

Advanced Battery Electrode Development and Manufacturing

Improving quality, cost-effectiveness and speed-to-market for lithium-ion battery electrodes



Why Dürr MEGTEC for Advanced Battery Electrode Development and Production?

A legacy of product development and process improvement.

Dürr MEGTEC, LLC (Dürr MEGTEC) has pioneered industrial web coating and drying processes. Our patented technologies have made us a leading global provider of engineered solutions that optimize manufacturing processes.

As an OEM, Dürr MEGTEC engineering and R&D teams help customers pilot new technologies, optimize production processes, and minimize raw materials waste. In the end, we help our customers effectively go to market.

Dürr MEGTEC is a single-source OEM that can meet the broadest range of electrode production requirements, from an R&D coater developing new chemistries to a coating line that meets the basic and competitive needs of a new player in the market to a fully integrated manufacturing plant for high-volume runs.

Our capabilities cover the entire production line, with systems for raw material handling, slurry mixing and fluid delivery, web handling, coating and drying, solvent recovery and purification, calendaring, and slitting. We also offer a world-class laboratory—a controlled test environment with a complete roll-to-roll pilot coating line that can help establish the viability of emerging and advanced materials applications.

R&D to Mass Production Coating Lines

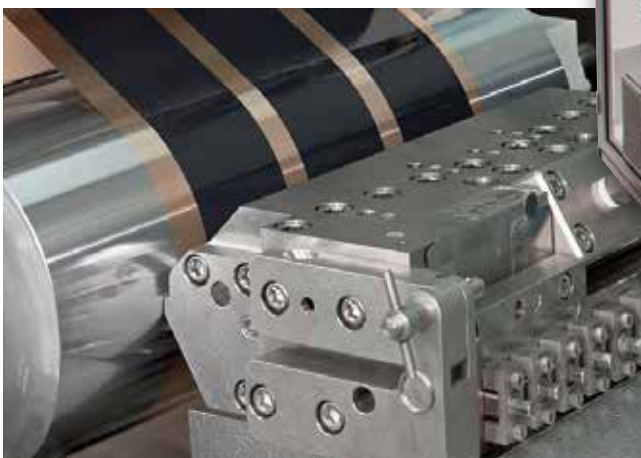
	R&D Coater	LabCoater	PilotCoater	ProCoater™	GigaCoater™	GigaCoaterXL™
Foil Width mm	250	300	350	700	1400	2200
Speed m/min	0.5	3	5	20	40	60
Capacity MW/a	0.1	5	50	500	2000	5000
Simultaneous 2-Sided Coating	No	No	Yes	Yes	Yes	Yes
Coating Side A	Slot-Die Tension Web or Comma Bar	Slot-Die Backing Roll or Comma Bar	Slot-Die Backing Roll or Comma Bar	Slot-Die Backing Roll	Slot-Die Backing Roll	Slot-Die Tensioned Web
Coating Side B	Second Pass	Second Pass	Slot-Die Tensioned Web	Slot-Die Tensioned Web	Slot-Die Tensioned Web	Slot-Die Tensioned Web
Multi-Lane	With Slot-Die	With Slot-Die	Yes	Yes	Yes	Yes
Intermittent	No	Option	Option	Option	Option	Option
Unwind	Single	Single	Single	Single	Non-Stop Auto	Non-Stop Auto
Rewind	Single	Single	Single	Non-Stop	Non-Stop Auto	Non-Stop Auto
Dryer	Roll Support 0.6 m	Roll Support 1-3 m	Flotation 6 m	Flotation 15 - 30 m	Flotation 40 - 48 m	Flotation 50 - 70 m

The Coating Process—Slot-Die Against a Backing Roll

To ensure optimum battery performance, every step in the coating process must be tightly controlled. Slot-die coating against a backing roll is the most common method for applying lithium-ion and supercapacitor slurries. Mixing conditions and the related equipment have a strong impact on the slurry, as does the coating and drying process. Dürr MEGTEC technicians closely manage the precise combination of dry solids and liquid components to maintain the integrity of the electrode chemistry.

Because the slurry carries particle dispersions, the particles can become trapped in the gap between the slot-die lips and the backing roll/foil. This can result in a streak, or even worse, cause the web to break. For energy cells, which require heavier/thicker coat loads, the trapped particles occur infrequently. However, power cells call for lighter/thinner coat loads, which require tighter control to keep the particles from becoming trapped and affecting the coating run.

The largest challenge when slot-die coating against a backing roll occurs when applying the active materials to both sides of the current collector. When coating with a backing roll, the substrate is supported by and wraps a roller. The backing roll provides a very good datum to produce an accurate wet coating layer. Whatever coating process is used, it is imperative the coating be uniform on each side. If the Side A coating is not uniform, the condition will negatively impact the coating of Side B, thereby resulting in an uneven distribution of the active material. This ultimately affects battery performance.



Slot-die coating against a backing roll is a common coating method. Dürr MEGTEC is a single-source OEM, offering turnkey coating lines that are fully integrated and engineered to deliver greater throughput, better quality and eliminate waste.



Dürr MEGTEC developed an easy-to-use laboratory coating line designed specifically for short production runs. Its lab coater utilizes slot-die coating against a backing roll and can produce up to 250 mm-wide coated substrates running at speeds up to 3 meters/minute.

The Coating Process—Simultaneous Two-Sided Coating

Engineering a smarter way to manufacture battery electrodes.

A slot die with a backing roll only allows coating battery electrodes one side at a time. This requires two separate passes through the same coating line, whereby a second coating station is installed after the drying oven. However, a more efficient method is to coat both sides in a single pass. This can be accomplished in two different ways: 1) with a sequential or tandem coating system or 2) simultaneous two-sided coating.

Recognizing the promise of simultaneous two-sided coating for battery manufacturers, Dürr MEGTEC engineers developed a tensioned-web coating process using a slot-die mounted in a vertical orientation to simultaneously coat both sides of electrode foil traveling horizontally. The process delivers a uniform coat weight matched to that of backing roll coating with the proper configuration and process parameters.

Without a backing roll, there is no gap between the slurry coating and the foil. For light coat weights used in power cells, this method provides uniform coatings down to 20 gsm coat weight or loading with enough flexibility to also meet the needs of energy cells at coat weights up to 200+gsm. In addition, by removing the backing roll, particles of active material do not become trapped, which eliminates the risk of streaks. Finally, tensioned-web coating has been deployed in the production of primer coating on aluminum foil, which means it has been used to coat carbon slurry as thin as 2 gsm.

Key benefits of simultaneous two-sided electrode coating include:

- Twice the throughput compared to single-side coaters
- Requires only one pass through the dryer, delivering equal drying of both coated sides
- Smaller overall manufacturing footprint compared to tandem lines
- Lower capital and operating costs compared to tandem coating lines
- Increases the range of coat weights for lithium-ion slurries
- Reduces incidents of particles being trapped at the coating point (no streaks, no foil breaks)
- Fewer problems with wrinkles at the coating point.

As the lithium-ion battery industry matures, pressure to decrease costs mounts. Battery manufacturers are seeking to lower material and processing costs. Simultaneous two-sided coating using the tensioned-web process enables battery manufacturers to be more cost-effective, and therefore, more competitive.

While the full limits of the tensioned-web coating process continue to be defined, Dürr MEGTEC is committed to improving this technique and exploring an ever-increasing range of capabilities.

In the tensioned-web coating process, a slot-die with a backing roll applies the electrode coating to the topside of the web, while the back side is simultaneously coated in the horizontal tensioned-web mode just prior to entering the dryer.



Enhancing efficiencies and increasing yields.

The energy storage industry is demanding a significant reduction in production costs in combination with increased yields and product quality. Manufacturing large quantities of lithium-ion battery cells requires a significant change and dimensional upscaling of the production equipment and output per line to achieve industry targets.

At the same time, the benefits of two-sided simultaneous coating technology become increasingly important the wider and faster coating lines are required to get. To meet these demands, the Dürr MEGTEC GigaCoater™ and GigaCoaterXL™ coating lines are engineered for large-scale lithium-ion battery manufacturing plants.

With an effective output volume of up to 12 times our conventional two-sided coater, the GigaCoater™ and GigaCoaterXL™ maximize manufacturing at a significantly lower total production cost:

- 50%-70% less floor space than typical single-side coating operations
- A small footprint that allows for efficient plant layouts and reduced floor space
- Thermal efficiencies that deliver lower energy requirements
- Wider web widths significantly reduce the number of coils that need to be handled
- Simpler material flow enhances overall throughput
- Higher automation maximizes production volume
- Intuitive operator interface does not require an increase in operators per coating line, improves efficiencies, and yields an overall lower cost of production.



The Dürr MEGTEC GigaCoater™ with simultaneous two-sided coating delivers twice the production volume compared to single-side coaters. The dual coating method, in combination with coating rheology and GigaCoater™ machine properties, maximizes production and improved in-line quality control. The wide-web GigaCoater system can provide an annual output of 2 to 3 gigawatt hours (GWh) per machine.

The Complete Li-Ion Battery Electrode Manufacturing Plant

Improving quality, cost-effectiveness and speed-to-market.

By leveraging its full array of product development and process improvement capabilities with those of world-class partners, Dürr MEGTEC offers a complete battery electrode manufacturing plant. Matched to meet specific production requirements, each plant configuration is a complete manufacturing operation, encompassing every stage in the production process from powder handling to slurry mixing; coating and drying to NMP recovery and purification; calendaring/roll pressing to secondary drying; slitting to project management.

Process Development and Team Training

During the machine build period, Dürr MEGTEC provides customer-specific process development trials, making it possible to dramatically reduce time from commissioning to full production:

- Fully train technicians before installation
- Achieve steady-state production in a shorter time
- Save time and money

Lower Total Costs

The simpler manufacturing flow and machinery design of the Dürr MEGTEC electrode plant provides:

- Reduced utility demand
- Fewer technicians
 - Two-sided coating: 1 per shift
 - Inline calendaring/pressing: 2 per shift
 - Continuous mixing: 1 per shift
- Improved quality means higher yields with less waste
- Simpler factory layout/straight-line product flow and single-level footprint
 - Less material handling/improved material flow
 - Less fixed waste of materials
 - Direct slurry piping to a single coating station

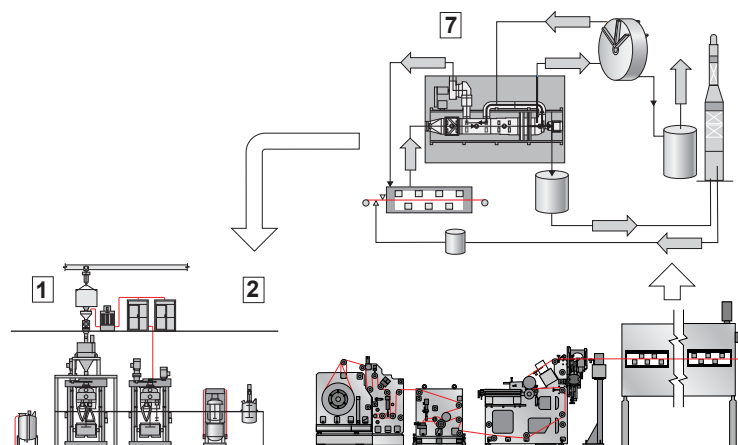
- Simplified process design, requiring lower capital investment

Quality Control

Dürr MEGTEC offers a fully integrated data capture and management tool that provides complete traceability from raw materials to finished cells. Inline process control helps improve product quality and confidence and is based on:

- Rheology monitoring
- Coat weight measurement at multiple locations
- Physical quality inspection system
- Thickness measurement and control
- Two-sided coating coupled with flotation drying
 - Improves Side A to Side B alignment
 - No edge curl after drying
 - Better drying consistency improves yield
 - Reduces wrinkles

The cornerstone of each Dürr MEGTEC electrode manufacturing plant is simultaneous two-sided coating enabled by its exclusive tensioned-web coating system. As detailed above, simultaneous two-sided coating systems provide many benefits. The complete electrode plant increases these benefits by translating them to all process stages.



1-Powder Handling

The Dürr MEGTEC system includes an unloading station for super-sacks, pneumatic conveying of powder to hoppers, and loss-in-weight screw feeders for precise delivery of powder to the mixing system. The unloading station and pneumatic conveyor are segregated from the mix room, ensuring any airborne powder is contained. This keeps the mix room clean.

2-Slurry Mixing

Dürr MEGTEC can meet your mixing preferences, or recommend the best solution for your project, from R&D to mass production. Technologies offered include:

- Planetary dispersing mixers from 2 liters to 1,500 liters
- Semi-continuous dispersing systems from 1 to 960 liters/hr
- Continuous mixing systems from 20 to 2,000 kg/hr

3-Coating & Drying

The coating and drying step features simultaneous two-sided horizontal, tensioned web coating with flotation drying. Process benefits include:

- Lower costs
- Simplified factory layout
- Increased productivity
- Improved quality from no edge curl, high dimensional accuracy, and lowest coat-weight tolerances
- Improved process flexibility
- Allows for inline calendaring/roll pressing

4-Calendering/Roll Pressing

Whatever your process requirements, Dürr MEGTEC provides inline or traditional stand-alone calendaring/roll pressing systems. From narrow widths for product development to wide widths for mass production, we work with our partners to provide the right solution for your products and process needs. Summary specifications include:

- Width: 250 mm to 1300 mm
- Hot or cold pressing
- Inline thickness control

5-Secondary Drying

Our continuous roll-to-roll drying system eliminates work-in-process storage, increases throughput, and improves drying uniformity. Additional features include:

- Uniform drying of the entire electrode area
- Tailored to specific chemistry
- Installed in dry room or pass-into dry room
- Reduced floor space for drying process

6-Slitting

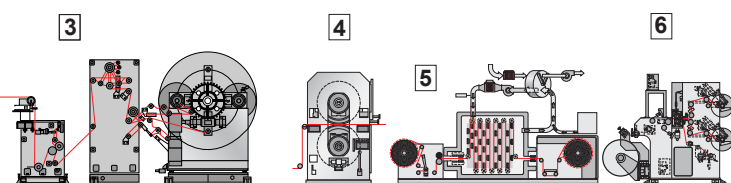
Whatever your width requirements, Dürr MEGTEC can meet them with flexible machines for multiple products. Features include:

- Individual friction shafts
- Tangential shear cutting method
- Cassette system for setting knife offline to minimize changeover time
- Speeds up to 50 m/min with lay-on roll

7-NMP Recovery & Purification

Solvent Recovery for any Scale

Proprietary solvent recovery systems from Dürr MEGTEC effectively remove, recover, and purify solvents from coating-line exhaust air streams. For high volumes, adding a purification system makes it possible to produce electronic-grade NMP and allow immediate re-use onsite. The typical recovery rate is > 99% and savings of \$2/kg can be achieved.



Drying & Curing

Dürr MEGTEC provides total drying and curing solutions for producing advanced web-based materials such as lithium-ion battery cathode and anode electrodes. We continue to pioneer the engineering and development of non-contact flotation dryers and ovens.

Our 45+ years of experience, more than 100 patents, and thousands of dryer installations worldwide confirm our leadership position as a world-class supplier of drying and curing systems for industrial applications. Our custom convection and hybrid dryer styles and designs include different types of heat sources, zone lengths, web widths and nozzle configurations, all of which provide superior drying, curing, and web handling.

We apply our extensive roll-to-roll drying, curing and thermal air handling experience across a wide range of flexible web materials, such as:

- Foils
- Ultra-thin films
- Laminates
- Fabrics

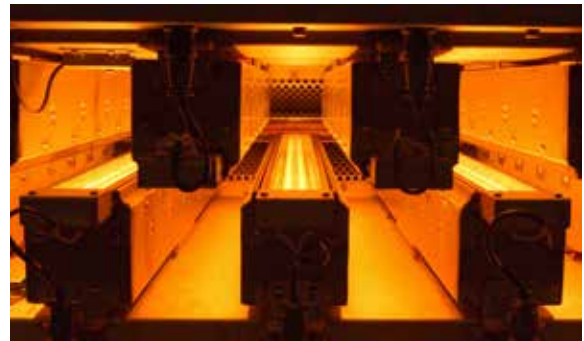
Facilitating Secondary Drying

Dürr MEGTEC continues to build on its long history of innovation in drying systems. It is developing a continuous roll-to-roll secondary drying system to replace the current batch process that is standard in many li-ion battery plants. This concept is shown as a key step in the battery electrode manufacturing line.

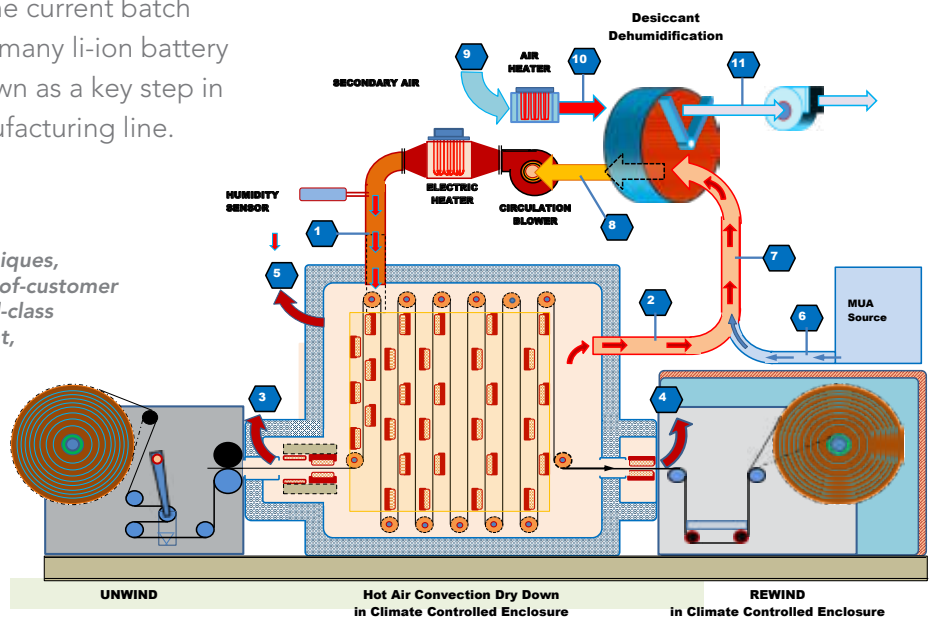
Using Design for Six Sigma techniques, Dürr MEGTEC is collecting voice-of-customer and empirical data from its world-class Drying Lab to develop an efficient, low-cost approach to secondary drying. For lithium-ion battery electrode coating, the in-line drying configuration significantly reduces drying time and improves overall product consistency compared to drying the electrode coil in a batch oven.

Infrared (IR) Configurations

To meet the demands of product variety and manufacturing applications, Dürr MEGTEC offers a wide range of infrared (IR) options. These include systems designed for complete drying, preheating, pre-drying, fusing, curing and profiling. By combining the correct wavelength IR and optimization of the control system, precise process conditions can be achieved that maximize product quality in the most efficient manner.



Dürr MEGTEC can also combine IR with flotation and/or impingement drying systems to enhance the performance of the overall drying or curing process



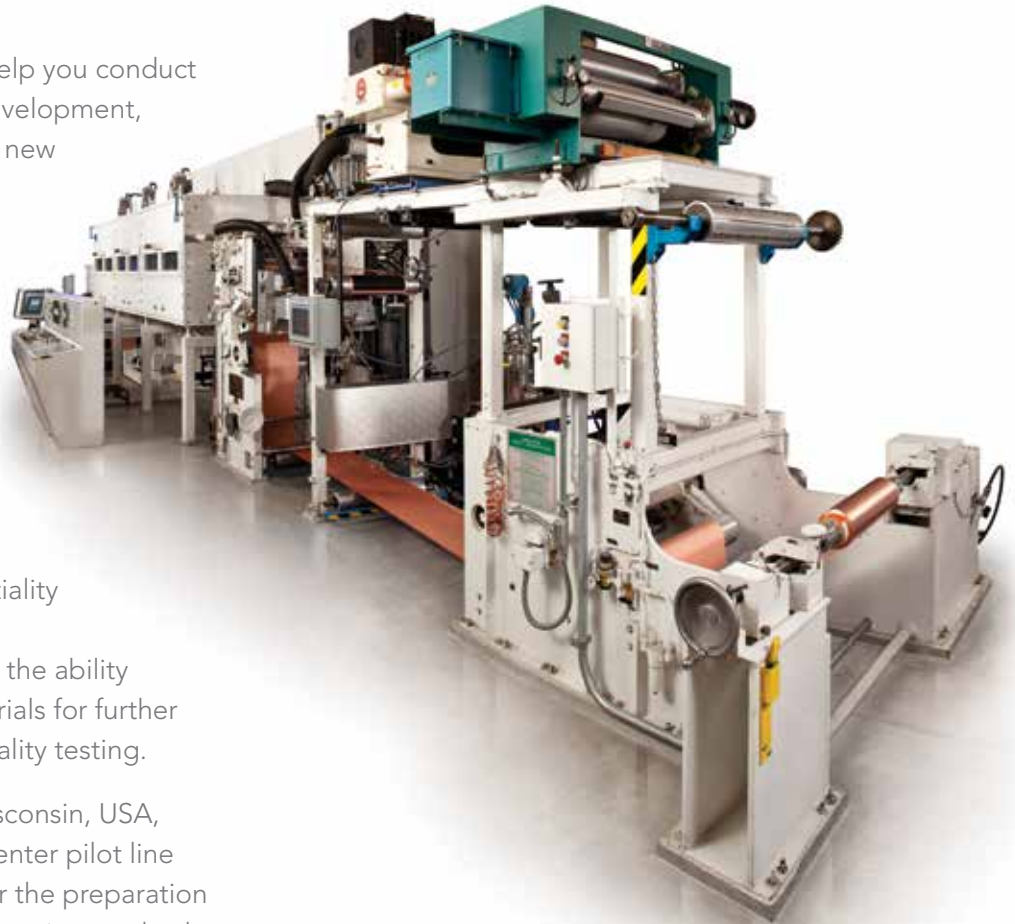
Development Center Pilot Line

To support the development of specialized and proprietary coating applications, Dürr MEGTEC has an in-house Development Center with a pilot line that includes coating and drying capabilities. The coater offers a fully controlled test environment for complete process development and testing of short production runs.

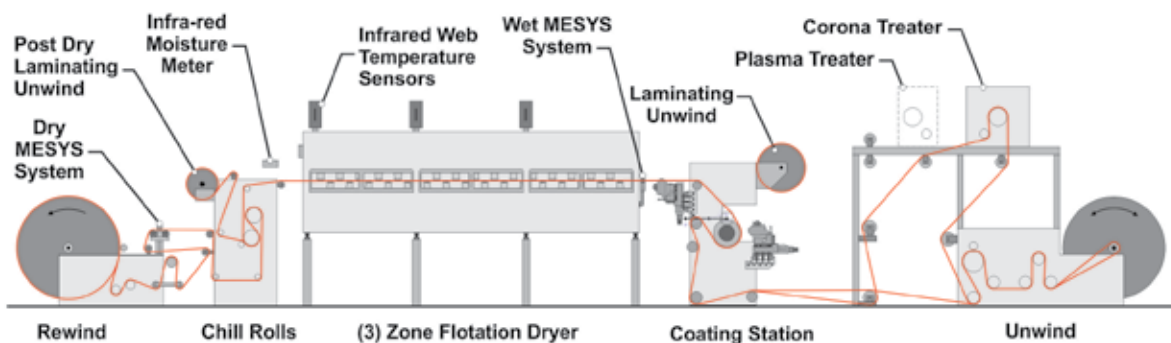
Our pilot coating line can help you conduct proprietary research and development, as well as test and optimize new or existing coatings, web materials and processes. The Development Center also helps avoid unnecessary expenditures of overhead, capital equipment and start-up costs while developing new products. It provides the versatility and confidentiality needed for new product development, coupled with the ability to produce prototype materials for further research, marketing and quality testing.

Located in our De Pere, Wisconsin, USA, facility, the Development Center pilot line offers mixing capabilities for the preparation of slurry mixtures, multiple coating methods, a three-zone dryer that can be used with a wide range of substrates and tensions, plasma and corona treater for foil substrates, and on-line coating thickness measurement and tracking.

Process engineers, R&D technicians, and analytic staff provide their collective expertise to solve drying and coating challenges for an ever-increasing array of substrates.



The Dürr MEGTEC pilot coating line provides the versatility and confidentiality needed to produce prototype materials for further research, quality testing, and overall marketing viability.



Solvent Recovery Process

Dürr MEGTEC has developed proprietary systems for the high-efficiency removal, recovery, and purification of solvents from coating line exhaust air streams in the battery electrode manufacturing process. These systems produce electronic-grade solvents and can be configured to achieve compliance with global and local emissions standards. System considerations could include:

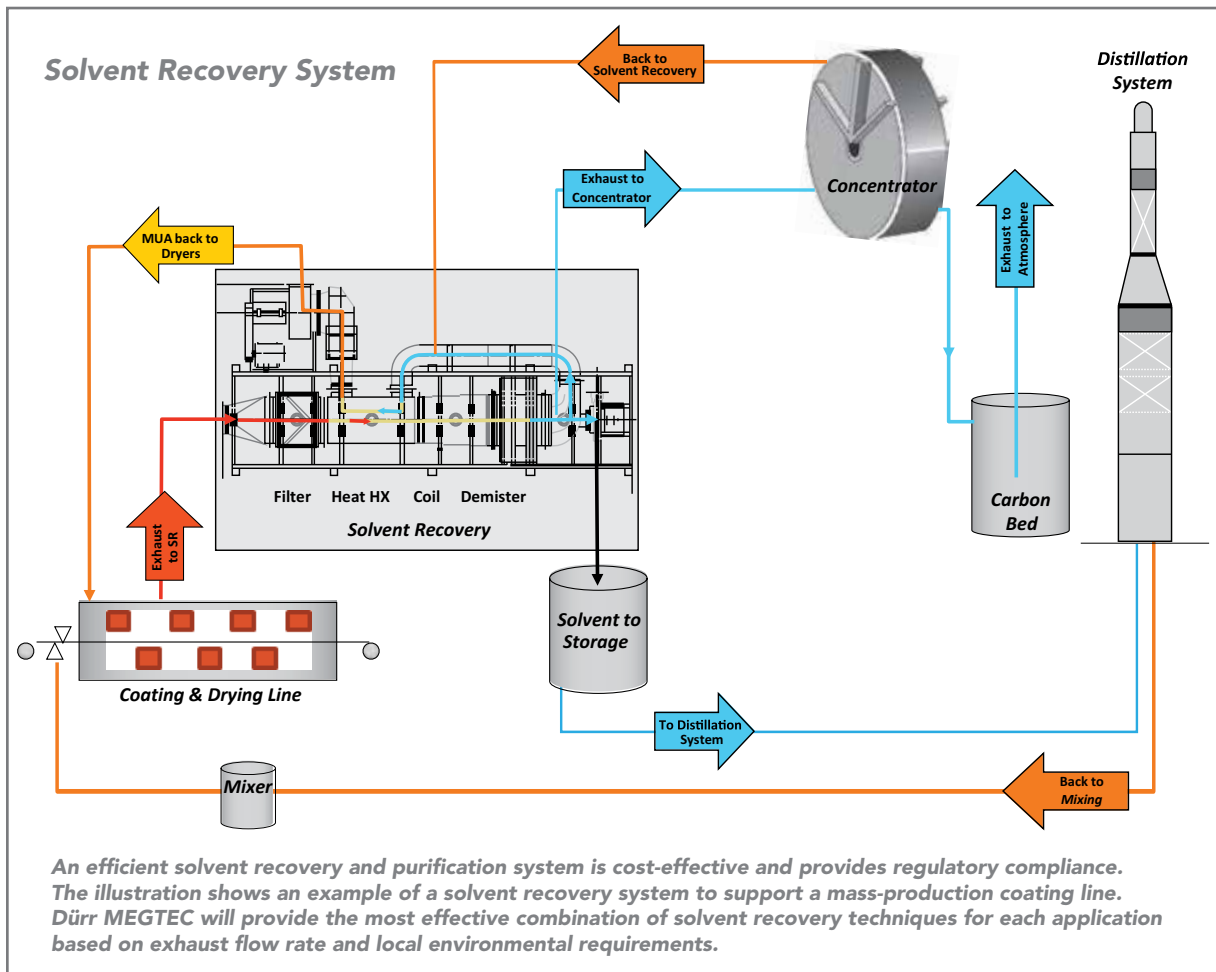
- On-site dehydration/distillation of NMP has an extremely short return-on-investment cycle, compared to the cost of new NMP.
- In a laboratory environment with limited hours of operation, a carbon bed may be the most effective solution.
- For large industrial installations, such as mass manufacturing of battery electrodes, a condenser followed by either a concentrator or a scrubber is an effective solution. A final carbon bed can be used to reduce the solvent output of the system for applications requiring extremely low-level emissions to meet strict requirements.

- The process is a closed-loop system. The exhaust air stream from the dryer is first pre-cooled via heat exchange with the dryer exhaust that is returned to the dryer as make-up air.
- The solvent is recovered from the exhaust stream via chilled water condensation.
- The exhaust air stream is reheated via heat exchange with the dryer exhaust and is returned to the dryer as make-up air.
- A small slip-stream due to air infiltration into the dryers is sent to a water scrubber or concentrator prior to being discharged to the atmosphere. In some cases, a carbon bed may be required.
- The liquid solvent can be reused onsite by sending it to a distillation system for dehydration and purification, or it can be processed off-site.



All Dürr MEGTEC distillation and purification systems can be supplied pre-assembled on skids for timely and easy installation.





Service and Support

Dürr MEGTEC offers aftermarket services, upgrades, rebuilds, system integration services, and field services for the complete coating line and electrode plant:

- Existing equipment capability and process evaluation
- Line speed upgrades and system expansion
- Installation and commissioning of web treatment systems, measurement systems, web handling and auxiliaries
- Web path modifications, including backing roll and idler roll upgrades
- Addition or upgrade of drying zones, including air bars/nozzles and heat sources
- Air flow balancing, drying efficiency and exhaust reduction
- Optimization of air flows, temperature/pressure controls, tension controls, roller alignment and vibration analysis
- Retrofitting complementary posttreatment process equipment
- Replacing re-boilers and heat exchangers
- Replacing distillation column trays and packing material
- Equipment relocation



Dürr – Leading in Production Efficiency

Five divisions, one goal: maximum production efficiency for our customers

- » **Paint and Final Assembly Systems:** paint shops and final assembly systems for the automotive industry
- » **Application Technology:** robot technologies for the automatic application of paint as well as sealants and adhesives
- » **Clean Technology Systems:** air pollution control systems and noise abatement systems
- » **Measuring and Process Systems:** balancing systems as well as assembly, testing and filling technology
- » **Woodworking Machinery and Systems:** machinery and systems for the woodworking industry

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