

The chosen evaluation is based on four criteria, combining different impulses for the possible potential of plastic pipe systems compared to stainless steel pipe systems.

The "compatibility" criterion is of major importance, especially for applications involving chemical substances. For battery cell production, electrolytes and solvents in different aggregate states must also be supplied or discharged in addition to the electrode materials. Therefore, chemical compatibility must be

Figure 6: Evaluation Criteria

checked with the selection of available plastics. Often, the diversity of plastic materials offers an opportunity in this case.

The "environment" criterion evaluates the handling of the process parameters of the medium for plastic pipes. Here, pressure, temperature, and other parameters are reviewed with the capabilities of various plastic piping materials.

With the "market" criterion, the market is included. The current situation in the market, as well as future trends, are covered in the analysis.

Finally, the "value" criterion assesses whether plastic piping could provide added value for this application, always compared with a stainless-steel piping version.

Where plastic piping can bring the greatest benefits

Results of the evaluation

Applications that did not meet specific criteria were previously disregarded. The results of the evaluation of the pre-selected 14 piping applications are shown in Figure 7. The arrows rate each criteri-on from "very high", through "high", "neutral", "low", to "very low". In the figure, no specific materials are mentioned which were used for the compatibility evaluation. The investigation covers a range of potential materials in this regard.

	Compatibility	Environment	Market	Value
Solvent recovery: condenser circulation	Very high	Low	Neutral	Very low
Solvent recovery: exhaust air	Very high	High	Neutral	Neutral
Feed electrolyte	Very high	High	Low	Neutral
Electrolyte loaded wastewater	High	Very high	Low	Neutral
Material flow to the mixing	Very high	Very high	Very high	Very high
Material flow after the mixing	Very high	Very high	Very high	Very high
Circular rinsing process	Very high	Very high	Neutral	High
Cooling water 6/12°C	Very high	High	Very high	Very high
Cooling water 10/16°C	Very high	High	Very high	Very high
Heating water 40/35°C	Very high	High	Very high	Very high
Heating water 70/45°C	Very high	High	Neutral	Very high
Heating water 90/70°C	Very high	Very low	Neutral	Very low
Process gases: Nitrogen, Argon	Very high	High	Very high	Neutral
Process gases: Carbon, Dioxide	Very low	High	Low	Neutral

Very high · High · Neutral · Low · Very low

Figure 7: Potential for plastic piping of pre-selected applications

Solvent recovery: condenser circulation & exhaust air

The process of solvent recovery involves various piping applications. Within the condenser, there are areas where temperatures of the solvent-rich air reach up to 140 °C, while other areas cool the air down to 25°C. In the case of NMP solvent, chemical compatibility with plastic pipes is feasible, and therefore under certain conditions, the use of plastic piping in solvent recovery can be a good alternative. Individual consideration is necessary in each case, in which the temperature zone and the type of solvent must be considered. An interesting area for potential plastic piping independ-ent from the condenser is the transportation process for the liquid solvent to and from the tanks, which occurs under ambient conditions.

Feed electrolytes & electrolyte loaded wastewater

The compatibility with electrolytes still needs to be clarified. Furthermore, the development goes from less to the complete removal of liquid electrolytes, which is why the future necessity of this process is not given. Wastewater from cell washing can also contain small amounts of electrolytes. Therefore, the use of plastic tubes for this application must also be tested first.

Mixing: Material flow to and after the mixing process

The chemical resistance of common materials for anode and cathode receipts in the mixing process is given for commercially available plastic pipes. Room temperatures and low pressures do not pose major challenges for piping. Low abrasion and corrosion with liquid materials are advantageous for this application. After the mixing process, pipelines may be necessary for further transportation of the mixed slurry or mobile or stationary storage.

Process gases Argon and Nitrogen

Chemical resistance of the Argon and Nitrogen gases required in various processes with plastic pip-ing is given. Due to the various consumers, possible pipelines can become very long. Although plas-tic pipes are possible here, their advantages over steel piping may be less significant.

Process gases Carbon Dioxide

CO2 causes swelling of plastic piping. Therefore, the chemical resistance of this application is not given.

Circular rinsing process

Controlled environmental conditions are necessary in many areas of battery cell production. There-fore, the introduced external components must be cleaned of contaminants such as oil or grease. Circuits within the technical equipment pump water with cleaning agents, including the possible contaminants through the system. Plastic pipes have no difficulties in terms of compatibility as well with the volume flows, temperatures, and pressures. Technical cleanliness systems are interesting not only in the battery cell industry but also in other industries.

Cooling 6/12, cooling 10/16, heating 40/35, heating 70/45

Cooling and heating circuits are commonly centrally provided in battery cell production. As cooling and heating levels are required in various areas of the production process, very long piping may be necessary. With low chemical requirements and no extreme temperatures or pressures, plastic pipes, with their advantages, are an alternative to steel piping. However, the necessary flow rates can lead to large pipe diameters which need to be served.

Heating 90/70

The use of plastics in the hot water circuit with a flow temperature of 90 °C is generally possible but is not to its liking from an economic point of view.

Maximizing benefits

Key technologies to unlock the potential of plastic piping

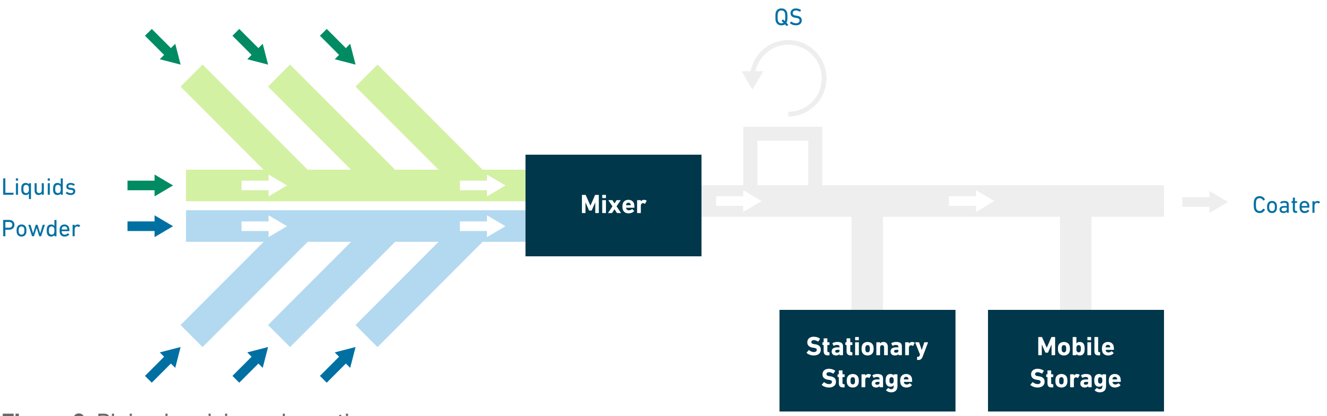

Figure 8: Piping in mixing schematic

Mixing

An interesting area for piping applications in the process chain for battery cell production is mixing. The mixing pro-cess itself is highly complex. Raw materials are mixed to produce anode and cathode pastes (slurries); the process can show differences depending on the material recipe. The chemi-cals come in liquid or solid state and with different particle sizes and quantities. They are precisely dosed for a following batch or continuous mixing process. Afterward, the finished mixed anode or cathode slurry must be provided for the coating process. When considering the entire process against the piping background, it can be divided into two in-teresting phases: the dosing of raw ma-terials and the sub-sequent feeding of slurry to the coater.

Dosing defines the supply of raw materials to the mixing zone. The requirements for the piping regarding the chemical resistance depend on the respective material. Either solids in the form of powder (< 100 µm) or fluids, e.g., water or solvents, are dosed to the process zone. The main challenge is a precise and fast supply of the material to reduce the time between individual batches or production runs while maintaining a reproducible adherence to the recipe. Due to the different aggregate states, necessary feed volumes, and materials' properties, the piping requirements are also diverse. However, it can generally be assumed that the environmental conditions do not in-clude high pressures (< 5 bar) and temperatures in the room temperature range. The chemical compatibility of plastic piping with current anode and cathode recipe is established. Moreover, its chemical resistance properties can offer benefits over steel pipes for transporting slurry and raw materials as corrosion cannot occur, and additionally, the surface properties reduce abrasion.

After mixing, the slurry is transported to the subsequent pro-cess step, coating. A transport with mobile storage systems is taking place, or a direct feed via piping from the continuous mixing pro-cess to the coating is provided. Stationary storage systems can also be filled. In the stationary stor-ages, the material circulates to avoid sedimentation. Additionally, it is possible to attach a quality assurance system (QS) to these pipes to measure some inherent properties of the slurries, such as viscosity, particle size distribution, and others. Anode and cathode slurry are mostly equal in han-dling. Anode slurry tends to be corrosive as water is the main solvent, while cathode slurry tends to be more abrasive than anode slurry due to NMC as a solvent. Piping is required to connect the stor-ages and provide QS for the realization of the material circulation in the storages. As is already the case for the individual materials while dosing, there are also no compatibility difficulties with availa-ble plastic pipes for typical slurry recipes.

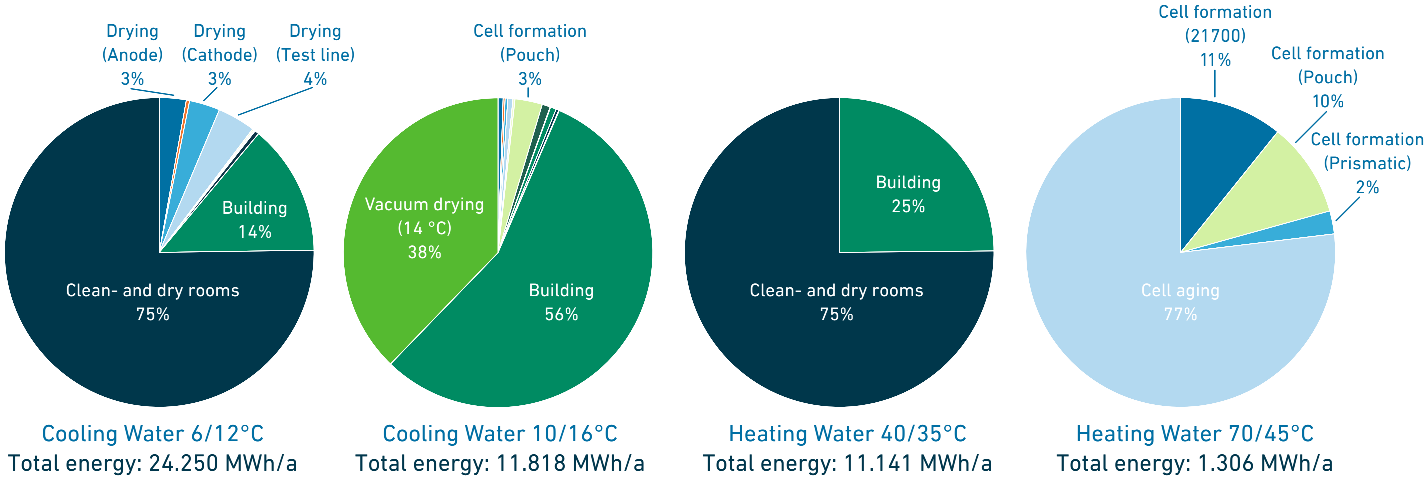

Figure 9: Energy consumption for cooling and heating circuits of Fraunhofer FFB

The advantages of plastic piping can be exploited for both piping applications in the mixing process. Since chemical resistance is given and recipe trends do not pose any difficulties, plastic pipes should be regarded as a possible alternative. Compared to steel pipes, corrosion is not present. In addi-tion, good sliding properties and additional favorable surface properties of plastic materials create a lower sensitivity to abrasion.

An additional follow-up application is the wastewater from the cleaning of the equipment for the mixing process. This water contains the same composition as the slurries, only highly diluted with water, and therefore also offers an area where plastic piping could be used with positive effects.

Cooling and heating

Numerous cooling and heating circuits are required in battery cell production. Different tempera-ture levels must be provided for various applications. These applications include equipment, build-ing technology, and clean and dry room technology. Generally, the generation of the circuits is centralized and supported by strategically placed heat pumps and cooling machines. Due to the distri-bution of the various stages over the entire production area, long pipes are required. The distribu-tion of the energy demands of the four temperature levels, which can be supplied by plastic piping, are shown in Figure 9.

The highest cooling water demands are for clean and dry rooms, air conditioning for the building, vacuum drying, and drying the electrode foils. The cooling is required for the preconditioning of the outside air and within the air flows in the dehumidifier for the dry rooms. Cooling demand for vacu-um drying and electrode drying is required for vapor condensation and NMP solvent recovery.

Low-temperature heating water is also used mainly in clean and dry rooms and building heating. At a higher temperature level, heating water is required for the cell finalization. Depending on the design of the dry room technology, no low-temperature heating water is required for precondition-ing the fresh air, but the regeneration airflow is supplied completely at a high-temperature level, such as 90 °C. The heating demand in the cell finalization is for heated climate chambers.

If the temperature limit of the materials is not exceeded, the advantages of plastic piping systems can be applied. This includes increasing energy efficiency by a good insulating system, significantly reducing the OpEx. In addition, plastic pipes are quicker and easier to install and are more sustaina-ble in production and transport because they are lighter. Furthermore, the risk of bimetal contact corrosion is minimized.


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Conclusion

Plastic piping has proven benefits

This study has demonstrated that plastic piping offers significant advantages over steel in several key applications for battery cell production. They include classic advantages such as cost reduction, handling, weight, and installation time, which are especially effective in building systems (see Fig-ure 2). For cooling and heating, which require large amounts of pipe, energy efficiency and insula-tion play an important role. Application-specific properties such as material compatibility, corrosion resistance, and abrasion resistance are also highly relevant.

The study suggests that the building's cooling and heating circuits are one of the most promising areas for plastic piping. In particular, plastic piping shows great potential for the mixing of electrode slurries. However, to fully realize plastic pipes' benefits and ensure that high-quality cells are produced, it is essential to validate material compatibility through long-term tests. By conducting thor-ough material compatibility tests, the industry can have confidence in the performance of plastic pipes and unlock their potential for a range of applications.

In conclusion, the analysis demonstrates the significant benefits of utilizing plastic piping over steel pipes in battery cell production, encompassing both building and production technologies. These findings underscore the potential for plastic piping to contribute to more efficient and cost-effective processes, further enhancing the overall performance of battery cell manufacturing.

Advantages of plastic piping over steel

Cost reduction

Easy handling

Lightweight

Reduced installation time

Material compatibility: corrosion resistance and abrasion resistance

Legend

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A study from Fraunhofer FFB and GF Piping Systems

Authors / Contributors

Fraunhofer Research Institution for Battery Cell Production FFB

- Philipp Sanders
- Finn Kutschmann
- Jakob Palm
- Marcel Berling
- Miha Podbreznik
- Markus Christian Eckstein
- Daniel Becker
- Dr. Saskia Wessel

GF Piping Systems Ltd

- Marthinus Venter
- Cyrus Ardjomandi
- Felix Sandt
- Kevin Blumberg
- Pietro Zappone

Your Contact

Finn Kutschmann
Grp Energy Technology
Mobile: +49 174 683 17 17
Jonas.finn.kutschman@ffb.fraunhofer.de

Fraunhofer Research Institution for Battery Cell Production FFB
Bergiusstrasse 8
48165 Münster
Germany

www.ffb.fraunhofer.de

Marthinus Venter
Senior Business Development Manager – Battery Production
Mobile: +49 170 476 6651
marthinus.venter@georgfischer.com

Georg Fischer GmbH
Daimlerstrasse 6
73095 Albershausen
Germany

www.gfps.com/batteryproduction

GFDO_BR_00099_EN (08.23)