



The Capacity Boosters

Our graphite based battery solutions

SIGRACELL®
SIGRACET®

Graphite Materials & Systems



34

SIGRACELL® materials for batteries Enhancing energy storage for tomorrow's needs

We produce high-quality graphite material for lithium-ion battery anodes amounting to double-digit thousands of tons each year. Fueling battery gigafactories with our products is our mission. And we are able to scale up volumes as requested – always maintaining the high performance that characterizes all of our materials. That's why our products really are "capacity boosters" for energy storage systems, which will help usher in the new era of energy.

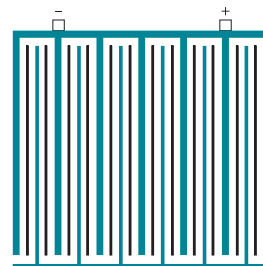
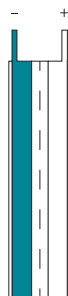


GWh



Our graphite based battery solutions

With their optimized electrochemical profile and material purity, our materials and products for battery electrodes meet the highest standards for quality, efficiency and environmental compatibility.



Typical applications

Lithium-ion batteries

- Mobility (automotive, buses, trucks, forklift trucks)
- Consumer electronics (cameras, mobile phones, computers)
- Industrial applications (power tools)
- Stationary applications (from home storages to grid-scale systems)

Lead acid batteries

- Mobility (starter batteries for automotive)

Materials made of carbon and graphite

- Graphite anode materials
- Carbon composite anode materials
- Conductive carbon additives
- Graphite based solutions for battery thermal management
- Battery housing

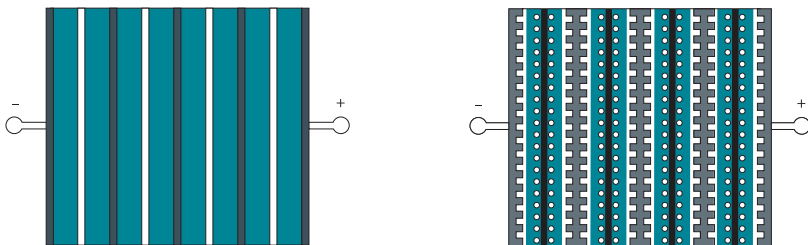
- Performance and conductive additives

SGL Carbon products

- SIGRACELL® specialty graphites

- SIGRACELL® synthetic graphite powders
 - SIGRACELL® expanded graphite powders
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Our customers benefit from energy storage with increased performance and reliability in a wide range of applications across all relevant industries. We provide tailor-made solutions based on our long-term experience and close development partnerships, including the option of large-scale production.



Redox flow batteries Vanadium [VRFB] or Zink-bromine [Zn-Br]

- Stationary applications (from home storage to grid-scale systems)

- Electrodes
- Bipolar plates

- SIGRACELL® battery felts
- SIGRACELL® bipolar plates

Proton exchange membrane [PEM] fuel cells

- E-mobility (automotive, trains, trucks, buses & forklifts)
- Stationary power generation and back-up power
- Power chargers for consumer electronics

- Gas diffusion layers [GDL]
- Separators and bipolar plates

- SIGRACET® carbon paper
- SIGRACELL® graphite foils

Products for lithium-ion batteries

Thanks to our extensive expertise, we offer the broadest range of customizable high-quality products and solutions for lithium-ion batteries.



We are a leading specialist for carbonization and graphitization, covering every phase from the purchasing of raw materials to continuously high-quality mass production. Our versatile process enables us to customize products for a high variety of application requirements, e.g. for the automotive industry, stationary energy storage, consumer goods or power tools.

Expertise and innovation

In 20 years of delivering materials at the leading edge of technology, we have gained profound expertise in lithium-ion batteries. At the same time, we strive to strengthen the connection between research and industry to foster innovation, e.g. in communities devoted to this purpose like the German Competence Network for Lithium-Ion Batteries (KLIB).

With the state-of-the-art equipment for mixing of slurries and coating of electrodes as well as for building of two- and three-electrode pouch, Swagelok and coin cells in our modern laboratories, we can conduct testing of our tailored materials, developed to our customers' specifications. Tests for both graphite materials and innovative carbon silicon composites can be adjusted to customer needs.

Global presence

SGL is a global top player in synthetic graphite anode materials for lithium-ion batteries and the only significant western manufacturer. Our sites in Europe and the United States are located close to the production facilities of relevant OEMs and in regions of planned battery production lines. Our Asian locations are also close to the main markets of lithium-ion batteries.

Quality and volume

Through decades of experience as a graphite producer, we have established a sophisticated supply chain benefitting from long-term relationships with raw material suppliers. This allows us to ensure both large volume deliveries and high-quality results.

Our products for lithium-ion battery application

- Graphite anode materials
- C/Si composites
- Additives
- Solutions for battery thermal management
- Battery housing



↑ Glove-box for cell building. In our laboratory we produce cells for testing according to standard and customized protocols

Advantages of synthetic graphite over natural graphite

- Better cycling stability
- Better fast charging performance
- Higher quality consistency
- Faster production scalability

Graphite anode materials

Backed by decades of experience and reliable, mass and diversified production, we are able to provide synthetic graphite for anode materials at the highest quality level. As a large-scale producer, we also profit from our highly developed knowledge and skills along the complete value chain.

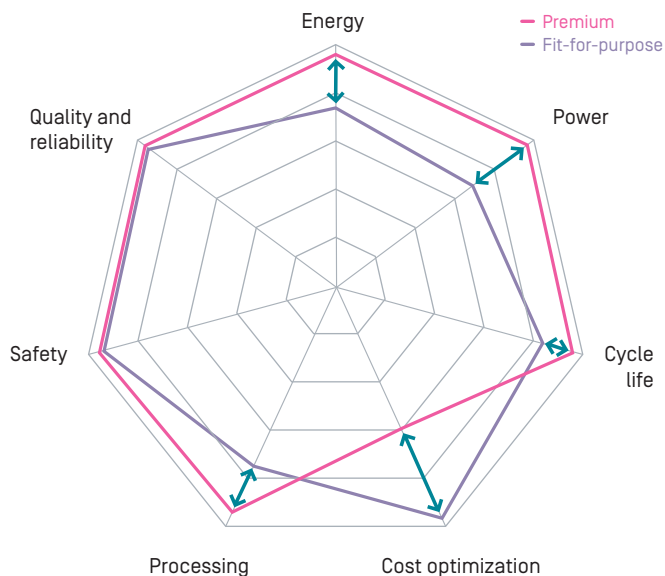
Purity for top-level requirements

We execute graphitization at technically highest possible temperatures leading to highest purity and optimized product performance. By our long term experience and know-how in production process control, we have reduced batch-to-batch variations to a minimum. Additionally, our high production capacity and special process design allows us to quickly scale up delivery volumes. These aspects ensure that our graphite meets the requirements of high-end applications: performance, reliability, quality, and safety.

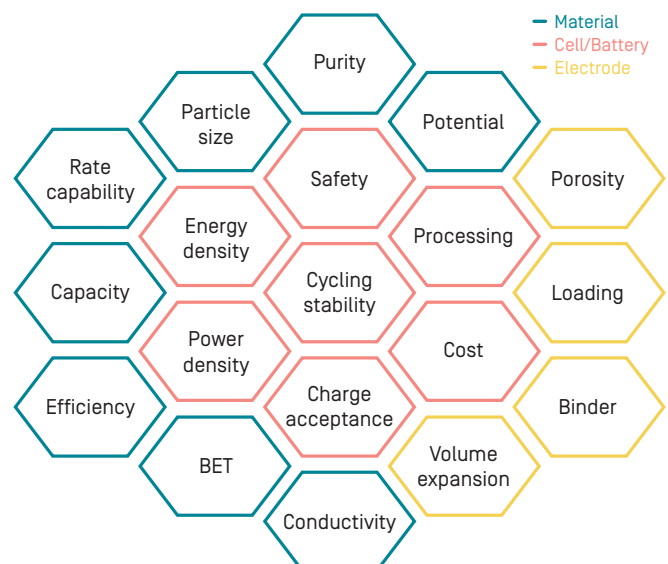
Customization

Our highly versatile production process allows us to influence various material parameters – from the selection of raw materials to carbonization and graphitization, as well as properties of the final product. This enables us to flexibly adapt our products to special application requirements.

We design products with the cost-performance profile you need



With material properties we control electrochemical battery performances

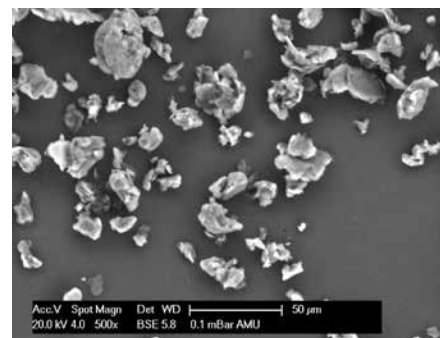
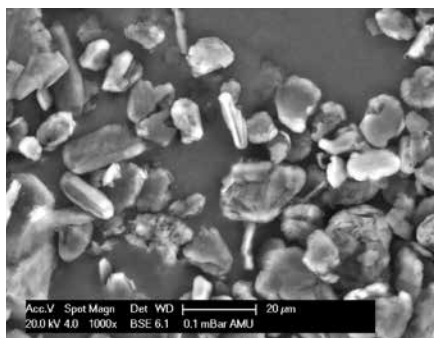
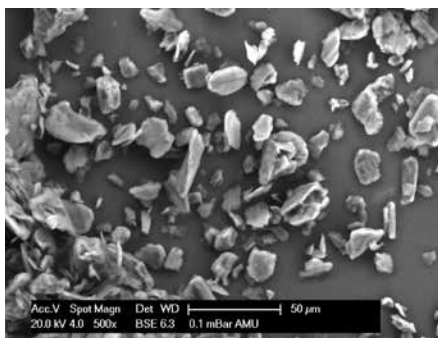


Additives for cathodes

We offer a large portfolio of additives based both on synthetic graphite and processed natural graphite. Due to their high degree of graphitization, our powders show an extremely high electrical conductivity which significantly increases the

performance of the battery. Furthermore, the high level of purity and the surface area control avoid any unwanted reaction within the cell.

SGL designing material to address customers' needs



↑ REM photos of selected graphite grades

Carbon-silicon composite anode material

Combining favorable properties

Our C/Si composite anode material integrates carefully tailored silicon-based materials with our optimized high-performance graphite anode materials to boost the anode's capacity beyond graphite's theoretical limits. Highly conductive carbon and graphite allow usage in high-power applications and foster excellent process ability to electrodes like state-of-the-art graphite anodes.

Carbon for high performance ...

The carbon structure enables an attractive electrochemical performance profile, such as high coulombic efficiency, processability and an improved cycle life.

... silicon for energy density and high power

The use of silicon in the anode results in increased gravimetric and volumetric energy density and fast charging capability for our customers, especially when compared to other materials that meet the requirements for high energy applications.

Improving parameters through C/Si material

| Parameter | Units | SGL Carbon C/Si composite | Silicon sub-oxides | Silicon alloys | Silicon dominant composites | SGL Carbon graphite |
|-------------------------------------|-------|---------------------------|--------------------|----------------|-----------------------------|---------------------|
| Capacity | mAh/g | ++ | ++ | + | ++ | ○ |
| Volumetric energy density | Wh/L | ++ | + | + | + | ○ |
| Fast charging capability | | + | + | + | ++ | ○ |
| Initial coulombic efficiency | % | + | - | ○ | ○ | +++ |
| Costs | €/kWh | + | - | ○ | ○ | +++ |
| Producibility with existing process | | + | + | ○ | ○ | +++ |

Carbon-based additives for lead acid batteries

Designed according to the latest research results, SIGRACELL materials significantly improve battery performance.



Performance, conductivity, purity, particle shape

We offer a large portfolio of additives for lead acid batteries based on synthetic graphite, natural graphite and carbon fibers. We ensure the best solutions for our customers, with products that combine electrical conductivity, high purity and optimized particle shape.

Excellence through research

Our own focus on research as well as our extensive R&D network put us at the forefront of material development. This allows us to integrate the most recent scientific findings into our production of additives. We provide tailor-made solutions featuring an enhanced dynamic charge acceptance (DCA) in combination with low hydrogen development and improved cold-crank-ability.

Key advantages

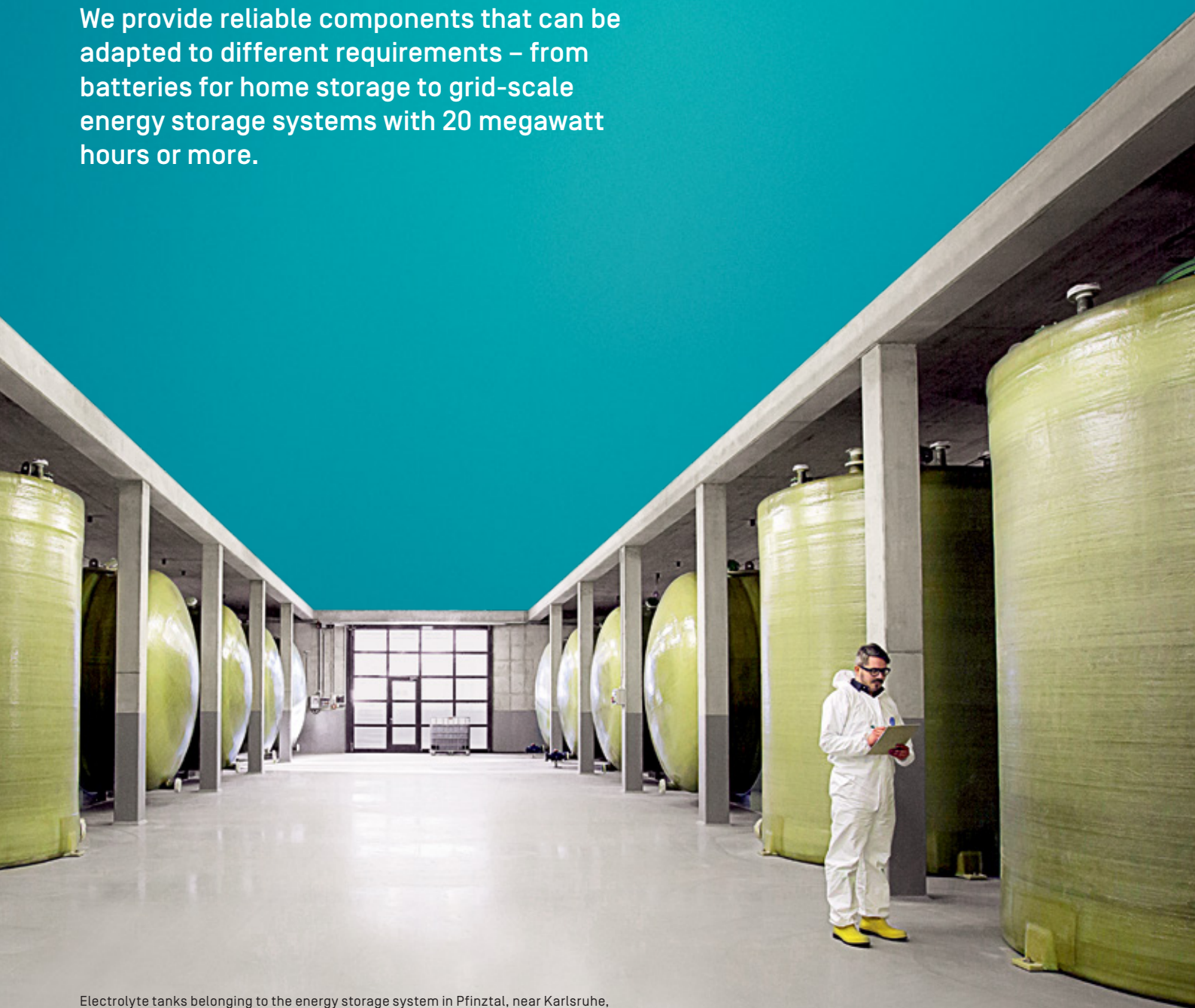
- Significant improvement of DCA
- High cycling stability
- Very low levels of metal impurities
- Excellent wettability
- Easy to mix into the lead paste
- Combination with conductive carbon blacks possible

Comparison

| Parameter | Units | GF620 HP | SGL Carbon SG |
|---------------------------------|-------|------------------|--------------------|
| Material classification | | Natural graphite | Synthetic graphite |
| Dynamic Charge Acceptance (DCA) | A/Ah | +++ | ++ |
| Cycle life | | ++ | +++ |
| Purity | | ++ | +++ |
| Costs | €/kg | + | +++ |
| Recommended concentration | wt% | < 3 | < 3 |

Graphite-based solutions for redox flow batteries

We provide reliable components that can be adapted to different requirements – from batteries for home storage to grid-scale energy storage systems with 20 megawatt hours or more.



Electrolyte tanks belonging to the energy storage system in Pfinztal, near Karlsruhe, each holding 45,000 liters. The 20 MWh system, run by the Fraunhofer Institute for Chemical Technology and equipped with SGL materials is part of the RedoxWind project supported by the German federal state of Baden-Württemberg and the Federal Ministry of Education and Research. © Fraunhofer-Institut für Chemische Technologie ICT

Ideal for stationary applications

Redox flow batteries enable energy storage on a scale of kWh to MWh and provide the perfect solution for stationary applications. Their main advantage is, that output (MW) and energy (MWh) can be adjusted independently of one another. This makes them easily adaptable to the specific requirements at hand.

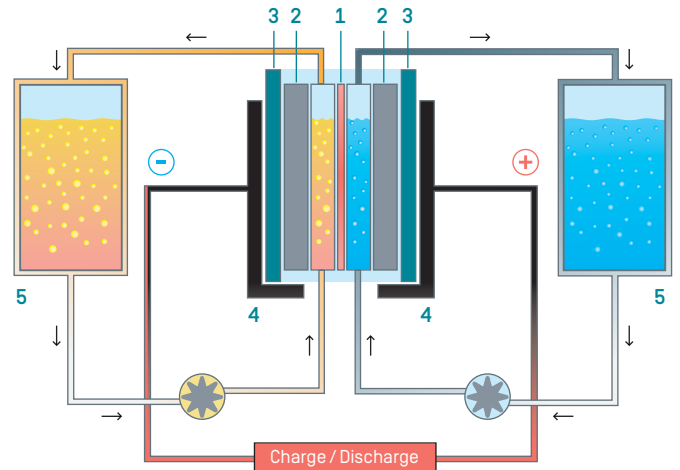
Expertise for enhanced performance and service life

We rank among the leading manufacturers of specialty graphite components for redox flow batteries. We have applied our long-term experience and close cooperation with customers to develop our SIGRACELL battery felts, bipolar plates and endplates. By constantly improving our materials, we significantly enhance the performance and service life of our customers' batteries.

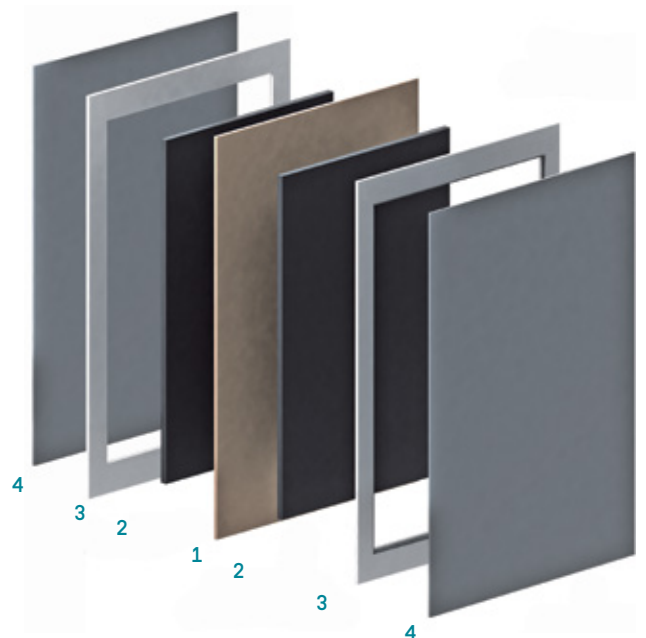
Optimizing performance through felt quality

Inhomogeneity in the battery felt can lead to impermeable areas that reduce overall system performance. As a result, we are continuously working on tighter tolerances for the area weight and thickness of our battery felts. This helps our customers optimize compression rates, thus ensuring the best possible battery performance.

Schematic diagram of redox flow battery



- 1 Membrane
- 2 Permeable electrode
- 3 Bipolar plate
- 4 Storage electrode
- 5 Electrolyte



- ↑ Flow battery components
- 1 Ion-exchange membrane
- 2 SIGRACELL battery felt
- 3 Flow frame
- 4 SIGRACELL bipolar plate

Specialty graphites for redox flow batteries

| Applications | SIGRACELL battery felts | SIGRACELL bipolar plates and end-plates |
|----------------------|-------------------------|---|
| Permeable electrodes | ● | |
| Bipolar plates | | ● |



SIGRACELL® battery felts

Ideal properties for an efficient charge exchange

Permeable electrodes made of SIGRACELL carbon and graphite felts are the first choice for high-temperature batteries like redox flow batteries. Our felts are used for anodes as well as cathodes. Thanks to a unique combination of electrical conductivity, electrochemical stability, high porosity and good elasticity, they facilitate an efficient charge exchange between the electrolyte and the bipolar plate.

↑ SIGRACELL carbon and graphite felts. We customize to your needs. Please contact us for details

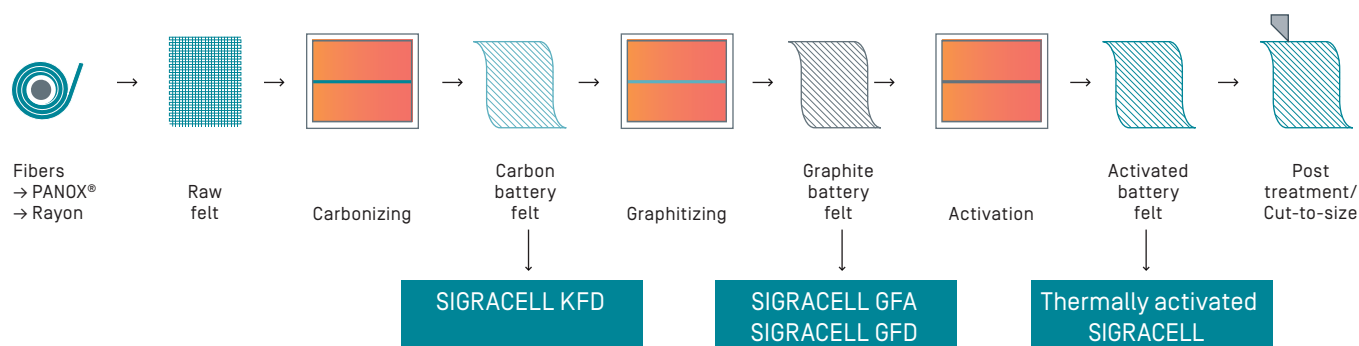
Felt activation for enhanced performance

As graphitized felts are non-wetting towards aqueous electrolytes, activation is strongly recommended in order to avoid slowdown of charge transfer and large resistances. We offer felt activation through thermal surface oxidation. This treatment induces wettability by generating hydrophilic surface functions while preserving the structural integrity of the fibers, since the burn-off only affects a few percent.

Adaptable sizes – including large-scale needs

The sizes we provide are even enough to cover the needs of large-scale redox flow systems. We supply battery felts in standard sizes up to 1350 mm [53"] in width in 25 m [82 ft] rolls. Beyond that, we produce carbon and graphite felts in customer-specific dimensions.

Ensuring quality – our complete in-house value chain



Felt comparison

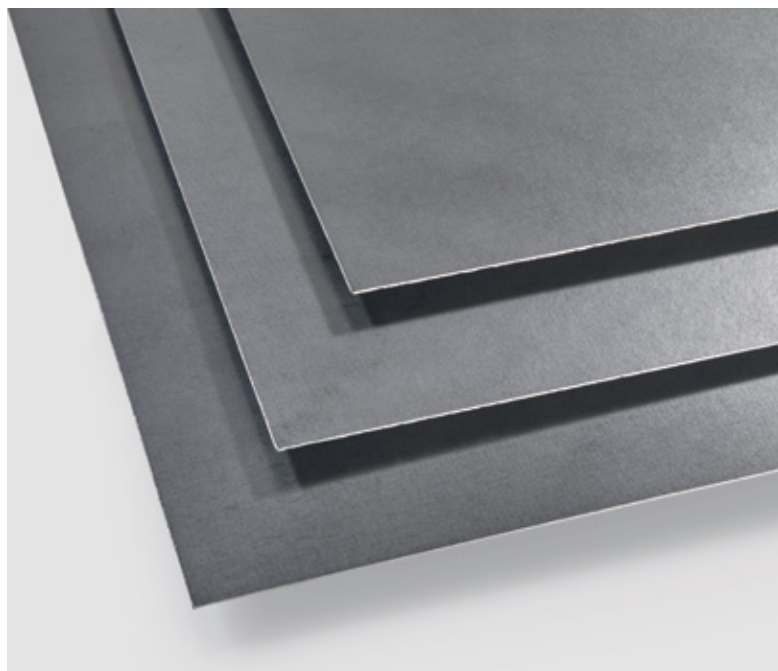
| Typical properties | Carbonized felts e.g. KFD2.5 | Graphitized felts e.g. GFA3.0 | Graphitized felts e.g. GFD4.6 | Thermally activated graphite felts GFA3.0 activated | Thermally activated graphite felts GFD4.6 activated |
|--|---------------------------------|----------------------------------|----------------------------------|---|---|
| Fiber precursor | PAN | Rayon | PAN | Rayon | PAN |
| Chemical resistivity | ○ | ++ | +++ | ++ | +++ |
| Low area-specific resistance \perp^1 | - | ++ | ++ | +++ | +++ |
| BET surface area | ○ | ○ | ○ | ++ | +++ |
| Compressibility | + | ++ | + | ++ | + |
| Total impurities | - | + | +++ | + | +++ |
| Costs | +++ | ++ | + | + | ○ |

¹⁾ \perp vertical to longitudinal direction of felt

SIGRACELL® bipolar plates and end plates

Resistance to chemicals meets high conductivity

The main features that distinguish expanded natural graphite are exceptional resistance to chemicals and good electrical conductivity. Together with high-grade fluoropolymers, our thin, high-density SIGRACELL bipolar plates can be used for a broad spectrum of applications. Thanks to their great resistance to corrosion, they are ideally suited for the demanding cell chemistry in battery systems.



↑ SIGRACELL bipolar plates made of expanded graphite (TF6/PV15)

Bipolar plates [BPP] comparison

| Typical properties | Extruded BPP | Injection molded BPP | Hot-pressed BPP | SGL Carbon bipolar foil | SGL Carbon graphite BPP |
|-------------------------|-------------------|----------------------|-------------------|--|--|
| | Polymer composite | Polymer composite | Polymer composite | Expanded graphite based bipolar foils SIGRACELL TF6 and PV15 | Machined extruded graphite – resin impregnated |
| Explanation | | | | | |
| Process ability | +++ | ++ | + | +++ | - |
| Electrical conductivity | ○ | + | ++ | ++ | +++ |
| Surface tolerance | - | ○ | - | ++ | ++ |
| Costs | +++ | + | ○ | ○ | - |

Carbon-based products for fuel cells

Our SIGRACET® gas diffusion layers (GDL) excel in performance, durability and adaptability to different applications.

Gas diffusion layers (GDLs) are key components of proton exchange membrane (PEM) fuel cells. They modulate all relevant transport processes concerning reaction products, electricity and heat.

Designed for high performance

Our high-performance products are the result of continuous research. We tailor their material properties to meet the requirements of the intended application. Our customers benefit from our know-how in fine-tuning the physical and electrochemical attributes of our materials to optimize their interaction with other cell components.

Great variety

Thanks to our sophisticated production process, we can offer a broad range of GDLs with variable thickness and porosity, each suited for a specific set of applications based on its physical attributes. Our portfolio has an extensive selection of GDLs for dry or wet operating conditions, based on their electrochemical attributes. For example, GDLs for dry conditions are designed to prevent membrane dehydration. We also offer solutions if high gas diffusivity is needed.

Other applications

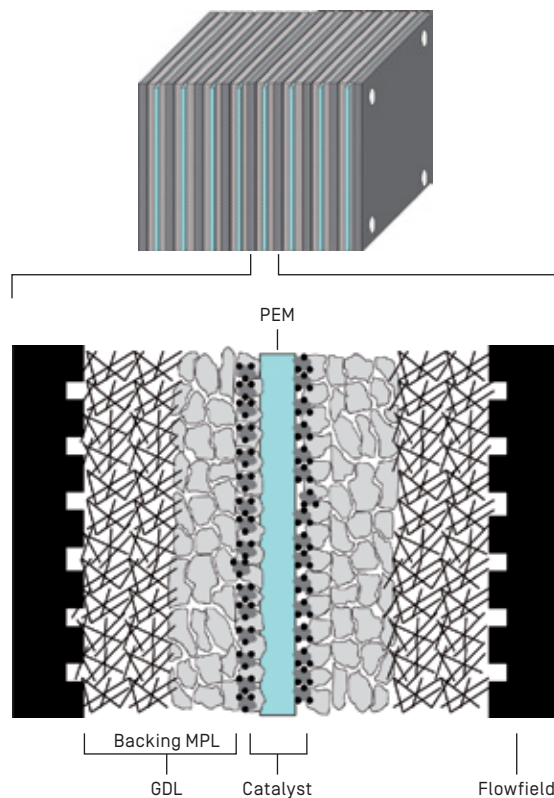
Our GDLs can also be used in electrochemical applications, such as redox flow or metal air batteries as well as for microbial fuel cells and PEM electrolysis.

Selection of non-fuel cell applications and recommended SIGRACET® grades

| Applications | Material applied as | Recommended grade(s) |
|----------------------|---|----------------------|
| Redox flow batteries | Porous electrode for zero-gap cell design | GDL 39 AA/38 AA |
| Metal-air batteries | Cathode support (for GDE) | GDL 39 AA/BC |
| Microbial fuel cells | Electrode support | GDL 39 AA/BC |
| PEM electrolysis | Cathode support | GDL 39 AA/BA/BC |

Preferred SIGRACET® grade for various applications

| Applications | GDL 28 200 µm Low porosity | GDL 29 200 µm High porosity | GDL 38 300 µm Low porosity | GDL 39 300 µm High porosity |
|------------------|----------------------------------|-----------------------------------|----------------------------------|-----------------------------------|
| PEMFC stationary | ● | | | |
| PEMFC automotive | ● | ●● | | |
| PEMFC portable | | | | ● |
| HT-PEMFC | | | ● | |
| DMFC | | ● | | ● |
| PEM electrolysis | | ● | | ●● |


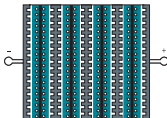



↑ Structure of a PEMFC single cell

SIGRACELL® and SIGRACET® in relevant industries

Our materials are widely used in a broad range of industries, helping to enhance energy storage and achieve more sustainable solutions.



| Segment | E-mobility | | |
|-----------------------------|---|--|--|
| Examples | Cars, buses, trucks, trains, forklift trucks and others | | |
| Application example | Electrical propulsion and fuel cell | Start-stop battery | |
| Products with our material | Li-ion batteries | PEM Fuel cells | Advanced Pb-acid batteries |
| |  |  |  |
| Our input | <ul style="list-style-type: none"> • Artificial graphite for anodes • Carbon-silicon composites for anodes • Graphite additives • Solutions for battery thermal management • Battery housing | <ul style="list-style-type: none"> • Gas diffusion layers • Bipolar plates | <ul style="list-style-type: none"> • SIGRACELL® additives from processed natural and artificial graphite |
| Our impact on the products | <ul style="list-style-type: none"> • Higher energy density • Improved C-rate • Higher stability and safety | <ul style="list-style-type: none"> • Higher cell performance • Various explicit product attributes | <ul style="list-style-type: none"> • Improved dynamic charge acceptance (DCA) • Reduced hydrogen evolution |
| Advantages of our materials | <ul style="list-style-type: none"> • High purity • Stable quality • Customized cost/performance • High production capacity | <ul style="list-style-type: none"> • Stable quality and performance depending on application needs | <ul style="list-style-type: none"> • High conductivity and purity • Stable quality and high performance |



Stationary storage solutions

Other mobile devices

Consumer products

Energy storage systems

Power tools, bicycles and others

Mobile phones, notebooks

Stationary power wall

Electrical stationary storage (ESS)

Electrical propulsion

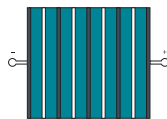
Battery

Li-ion batteries

Redox flow batteries

Li-ion batteries

Li-ion batteries



- Artificial graphite for anodes
- Carbon-silicon composites for anodes
- Graphite additives

- Bipolar plates, carbon and graphite felts

- Artificial graphite for anodes
- Carbon-silicon composites for anodes
- Graphite additives

- Artificial graphite for anodes
- Carbon-silicon composites for anodes
- Graphite additives

- Higher energy density
- Improved C-rate
- Higher stability and safety

- Tight specification tolerances enabling best stack sealing

- Higher energy density
- Improved C-rate
- Higher stability and safety

- Higher energy density
- Improved C-rate
- Higher stability and safety

- High purity
- Stable quality
- Customized cost/performance
- High production capacity

- Homogeneous product quality
- Conductivity
- Power capability
- High volume production capability

- High purity
- Stable quality
- Customized cost/performance
- High production capacity

- High purity
- Stable quality
- Customized cost/performance
- High production capacity

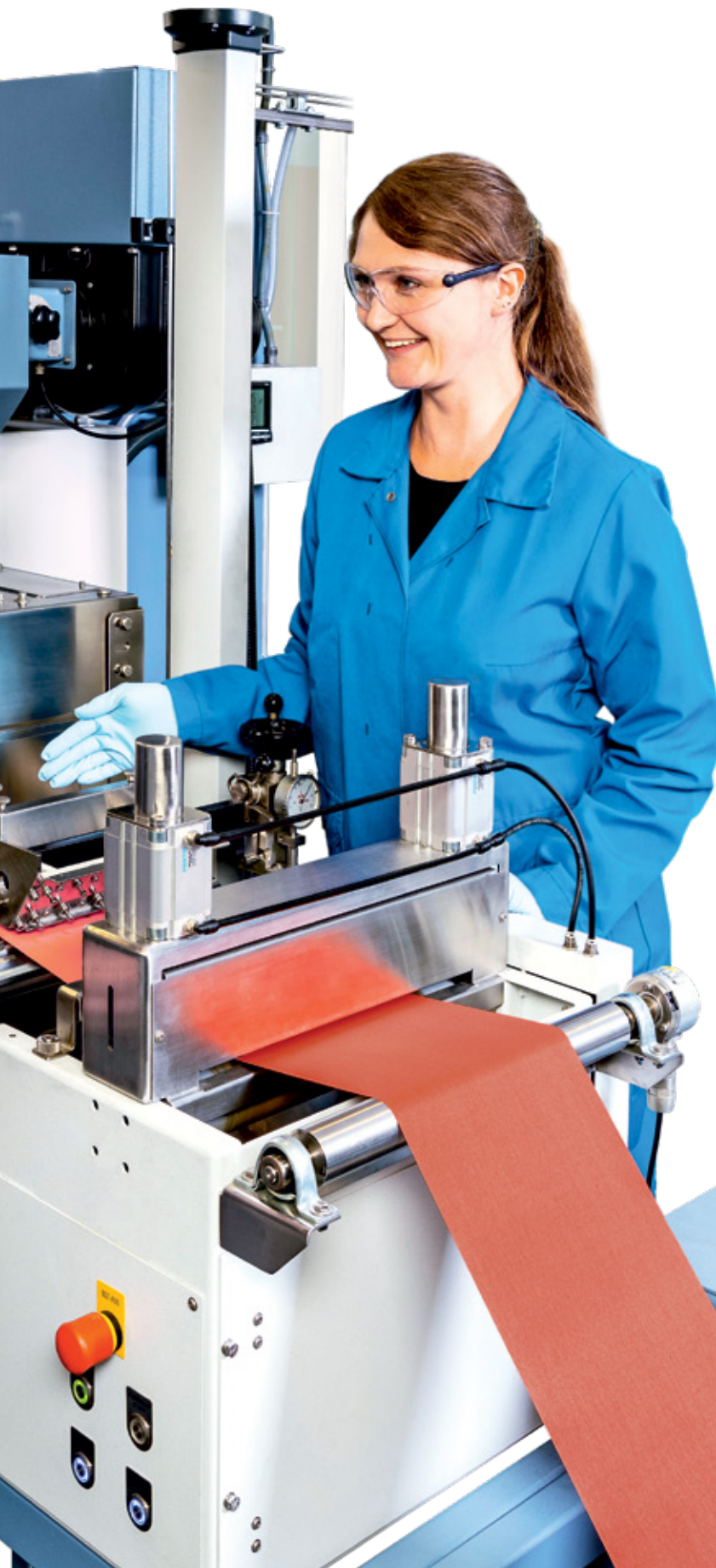
Successful together

Lithium-ion batteries are complex electrochemical systems involving dozens of components, all of which react with each other. Changing a single property of just one component can lead to a significant change in the entire cell.

This is why it is so crucial to test our materials according to our customers' specifications. Our laboratory meets this need and provides full characterization of the materials under different conditions. We also carry out further tests in collaboration with universities and research institutions.

As a result, we can deliver material with a characterization that is as close as possible to our customers' own characterization, helping to accelerate development and upscaling processes at customers' end.





A laboratory for tailor-made solutions

Special tests

We test according to the conditions of our customers.

Adjusting the electrode recipe

We adjust our standard electrode recipe to match the ones used by our customer.

Testing of properties

We test the properties of electrodes (e.g. adhesion and cohesion, particle orientation, wetting, SEM) according to customer specifications.

Use of same cathode type

We can use a cathode type identical or similar to those of our customers.

Adapting electrolyte and additives

We apply an electrolyte composition and/or additives identical or similar to the ones of our customers.

Variable test conditions

We can change the electrochemical characterization test conditions (e.g. C-Rate, cycling type, cycling temperature, storage condition, etc.) according to our customers' requirements.

Measuring swelling and gas

We measure the swelling of the electrodes and the gas development in a pouch cell.

Pouch, Swagelok and coin cells

Our cutting-edge equipment also enables us to build two- and three-electrode pouch, Swagelok and coin cells.

Smart Solutions

Be it materials, components or production processes, we focus our thinking and actions on the customer and keep an eye on the big picture. Our solutions already anticipate the future today.

The following examples show a selection of our unique product range.

Mobility

- Lightweight components and structural parts based on fiber-reinforced composites for automotive and aerospace manufacture
- Graphite anode material for lithium-ion batteries in electric vehicles
- Carbon-ceramic brake disks for sports cars and luxury sedans

Energy

- High-temperature solutions based on specialty graphites and fiber materials for the photovoltaic industry
- Carbon fiber materials for rotor blades
- Gas diffusion layers for fuel cells
- Systems for more efficient heat exchange and heat recovery
- Carbon fibers for pressurized gas containers

Digitization

- Carbon, graphite, and CFC components for polysilicon and monocrystal pulling in the semiconductor industry
- High precision, coated graphite carriers for the production of LEDs

→ State-of-the-art green production with the world's largest isostatic press



SGL Carbon

We are leaders in the development and manufacture of products based on carbon, graphite, carbon fibers, and fiber-reinforced composites. In partnership with our customers, we develop intelligent, trendsetting, and sustainable solutions that deliver a clear benefit.

With our in-depth material, engineering, and application know-how, we make a substantial contribution to the major future topics mobility, energy, and digitization.



Contact

Europe / Middle East / Africa

SGL CARBON GmbH
Soehnleinstrasse 8
65201 Wiesbaden/Germany
sigracell-europe@sglcarbon.com

Americas

SGL CARBON LLC
307 Jamestown Road
NC 28655 Morganton/USA
sigracell-america@sglcarbon.com

Asia / Pacific

SGL CARBON Far East Ltd.
No.151, East Huan Cheng Road
Fengxian district
201401 Shanghai/China
sigracell-asia@sglcarbon.com

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Graphite Materials & Systems
SGL CARBON GmbH
Soehnleinstrasse 8
65201 Wiesbaden/Germany
www.sglcarbon.com/gms