



TRAJECTORY MIXING

INNOVATIVE BATTERY PROCESSING

Rethinking Slurry Production with Ultra-Fast Micro Batches





“We focus on delivering processes and innovations for a scalable and efficient battery cell production.”

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Continuous, batch, quasi-continuous – A cross-section of the mixing process

Mixing in battery production

The mixing process is the first process step in the production of conventional lithium-ion batteries. It is crucial for the quality of the battery and has one of the greatest influences on the subsequent cell performance. In the mixing process, active material, binders and conductive additives are mixed with a solvent to form a so-called slurry. Different equipment is used for this process step, and this equipment can be divided into different types of operation. These are batch operation, continuous operation and quasi-continuous operation. Prominently represented on the market are planetary mixers, twin screw extruders, and intensive mixers. These are described in more detail in the following chapter.

Depending on the design of the mixer, there are different sequences for feeding the powdered active material and solvent. The feeding sequence and the duration of the mixing process can have a decisive influence on the later performance of the electrode coating. In general, energy is introduced into the electrode suspension via a rotating mixer. The aim is to distribute the particles homogeneously over the entire volume. However, this distributive mixing is only one basic requirement of a mixing tool. Especially in the production of electrode slurries for lithium-ion batteries, it might be necessary to reduce particle size. More precisely, shear energy is required to break up potential agglomerates and thus avoid local material accumulation at the microscopic level. Nevertheless, total separation of all particles is not necessarily required. It is crucial for the mixing process to be able to control this dispersing behavior.

In order to control the dispersive mixing behavior and the input of energy into the slurry, there are different phases or times at which the individual components of the slurry are added. The times and quantities of addition depend on the mixing equipment. Three different phases or operating modes for the previously named mixing equipment can be differentiated. These phases are dry mixing, wet mixing, and kneading.

In **dry mixing**, the dry materials are distributed as homogeneously as possible. The aim is to break up the heterogeneous phases to avoid unwanted agglomerates when adding the solvent later. The dry mixing phase is only required if different dry components are to be mixed first.

If a smaller proportion of dry materials or a suspension with higher viscosity is added or mixed to a larger proportion of solvent, this can be referred to as **wet mixing**. Depending on the type of mixer used, the primary work of slurry production is performed in this phase, or only the desired viscosity is produced and optionally liquid binder is admixed.

In the so-called **kneading phase**, a large part of the energy is often introduced into the slurry. In this case, the kneading phase largely consists of the formerly dry materials and a limited amount of solvent. As a result, the slurry has an increased viscosity, which makes it possible to introduce shear energy in a targeted manner.

Most mixing processes can be composed of these phases. This results in different process times which are primarily due to the mixing equipment.



EXPERT STATEMENT: MARTIN DOLL, BUSINESS SEGMENT MANAGER FOR BATTERIES AT COPERION

“The twin-screw extruder is one of the examples that is finding its way into battery production from a similar industry. Universities and innovative companies recognized the potential early on and paved the way for industrial application.”

Equipment used in electrode production

The **planetary mixer** is primarily offered by Asian equipment suppliers and is one of the most established mixing technology. Depending on the manufacturer, batch sizes of up to 2,000 liters are offered and sold.

One of the most common designs is the double planetary mixer. This design usually has two slow-running mixing blades as well as two high-speed dispersers and a rigid mixing vessel. Crucial to the mixing process of the planetary mixer is the planetary gearbox, which ensures that dead zones in the mixing vessel are limited. Dead zones are those ones in which the mixing tool does not perform any work because it cannot reach these areas.

Due to the design, such dead zones cannot be ruled out, for example, at the edge and bottom areas. The distances between the agitator and the mixing vessel are approximately between five and ten millimeters.

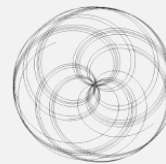
To achieve sufficient mixing, the mixing blades have a corresponding geometry to ensure material transport out of the dead zones. Depending on the process control and the times for dosing and discharging, the entire process takes between five and twelve or more hours.

In addition to this batch operation, continuous systems exist as well. Continuous production of battery slurries generally refers to co-rotating **twin-screw extruders**.

The components of the slurry are fed to different zones of this extruder. Due to the mostly modular design of the screw, it is possible to create different zones in order to adjust the desired properties of the slurry over the length of the extruder.

This is done by means of different elements which can be mounted onto the driven spindles. These can be, for example, kneading elements for an increased energy input or return-conveying elements for an extended retention time in the extruder. Based on these configurations, the retention time in the extruder can be varied.

Typically, the slurry or its individual components remain in the extruder for less than ten minutes. The throughput of the extruder is largely determined by the speed and diameter of the screws.



The line of movement of the mixing tool of the planetary mixer after three complete revolutions.

Mixing with an **intensive mixer** is significantly faster than with a planetary mixer. The mixing process itself takes place within 20 to 30 minutes. For example, up to 250 liters of slurry can be produced per batch.

Depending on the equipment dimensioning, larger volumes are feasible. Figure 1 gives an overview of the mixing process and the phases of a possible intensive mixing process. Like the planetary mixer, the intensive mixer has an agitator and a mixing vessel.

The biggest difference, however, is that the agitator does not pass through the volume of the mixing vessel. The material to be mixed is fed to the mixing tool through the rotating vessel.

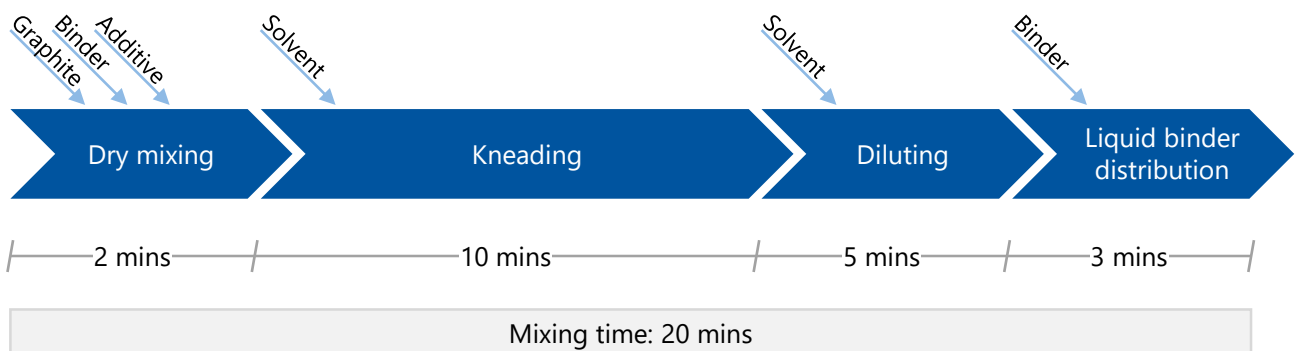


Figure 1: Illustration of a mixing process with an intensive mixer [based on Stefan Gerl 2021, Maschinenfabrik Gustav Eirich]

Depending on the design, there are scrapers that continuously clean the container wall so that there are virtually no dead zones. An intensive mixer can be operated both in batch mode and quasi-continuously. This means that after the mixing process the slurry is automatically removed from the mixing vessel and storage tanks are filled, so that a new mixing process can start again immediately afterwards and a steady volume is available for feeding the coater.

This process is identical to the continuous mixing process with a twin screw extruder. It is a fallacy to assume that the slurry is fed directly through the extruder to the coater. However, since the mixing process itself takes place in batch mode, this process control is referred to as "quasi-continuous".

Quality characteristics of the slurry

As mentioned at the beginning, the mixing process has one of the greatest influences on the subsequent cell performance and also on the cell quality. Therefore, it is crucial to be able to evaluate the quality of the slurry produced in the mixing process. Decisive parameters are, for example, the homogeneity of the slurry, the agglomerate size, the absence of bubbles, the purity, i.e. the low foreign body content, and the viscosity.

The **homogeneity** of the slurry is crucial for the consistent quality of the subsequent coating. In addition to identical physical properties resulting from the distribution and behavior of the binder, this also includes particle size distributions. For example, the slurry should have a similar particle size throughout the volume of the mixing vessel and not have larger particles in the bottom area than on the slurry surface.


Stable process control for coating through slurry nozzle is critical for battery production. The maximum particle, or **agglomerate**, size is therefore critical to avoid clogging of the slot die. On an industrial scale, this can cause scrap worth thousands of euros. But also a local accumulation of an agglomerate can have an impact and negatively influence the cell behavior. Typically, the slurry is vacuumed during or after the mixing

process in order to remove **bubbles** introduced by the process or air bound by agglomerates. Such bubbles can cause voids in the coating process and have a negative influence on the cell.

The active materials of cathode slurries in particular have an exceptionally high hardness and are considered abrasive. The mixing process is the only process step in cell production in which mechanical energy is introduced in the form of a rotating mixing tool. This inevitably results in a certain amount of wear and abrasion on the tool. Larger metallic particles within the coating can have fatal consequences in the operation of the battery cell. Therefore, it is essential to consider the wear and to ensure general **purity** of the slurry.

In industrial electrode manufacturing, the current collector foil is coated with a wet slurry layer of the specified thickness and then dried. Slot die high-speed coating equipment is the equipment of choice for this processing. For a stable coating process, it is important to stay within the process window required for this purpose. Besides the web speed and the surface tension of the slurry, **viscosity** is one of the main influencing factors. The control of this parameter is thus also decisive for the evaluation of a good mixing process.

The theoretical cell chemical potential is determined by the selection of the slurry material. Already the first process step of the electrode production has the possibility to influence this significantly. The control of all parameters and the quality is decisive for a good mixing process.



“With clever ideas and smart partners, we are bringing the trajectory mixer to the gigafactory.”

Ultra-fast micro-batch processing – The shaking mixing process

Fundamentals of trajectory mixing

Mixing in the conventional process takes place via a rotating mixing tool. This differs from trajectory mixing. Here, the mixing process is carried out by moving the mixing vessel along a specified line of motion in a plane. The basis for this movement comes from a push-crank gear. A servo motor drives an eccentric disk, which transfers the rotary motion into a linear motion via a connecting rod. The illustration of this thrust crank can be found in Figure 2:

The distance the mixing vessel travels through the push rod design can be calculated using equation (1). The coupling rods or the eccentric positioning are decisive for the stroke length.

$$x = l_1 * \cos\varphi + l_2 * \sqrt{1 - \left(\frac{l_1}{l_2}\right)^2 * \sin^2\varphi} \quad (1)$$

By adding a second thrust crank with a linear guide for the motion into a guided motion offset by 90 degrees, a motion line is obtained along a so-called Lissajous figure.

The time derivative of the position angle φ is the angular velocity ω . By varying the angular velocities of the thrust cranks with respect to each other by multiplying by a factor n and by adding a phase shift Φ , a variety of Lissajous figures are possible. The determination of the position during the mixing process can be done by means of the following equations:

$$x = \sin(\omega_1 t) \quad (2)$$

$$y = \sin(n\omega_1 t + \Phi) \quad (3)$$

Highlighted on the left side you find possible motion lines of the trajectory mixing or Lissajous figures depending on the angular velocity and phase shifts.

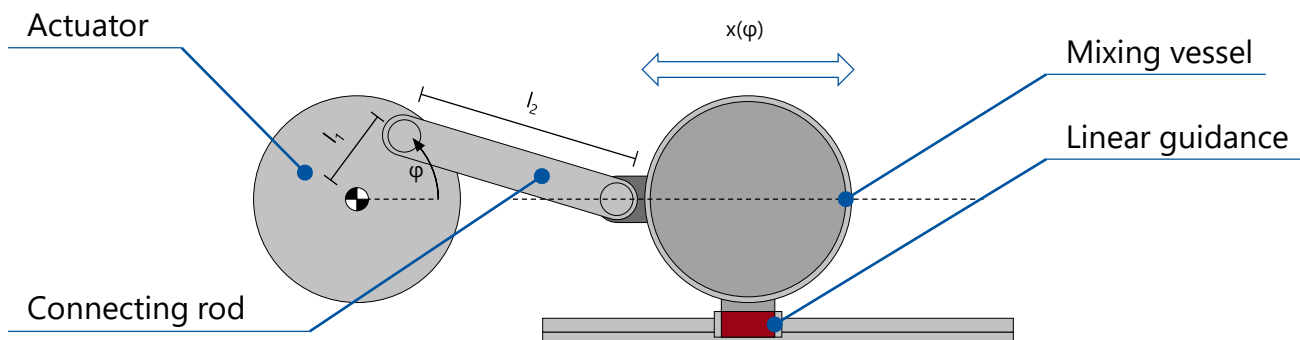
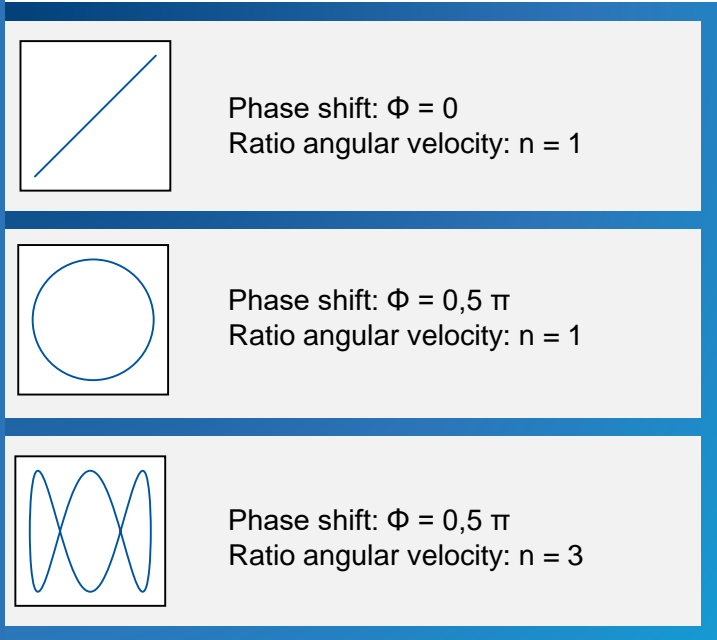


Figure 2: Illustration of the basic structure of a slider-crank gear unit; illustration with mixing vessel

Framework and predefined parameters

The trajectory mixing for battery production was carried out in the infrastructure of the chair "Production Engineering of E-Mobility Components" (PEM) of RWTH Aachen University in the pilot line of the Electromobility Laboratory "eLab". A K1 series trajectory mixer from hs-tumbler with a gross capacity of four liters was used for testing. For direct comparison of all results, a common mixer with stirrer with proven mixing protocol is used. An anode slurry is produced.

The trajectory mixing and the mixing processes as well as the machine are primarily evaluated under three aspects:

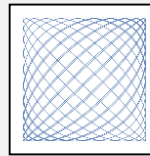
- The effectiveness and efficiency of the mixing process itself in the production of the slurry
- The processability by means of slurry application in a pilot plant and the resulting coating
- The cell chemical performance of the produced anode

The mixing process and the slurry are evaluated qualitatively and quantitatively. Here, the application in a pilot line or on a laboratory scale is considered first. In order to clarify the significance of the analysis and to be able to exclude influencing parameters of the material and the other equipment used as far as possible, the analysis is always carried out in direct comparison with a conventional mixer with an established mixing process.

Machine parameter – A constant speed as well as speed ratio, phase shift, and fill level are specified during all mixing preliminaries. The speed is 430 min^{-1} and the phase shift is set to 90 degrees. The speed ratio of the two thrust cranks is set to $n = 0.957$. From similar fields of application, it is clear that the filling height of the

vessel has a decisive influence on the mixing. The filling height is set at around 50% of the maximum volume.

For the **slurry**, a mass fraction of 94% synthetic graphite, 2% carboxymethyl cellulose, 1% conductive carbon black C45 and 3% styrene-butadiene rubber are used. The SBR is present in a 40% aqueous solution. A 1:1 ratio of dry materials and deionized water is used for processing.



Phase shift: $\Phi = 0,5 \pi$
Ratio angular velocity:
 $n = 0,957$

The **mixing process** is set up in parallel with the intensive mixing process. This comprises four phases and takes a total of 130 seconds:

- **Dry mixing:** All dry ingredients are added simultaneously to the cylindrical mixing vessel. Based on simulation results showing optimum mixing with identical and ideally round particles after a maximum of ten seconds, a mixing time of 30 seconds was specified.
- **Kneading:** In the kneading phase, the most energy is introduced into the slurry. This is where the highest shear forces occur in the conventional process. To simulate this, a phase with reduced solvent content was used. In the kneading phase, 70% of the solvent is added to the dry mix and kneaded for the duration of 60 seconds.

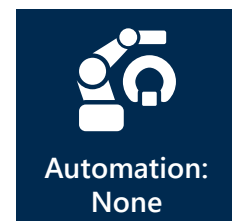


Figure 3: Properties and attributes of the hs-tumbler K1

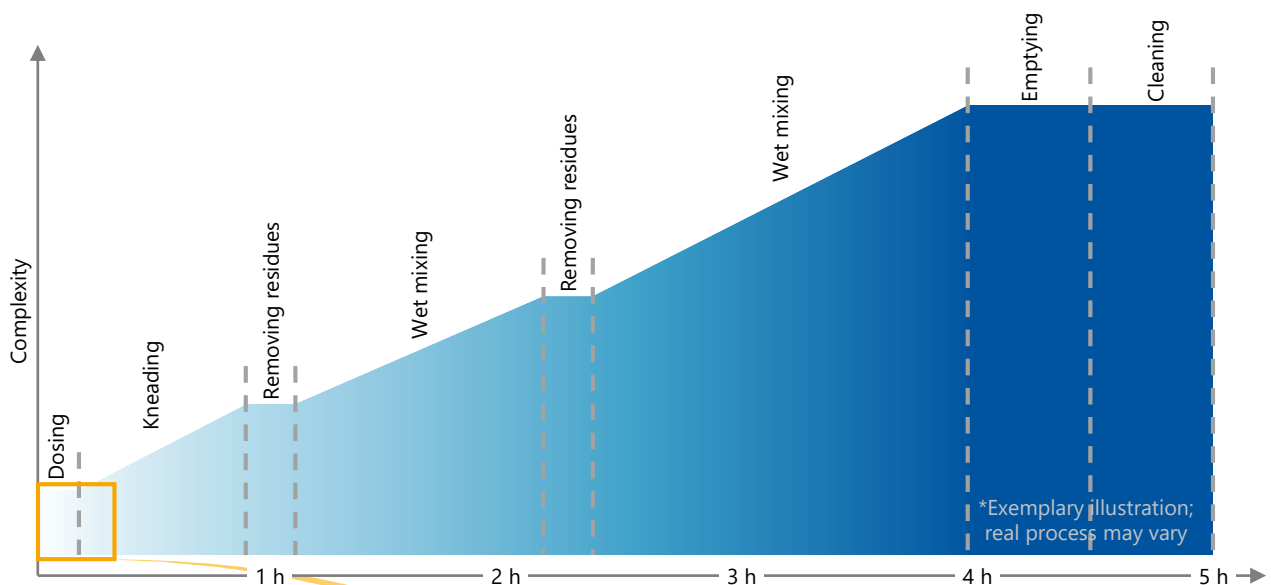
- **Wet mixing:** In the sponging phase, the remaining proportion of solvent is added to the kneaded slurry, and the binder solution is added as a supplement; rather it is shaken again for 30 seconds.
- **Vacuum mixing:** After the slurry has been mixed, the final step is to evacuate the container to remove air bubbles from the slurry. This is followed by a final stirring under vacuum to remove the last air bubbles, which may be bound by the smallest agglomerates, and to produce a slurry that is as homogeneous as possible.

A possible automated process for trajectory mixing is shown in Figure 4. To evaluate the mixing process and the quality of the slurry, the agglomerate size is determined by means of a

grindometer. In addition, the viscosity is analyzed to draw conclusions about the behavior of the binder. One of the most important properties of a slurry for battery production is its processability through a slot die onto the substrate foil. In this case, the anode slurry is applied to a copper foil.

The slurry is applied at a web speed of about 1.5 m/min over a width of 250 mm with a wet film thickness of 150 μm. Immediately after drying at about 150°C, a residual moisture measurement and a measurement of the adhesion of the coating are carried out. To validate the statement of a similar good mixing, a microscopic analysis is carried out using SEM. An analysis of the surface of the uncalendered samples is performed, as well as an assessment of the structure through an analysis of a section by SEM.

Planetary mixer



Trajectory mixing

Total time reduced to 200 seconds

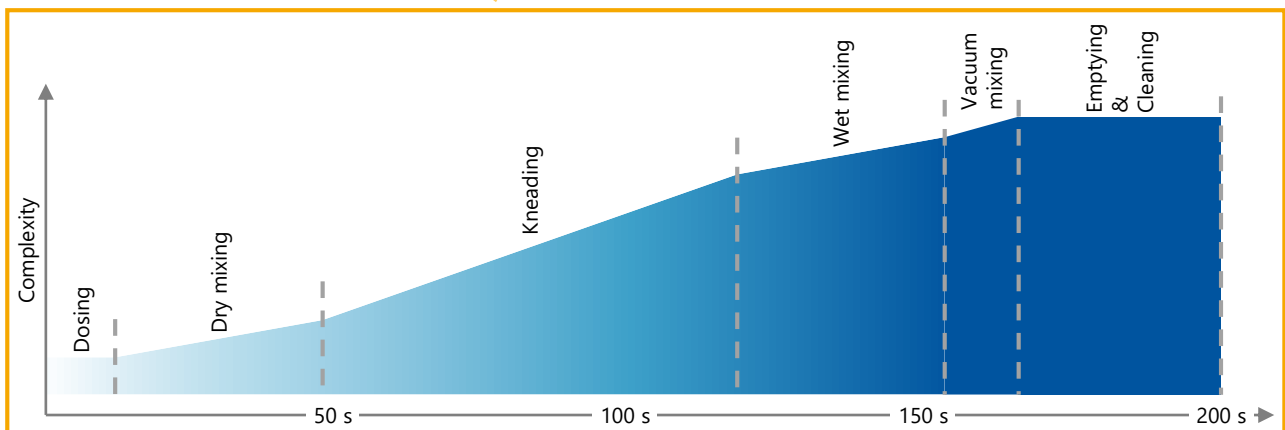


Figure 4: Representation of the automated trajectory mixing process versus planetary mixer process

For the electrochemical analyses, a three-electrode cell is fabricated using the electrodes produced by the trajectory mixer. A NMC622 electrode is used as the cathode. For validation, six cells are fabricated using the Celgard 2325 separator and LiPF6 electrolyte. During formation, the cell is first charged with C/20 to 4.2 V and then discharged with 1C to 2.9 V with a following CV phase. Then a capacity cycle is connected after the formation cycle to analyze the capacity.

Slurry evaluation

The slurry is produced as previously described. The movement and accelerations introduce shear forces throughout the mixing volume. Due to the high acceleration forces of up to 350 m/s^2 , an anode slurry can be produced in a very short time. This is confirmed by the analyses of the viscosity and the sample of the agglomerate size by means of a grindometer. The viscosity is comparable to the benchmark process. It is noticeable that despite the significantly shorter mixing time, the agglomerate size is slightly smaller than in a comparable mixing process with an established mixing equipment.

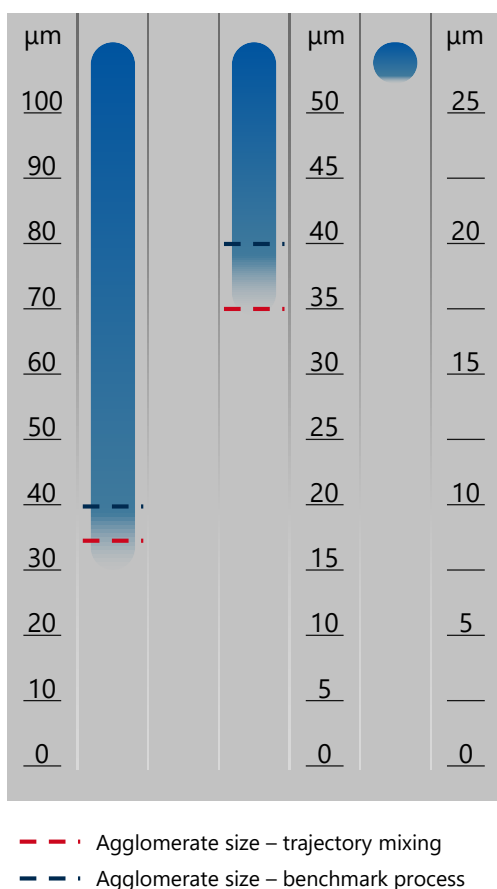


Figure 5: Evaluation of the maximum particle size

Figure 5 schematically shows the comparison between the two samples. The particle sizes of about 35 to 40 μm for the trajectory mixing process and the 40 to 45 μm for the benchmark process were confirmed in a large number of test series. It can be assumed that the larger particles have a higher inertia and thus collide with more or more intense with other components of the slurry, and thus a specific deagglomeration takes place. The kneading phase allows the dispersion behavior to be controlled, but a minimum amount of solvent is required to achieve a sweet spot of dispersion. This was identified in the experimental study at about 70% of the total amount of solvent.

Mixing in trajectory processes does not use a rotating mixing tool. Instead, the particles shear off from each other through almost instantaneous changes in direction. While the shear forces are usually highest at the rotating tool, in the trajectory mixing process they are highest near the wall and decrease towards the center depending on the line of motion.

Coating analysis

To evaluate the coating, the slurry is applied to the copper substrate as a wet film using a slot die. During coating, no conspicuous features – such as voids in the coating or longitudinal scratches – are visible, which indicate larger agglomerates in the coating. After coating, the coated copper foil undergoes a drying process in a convection oven. Again, no irregularities occurred in direct comparison to the established process. With both mixers and the selected formulation, an acceptable coating can be obtained. Dry film thicknesses are about 100 μm after convection drying. Immediately after drying, a sample of the coating is taken in each case and the residual moisture is determined as quickly as possible. The same is done to evaluate the adhesion of the coating. Both samples give comparable results, indicating that there is a similar structure as well as binder distribution in the coating and slurry, respectively. It can be concluded that on a macroscopic level there are no differences in the area of observation, and a scanning electron microscope is necessary to possibly identify differences.

SEM surface images are used to evaluate the coating in microscopic observation. Figure 6 shows the benchmark with the proven pilot line mixing equipment on the left. On the right, the sample prepared by the trajectory mixing process is pictured. The image shows the surface at 500 times magnification. Both images represent an approximately 150x250 µm section of the coating. The larger, clearly visible particles are the graphite, i.e. the active material of the anode.

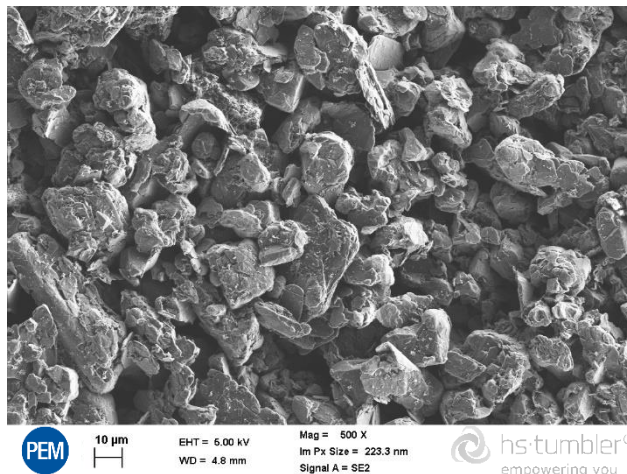
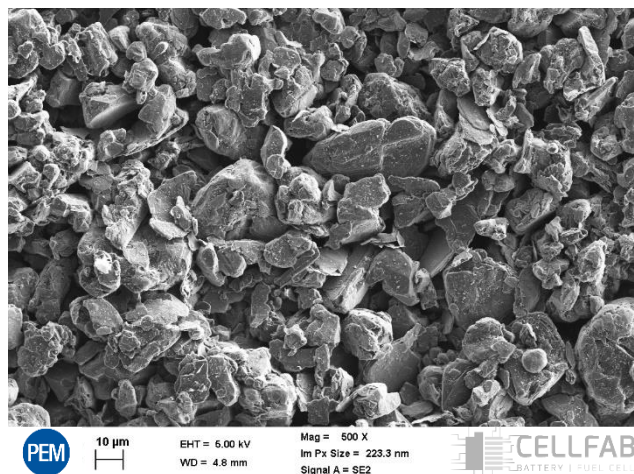


Figure 6: SEM surface sample; benchmark sample (left), trajectory mixing sample (right)

The much smaller particles, which are more visible as white dots, are the conductive carbon. These particles connect or improve the electrical conductivity of the active material.

The benchmark sample shows a very fine distribution of all particles. In the section shown, there are no irregularities such as larger agglomerates or foreign bodies. In addition, it can be seen that the conductive carbon has been very much reduced in size and evenly surrounds the larger graphite particles. In the image of the surface of the sample, in which the slurry was produced by the hs-tumbler system, a homogeneous distribution of all particles can also be seen. In contrast to the benchmark sample, however, a difference can be seen in the separa-

tion of the conductive carbon. It is well distributed and surrounds the larger graphite particles very homogeneously, but in direct comparison it can be seen that the conductive carbon black was dispersed less. The statement of a smaller particle size, which was represented by the grindometer, is difficult to evaluate pictorially.

For the surface analysis, it can be summarized that differences exist between the samples. These are primarily characterized by the separation of

the conductive carbon, but not by the distribution of the conductive carbon.

Further statements, which could be attributed to the shaking mixing process and, for example, the accumulation of conductive carbon on the surfaces or edges moved relative to one another, would only be a conjecture with this pictorial evaluation and could not be clearly proven.

Figure 7 shows a section of the non-calendered specimens. The copper foil is on the upper side, while the coating can be seen on the lower side. In the sectional view, the active material is shown in dark gray. The carbon binder domain is shown in a lighter gray. The nearly vertical streaks are due to ion polishing and have no effect on the coating or its evaluation.

EXPERT STATEMENT: DR. STEFAN PERMIEN, CEO UNIVERCELL HOLDING GMBH

“In cell production, we need to excel in quality and innovative factors to gain competitive advantages in the market. Disruptive technologies are particularly exciting. If the trajectory mixing can demonstrate advantages, we could very well imagine using the technology in the area of dry coating, for example.”

Optical evaluation of the images shows a dry film thickness of 100 μm in each case. In addition, both samples have identical porosity of about 50% in the section plane. A good distribution of the binder can be seen in the two sections shown. In both figures, an increasing amount can be seen from the surface of the sample to the substrate. Thus, little or no binder migration has occurred as the electrode dries. The uniform distribution of the binder in the area of the copper foil supports the values from the

adhesion measurement, which provides comparable values.

In summary, the sectional view of the sample also demonstrates the applicability for anode slurries in battery production. The extent to which the local accumulations and the difference in the dispersion state of the conductive carbon has a negative influence on the cell chemical performance will be evaluated in the next analysis.

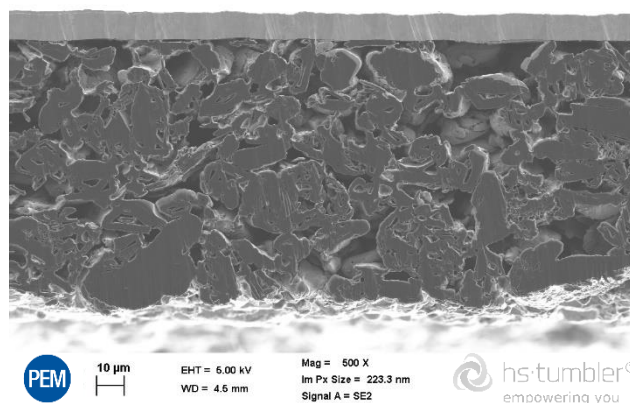
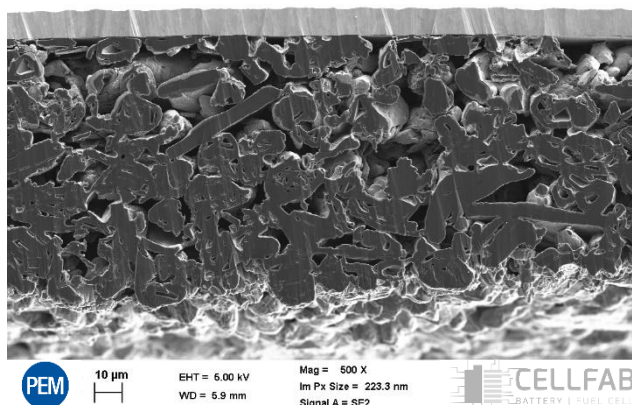


Figure 7: SEM cut sample; benchmark sample (left), trajectory mixing sample (right)

Electrochemical analysis

In addition to the six EL Cell cells produced using the trajectory mixing technology, the electrochemical analysis also included cells produced using the reference mixing technology. Comparable values to the reference technology were obtained in the formation of the trajectory-mixed electrodes. The charge capacity is approximately 7 mAh, and the discharge capacity is 5.3 mAh. The coulombic efficiency is approximately 76%. The first cycle of capacity measurements showed slight losses

due to post-SEI layer formation processes throughout all cells. A second cycle was then carried out on three of the six cells. In this cycle, the coulombic efficiency was around 94% to 99%. The values achieved in the formation cycle and the capacity test were homogeneous over the series of tests, indicating a very homogeneous coating result for the materials coated with the trajectory mixing technology. All cells show no lithium plating after the first capacity test.

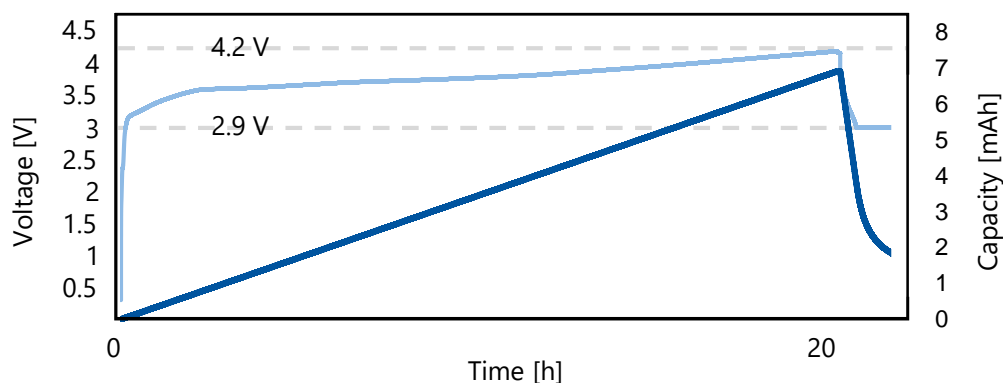


Figure 8: Overview of the electrochemical analysis: Exemplary voltage and capacity curve

Scaling up the pilot process for the gigafactory – The shaking mixing process

Mixing of four batches with the same drive



Figure 9: Properties and attributes of the hs-tumbler J4

A crucial point for an application in battery production is the scalability and automatability of the equipment and the development as well as the design of a reliable and accurate dosing system. For this purpose, hs-tumbler's larger mixing system, the J4 machine, is analyzed.

A mixing tank of the J4 machine holds five times the volume of the pilot plant. The machine itself has a footprint of 2x2 m. Compared to the pilot plant, the mixer alone requires four times the space. The special feature of the J4 machine, however, is that it has not just one mixing vessel, but four identical mixing vessels, thus significantly increasing output. An automated and residue-free emptying of these mixing containers is currently under development at hs-tumbler.

A special mechanism makes it possible for the mixing vessels to always move exactly in opposite directions when moving in the plane, so that the forces acting externally almost dissipate. This enables very quiet operation without vibrations at high speeds.

hs-tumbler has already demonstrated the scalability from the K1 to the J4 machine in related areas for battery production. With a previously used filling level of 50%, around 40 liters of slurry can be produced in just over two minutes.

On an industrial scale, batch dosing and emptying times are a decisive factor for the performance of an equipment. Elaborate cleaning between batches can have a further negative impact on output. Quasi-continuous systems with automated and residue-free discharge can significantly increase this output if designed appropriately.

The mixing process of the ultra-fast micro batch opens up new possibilities for dosing and material feeding. **Coperion K-Tron** has developed a concept specifically for this application. The basis is high-precision dosing equipment, which can work almost continuously and thus significantly more efficiently due to the short batch times. This offers the potential to save acquisition costs.

Efficient use of automated dosing

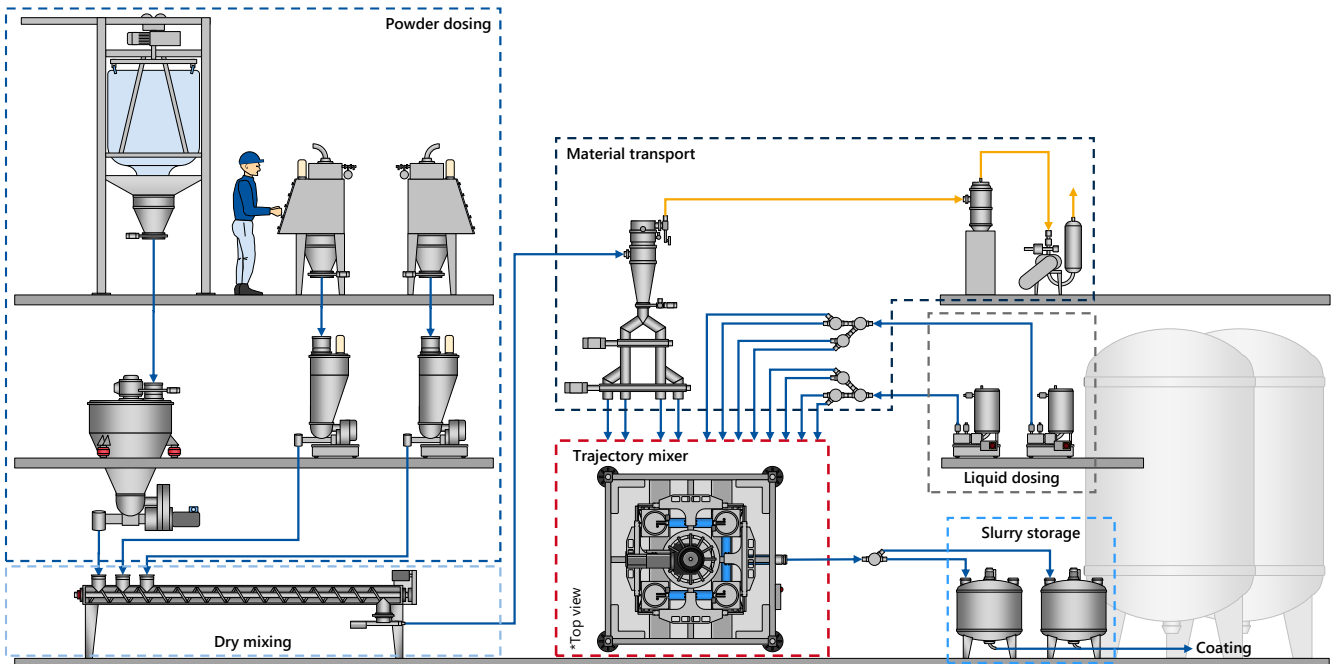


Figure 10: Automated dosing concept for a gigafactory with hs-tumbler's trajectory mixer based on Coperion K-Tron

Figure 10 shows an illustrative representation of the concept of the dosing specialist. The same material feed consisting of active material, dry binder, conductive carbon black, liquid binder, and solvent was considered for the dispensing system analysis and design.

As is common in battery production, the dry materials are delivered in big bags or larger sacks and emptied into the respective devices. This can be done, for example, in gloveboxes or big-bag feeding stations. A gravimetric dosing unit feeds the dry materials almost continuously with high accuracy to a mixing screw. On the one hand, this process of dry mixing by means of screw conveying ensures the necessary breaking up of the heterogeneous phases, and on the other hand it makes sure that dry mixing no longer has to take place in the actual mixing process in the trajectory mixer, which limits

the actual mixing process time to 100 seconds. The premixed material is then fed via a pneumatic conveying system to the distribution system, which distributes the materials evenly among the four mixing vessels. The solvent and any liquid binder can be fed via flexible hoses, so there is no need to disconnect from the mixing container. After the mixing process is complete, the slurry is pumped out of the cylindrical mixing vessel and fed to intermediate tanks from which the coater can be fed. Due to the small volume of ten liters, emptying and any cleaning is carried out in a very short time. Based on PEM calculations regarding dosing times and assumptions for emptying, it is possible to produce a slurry output of up to 1,000 liters per hour with the equipment presented here in a fully automated process. Such an amount corresponds to a production capacity of six gigawatt-hours per year.

EXPERT QUOTE: PROF. ACHIM KAMPKER, PEM OF RWTH AACHEN UNIVERSITY

"Openness to technology is a key component in equipment-side process optimization. Efficient and optimized equipment utilization is a unique selling point of German mechanical engineering which we should transfer to battery production as quickly as possible."

Cost potentials of the trajectory mixer

The total investment cost for the construction of a production plant with a capacity of 10 GWh is approximately 32 to 40 million Euros for the area of dosing and mixing. Simplified, these costs can be divided into three sections: mixing equipment, material handling, and peripherals such as piping and steel construction. In addition, there is the development and installation of the equipment at the customer's site.

Due to the increased output, which can already be achieved with the current process, there are clear price advantages in the area of mixing equipment. Due to the more efficient use of the mixing equipment and possible smaller dimensioning, there are further potential cost savings. Depending on the development costs and the costs of the peripherals, savings of up to 30% are conceivable.

By considering ideal automation, potential operating cost savings can be identified. The J4 machine from hs-tumbler has a nominal con-

nected load of 22.5 kWh. This can only be accessed about half the time due to dosing and emptying operations. In addition, not all of the power is expected to be needed for operation. This results in an average output of nine kilowatt-hours or nine watt-hours per liter, equivalent to half the energy consumption of an intensive mixer or a 98% energy saving over a planetary mixer. In practical trials, no greater heating of the slurry could be identified due to the very short mixing time. It can therefore be assumed that no cooling is required.

Regardless of this fact, it can be assumed that due to the mixing process, in which the container wall primarily transfers energy into the material, cooling would be very efficient. Due to the modular design of the overall system, a shortened maintenance time and thus a shorter downtime is also expected. Due to the cylindrical vessel shape, accelerated cleaning can also be expected.

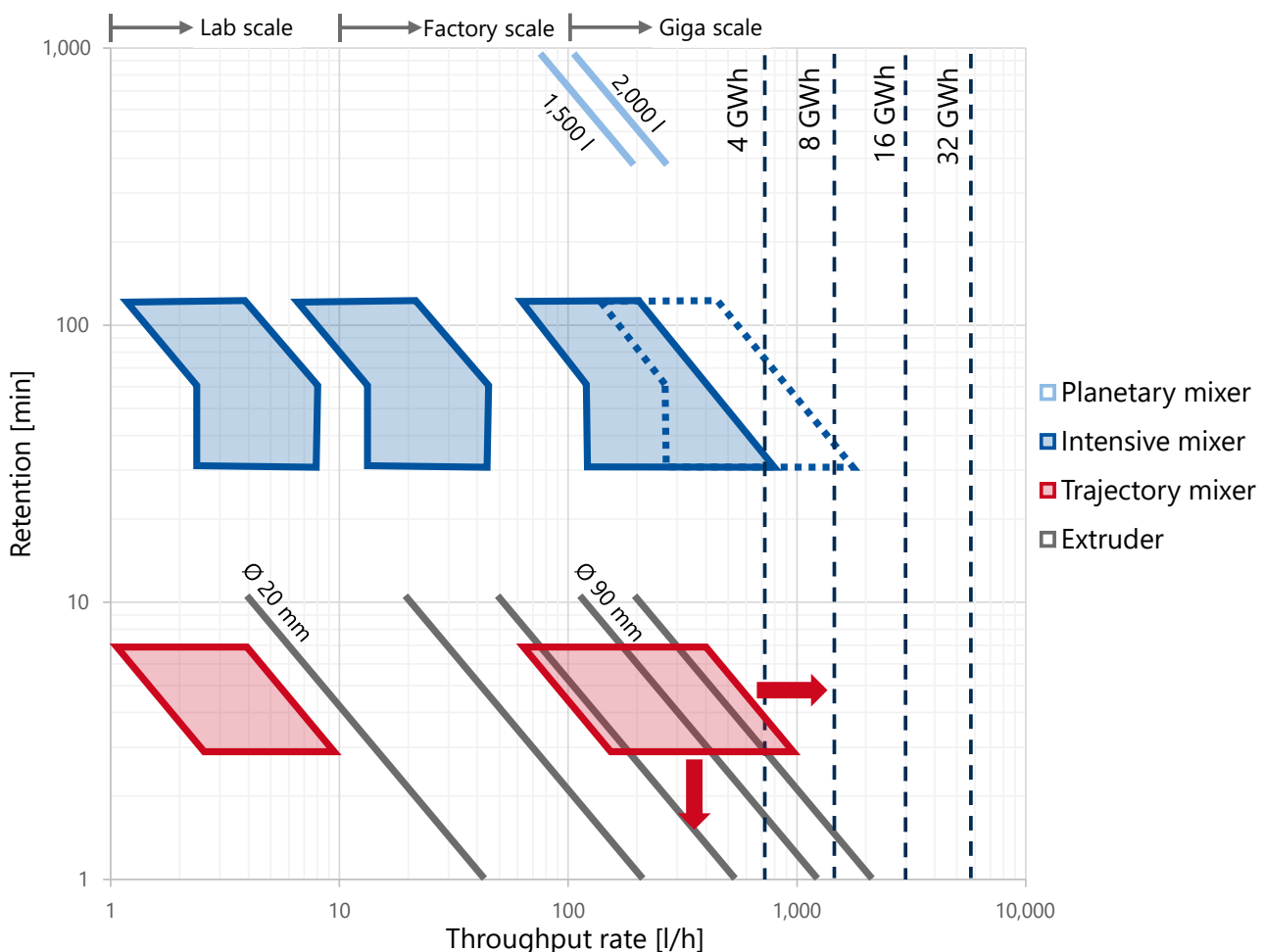


Figure 11: Comparison of trajectory mixing with competing technologies [based on Stefan Gerl 2021, Maschinenfabrik Gustav Eirich]

Trajectory mixing in a nutshell – ultra-fast micro batch processing for battery industry

Disruptive process technology at a glance

In this paper, the applicability of trajectory mixing for battery production was analyzed and presented. For this purpose, practical tests were carried out at the “eLab” of RWTH Aachen University. The slurry was then analyzed, and anodes were produced using a pilot plant. Here, the process was analyzed qualitatively, and quantifiable measurements were performed. Imaging techniques were selected for a more detailed examination of the coating. For statements on the cell chemical behavior of the coating and for conclusions on the trajectory mixing, three-electrode cells were set up and formed.

The tests clearly show that it is possible to produce anode slurries by the trajectory mixing process. The enormous acceleration forces and the rapid changes in direction mean that no mixing tool is required and a slurry of good quality is produced in a very short time. With a single mixing figure used for the production of pizza dough, the process could be confirmed to a mixing time of 130 and 100 seconds, respectively. Furthermore, no changes in the rotation speed of the motors took place. It can therefore be assumed that there is some optimization potential for batteries in the hs-tumbler trajectory mixer.

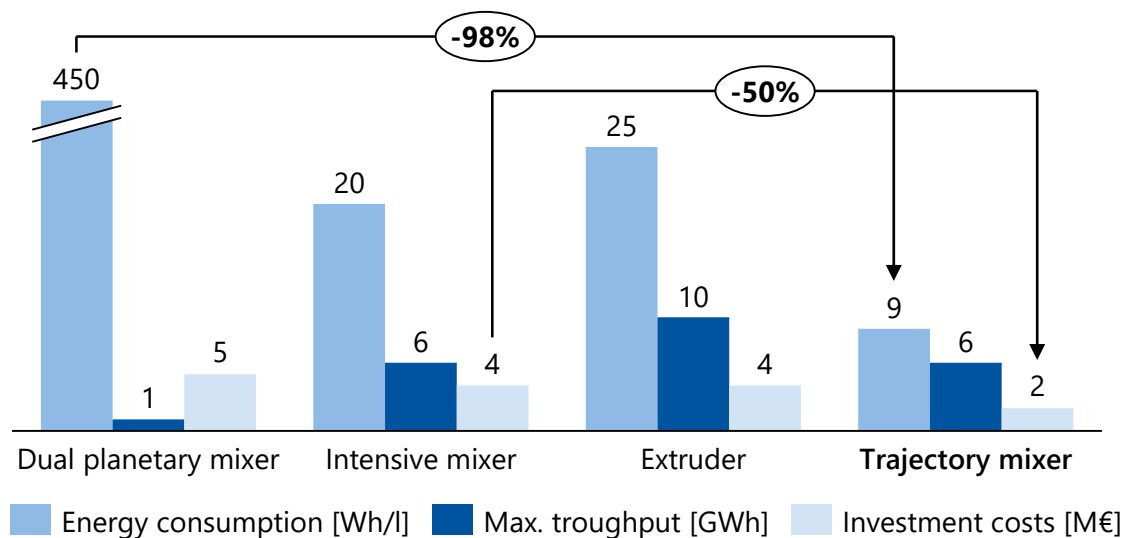


Figure 12: Presentation of key performance indicators for mixing equipment [PEM market research]

In addition to the analysis of the machine and the mixing process as well as the product thus generated, the scalability was considered in more detail. With the kind support of Coperion K-Tron, a concept was developed for the applicability in a gigafactory. Finally, the key performance indicators of energy consumption per liter for the slurry and the throughput of the mixing equipment were considered together with the related costs for the overall system. The comparison of the parameters is shown in Figure 12.

It is planned to validate the scaling potential in practical trials and to qualify the process for further cell chemistries. This consideration includes investigating new approaches such as material preparation for dry coating.

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The chair "Production Management of E-Mobility Components" (PEM) of RWTH Aachen University was founded in 2014 by Professor Achim Kampker and is active in the field of production of lithium-ion battery technology. In numerous research groups, PEM is dedicated to all aspects of the development, manufacturing and recycling of battery cells and systems as well as their individual components. PEM's activities cover both automotive and stationary applications. Due to a multitude of national and international industrial projects with companies of all stages of the value chain as well as central positions in renowned research projects, PEM offers extensive expertise, focusing on sustainability and cost reduction with the goal of an "Innovation Chain" from fundamental re-search to large-scale production.

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The German innovative start-up "hs-tumbler" was founded in May 2021 in Quakenbrück by Bernhard Hukelmann as the inventor of the trajectory mixing process and two investors. In September 2021, Peter Stellbrink joined "hs-tumbler" as Managing Director. The company is focused on the development and optimization of an innovative mixing process. Several machines already demonstrate the potential of the trajectory mixing process in various countries. The spectrum of application ranges from the food industry to chemicals and pharmaceuticals to electric mobility. These markets are developed by "hs-tumbler" in partnerships with leading companies in the industry. Goals are pursued jointly and technologies are further developed for specific applications.

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The **Electromobility Lab** (eLab) provides an open infrastructure for researching various applications and stages of electric mobility. The eLab's resources can be rented and used flexibly. RWTH Aachen University as the eLab's operator is available to assist with its technology and consulting expertise.

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