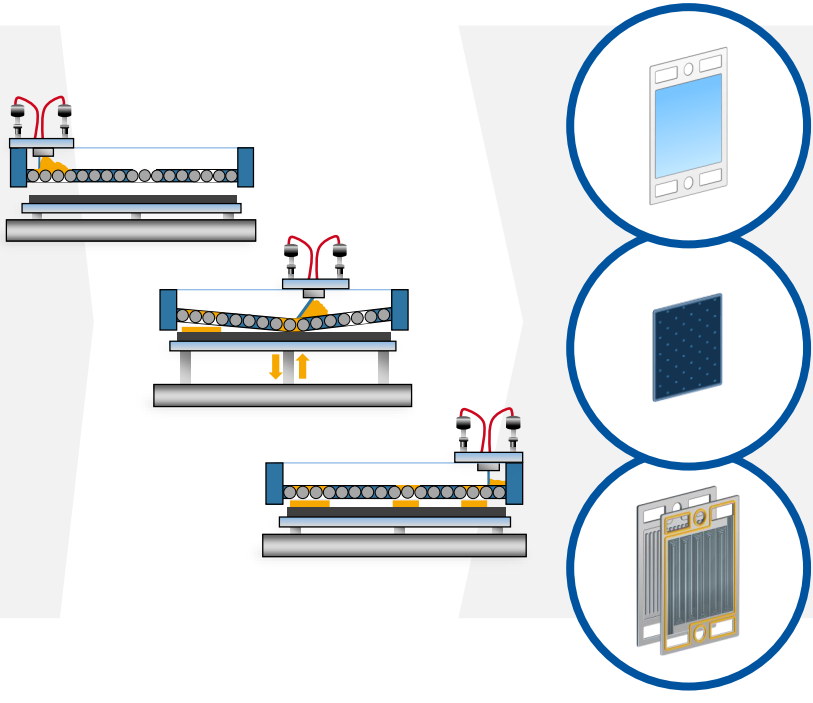

PRODUCTION OF FUEL CELL COMPONENTS

2nd edition

PEM | RWTH AACHEN UNIVERSITY

VDMA Fuel Cells

The chair "Production Engineering of E-Mobility Components" (PEM) of RWTH Aachen University deals with the production engineering of fuel cells. Within the mechanical engineering sector, the activities range from the cost-efficient production of hydrogen-powered drivetrain components to innovative mobility solutions and overall emission reduction. Through national and international projects in companies at various stages of the value chain as well as participation in numerous research projects, PEM offers extensive expertise.

The VDMA Fuel Cells Working Group supports manufacturers of fuel cell components and systems in Germany in expanding their industry network. It currently offers more than 80 leading, nationally and internationally active manufacturers and suppliers a communication platform for networking and joint representation of interests. Technical solutions for optimizing and reducing the costs of fuel cell systems and their respective components as well as for setting up series production are developed in project groups.

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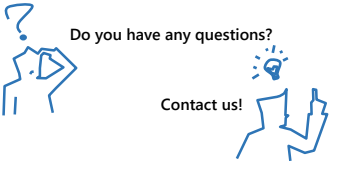

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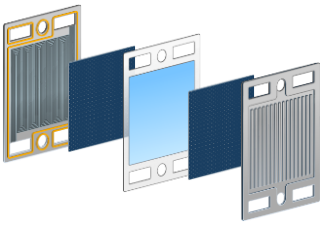
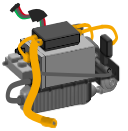
Overview
of PEM fuel cells

Fuel cell components



Fuel cell stack

Fuel cell system



Component production › Stack production › System production

In this guide, the manufacturing of fuel cell components as part of the production process of polymer electrolyte membrane (PEM) fuel cells is presented schematically.

The fuel cell components **bipolar plate**, **gas diffusion layer**, and **catalyst-coated membrane** are manufactured by using different materials in different production processes. Based on the current state of the art, this guide shows a manufacturing sequence for the component production. This selection serves as a basis for discussion within the industry. Other process step configurations are conceivable and desired. Alternative manufacturing processes for the production of fuel cell components are therefore referred to in excerpts. Further process variants can be specified in more detail in joint discussion with the RWTH PEM chair or VDMA.

Technology Development
of PEM fuel cells

The widespread introduction of fuel cell technology requires product and process innovations aimed at reducing production costs. This requires a scaling of production quantities while meeting constant quality requirements. The PEM chair of RWTH Aachen University has set itself this goal and identified the following research topics, among others:

Process innovation (example)

Component production
- Substitution of the decal process
- Increase in the share of "roll-to-roll" processes in the fuel cell production

Stack production
- High-speed stacking
- Reduction of stack activation time

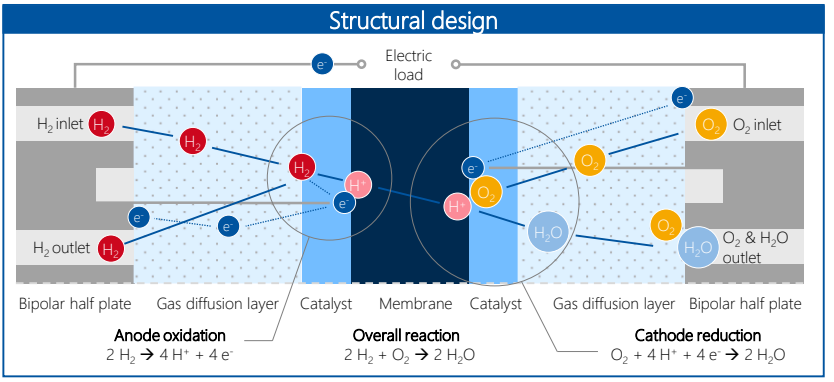
Product innovation (example)

Component production
- Development of adhesive bipolar plates
- Construction of "intermediate plates" to increase product modularity

Stack production
- Combination of membrane electrode assembly (MEA) and bipolar half plate (BPHP) into one component

Operating Principle

of PEM fuel cells



The conversion of chemical energy into electrical energy by the PEM fuel cell is based on the following operating principle:

- Hydrogen is supplied on the anode side and oxygen on the cathode side via the flow channels of the **bipolar half plates** (BPHP).
- The hydrogen diffuses via the **gas diffusion layer** (GDL) to the anode side of the **catalyst-coated membrane** (CCM).
- The hydrogen is catalytically oxidized and protons (H^+) are formed with the release of electrons which pass across the wet membrane to the cathode side. The electrons are conducted to the cathode side via an external circuit.
- The oxygen on the cathode side is reduced by the electrons and reacts with the protons (H^+) from the membrane to form H_2O (water) which is dissipated.

Fuel Cell Types

in comparison

The following diagram shows an overview of the fuel cell types currently available in industry and research, their reaction media and usual operating temperature.

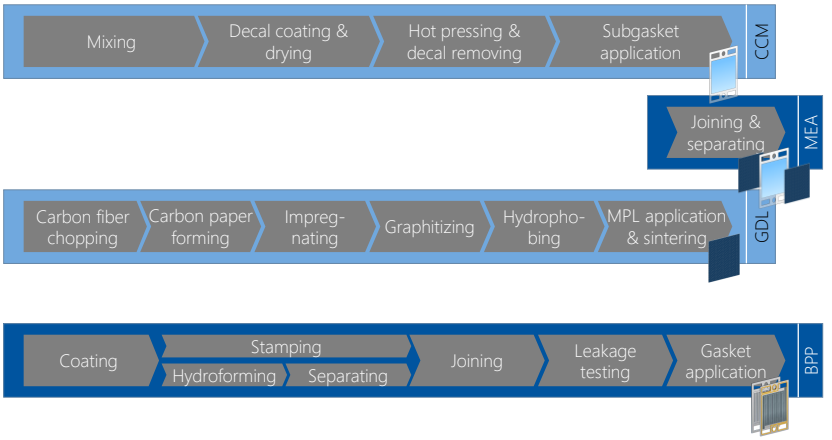
Fuel cell type		Anode in/out	Ion transport	Cathode in/out	Temp. [°C]
SOFC	Solid Oxide Fuel Cell	H_2 (Natural gas), CO / CO_2, H_2O	O^{2-}	O_2 (air)	900
MCFC	Molten Carbonate Fuel Cell	H_2 (Natural gas), CO / CO_2, H_2O	CO_3^{2-}	O_2 (air), CO_2	650
PAFC	Phosphoric Acid Fuel Cell	H_2	H^+	H_2O gaseous, O_2 (air)	220
HT-PEMFC	High Temperature Polymer Electrolyte Membrane FC	H_2	H^+	H_2O gaseous, O_2 (air)	160
DMFC	Direct Methanol Fuel Cell	CH_3OH / CO_2	H^+	H_2O liquid, O_2 (air)	90
LT-PEMFC	Low Temperature Polymer Electrolyte Membrane FC	H_2	H^+	H_2O liquid, O_2 (air)	80
AFC	Alkaline Fuel Cell	H_2 / H_2O	OH^-	O_2 (pure substance)	

Production Process

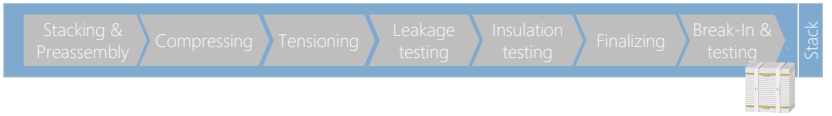
of PEM fuel cell components

- The process chain for series production of PEM fuel cell systems differs depending on the application and the number of units produced annually. Uniform standards are currently not yet available due to the **manufactory nature of fuel cell production**.
- The production of a PEM fuel cell system can be divided into three superordinate steps: **component production**, **stack production**, and **system production**.
- This guide presents the process steps that make up the current state of the art in the production of PEM fuel cell components.
- The production of the fuel cell stack and system is explained in more detail in a separate guide ("Production of Fuel Cell Systems").

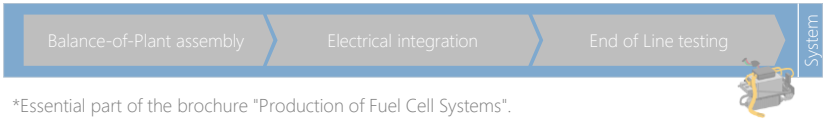
Component production:



Stack production*:



System production*:



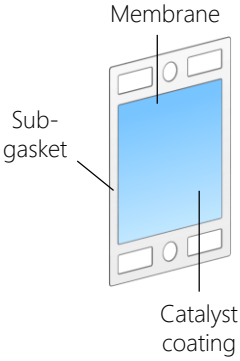
*Essential part of the brochure "Production of Fuel Cell Systems".

Process step | Intermediate product | Final product

Overview

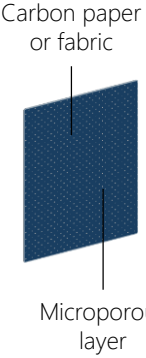
of PEM fuel cell components

Catalyst-coated membrane



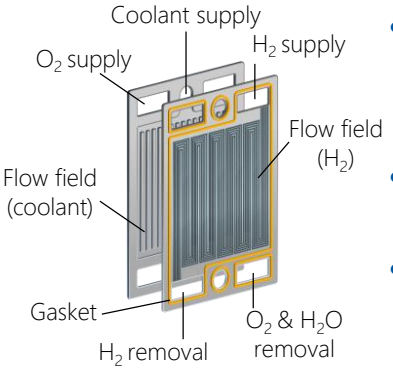
- The polymer membrane coated with platinum catalyst is called a "catalyst-coated membrane" (CCM).
- There is one catalyst layer on the anode side and one on the cathode side. The layers differ in their chemical composition and thickness.
- Proton transport takes place via the CCM, while the catalyst layers enable oxidation or rather reduction.

Gas diffusion layer



- The gas diffusion layer (GDL) consists of carbon paper or fabric and has a significant influence on the efficiency of the fuel cell.
- The GDL enables the uniform distribution of the reaction media to the catalyst layers on the anode and cathode sides.
- The microporous layer (MPL) improves the regulation of water retention at the electrodes.

Bipolar plate



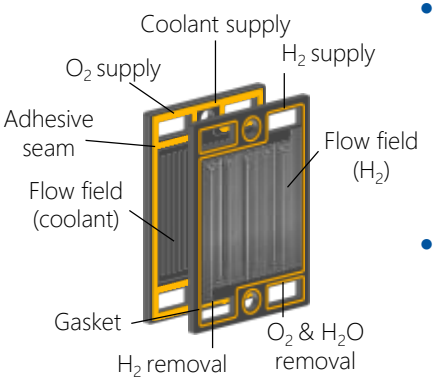
- The bipolar plate (BPP) usually consists of two bipolar half plates, which are formed, coated, and joined depending on the material (metallic* or graphite).
- The reaction media are conveyed via the BPP, and the reaction heat is dissipated from the fuel cell.
- The BPP is electrically conductive and thus feeds the electrons into the consumer circuit.

*Focus of this guide

Graphite Bipolar Plate

Information on the product in the form of an excursus

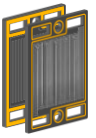
Graphite bipolar plate



- The material of a bipolar plate for use in long-life fuel cells brings with it ideal properties. These include high corrosion resistance, high mechanical strength, low interfacial contact resistance, high contact angle, impermeability to reaction gases and no brittleness.
- Compound bipolar plates also form an alternative to metal and consist of polymer-bonded, highly filled graphite-based compound materials.

Special Features

Due to the different material, the product- and process-related properties of graphite bipolar plates differ significantly from those of metallic bipolar plates. For example, two bipolar half plates are joined by an adhesive seam. The shaping also differs significantly from the process of metallic bipolar plates. Both products hold advantages and disadvantages.



Advantages

- Service life is more than 40,000 operating hours
- High corrosion resistance
- Low interfacial contact resistance
- For graphite composite: higher electrical conductivity due to a higher carbon/polymer ratio

Disadvantages

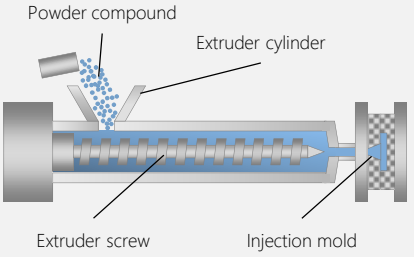
- Higher volume
- Brittleness
- Lower mechanical strength
- Higher production costs for large quantities
- More difficult producibility due to mechanical material behavior

Production of Graphite BPP

Excerpt of essential production processes

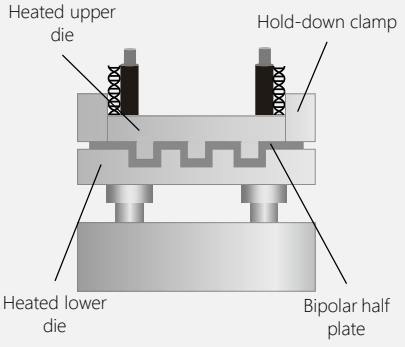
Graphite bipolar plates differ from metallic bipolar plates in terms of production. The shaping and bonding may entail essential differences in the production which are explained in the following.

Injection molding



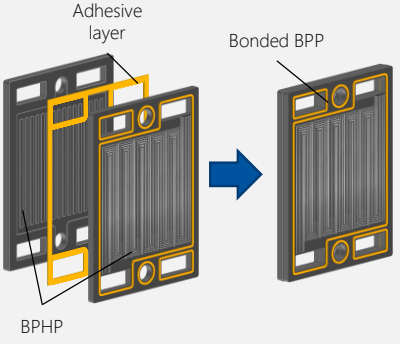
- The powder compound is fed to an extruder and melted into a homogeneous mass.
- The homogeneous mass is transported through the extruder screw to the injection mold and added to it.
- This is followed by component shaping and ejection of the component geometry from the mold.

Compression molding



- Compression molding requires a press, a molding tool, and molding compound.
- Hold-down or pressing force are relevant parameters to be considered.
- Excess molding compound material provides void filling.
- Losses due to high process scrap rates and the excess material

Bonding the BPHP



- Adhesive or sealant is applied directly to the BPHP and no longer slips.
- For sealing, "cure in place gaskets" are used, for example, which cure after application.
- "Non-adhesive" materials have the properties of a gasket after curing.
- "Permanently adhesive" substances form a bond in the classical sense.
- Pressure-sensitive adhesives are, for example, adhesive tapes or transfer films.

Mixing

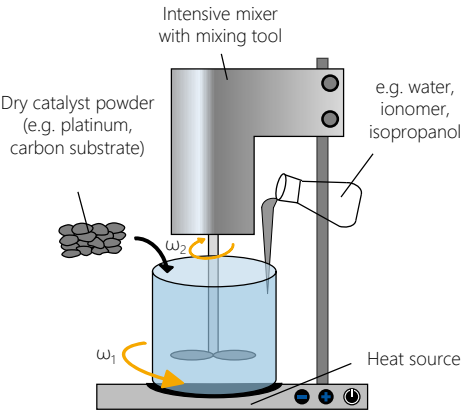
CCM production

Anode formula (example)

Catalyst powder:
Platinum-coated carbon substrate (about 15 wt%)
Solvent:
Deionized water (approx. 40 wt.%) and methanol (approx. 40 wt.%), e.g.
Binder:
Ionomer solution (approx. 5 wt.%)

Cathode formula (example)

Catalyst powder:
Platinum-coated carbon substrate (about 20 wt%).
Solvent:
Deionized water (35 wt.%) and methanol (35 wt.%), e.g.
Binder:
Ionomer solution (approx. 10 wt.%)



Component production | Stack production | System production

- By applying energy, several raw materials are combined via a rotating tool to form a catalyst ink.
- The catalyst ink consists mainly of carbon substrate (e.g. carbon black) and catalyst material (e.g. platinum, platinum-ruthenium, platinum-cobalt). Ionomer and solvent (e.g. water, isopropanol) are also required to produce the catalyst ink.
- The catalyst ink for the anode layer and the cathode layer of the CCM is mixed separately due to the different compositions.

Process parameters & requirements

- Platinum load cathode: approx. 0.4 mg/cm²
- Platinum load anode: approx. 0.1 mg/cm²
- Atmosphere: contamination-free
- Mixing time: >1 h
- Mixing temperature: 2°C
- Mixing speed: 600 - 4,000 rpm

Alternative technologies

- Paddle mixer
- Rotary ball mixer
- Ultrasonic mixer

Quality influences

- Mixing time
- Mixing temperature
- Mixing tool
- Ambient conditions

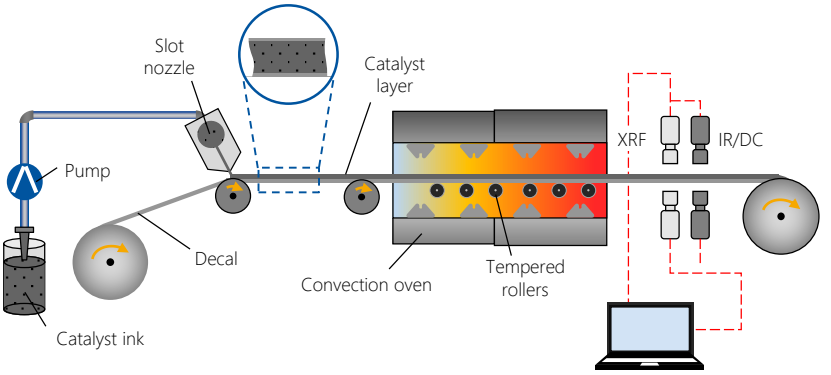
Quality characteristics

- Porosity
- Uniform platinum loading
- Viscosity

Production costs [excerpt] Invest for machinery and plant: € 0.3 - 0.4 m

Decal Coating & Drying

CCM production



Component production | Stack production | System production

- The decal process is an indirect coating of the polymer membrane by means of decal transfer carrier film, hereinafter referred to as "decal". The process enables dry coating of the moisture-sensitive polymer membrane.
- The catalyst ink prepared in the previous step is applied to the decal (e.g. polytetrafluoroethylene [PTFE], polypropylene [PP]) by slot die.
- The coated decal is then transferred to a convection oven and dried.
- After evaporation of the solvents, the decal is inspected for homogeneity as well as particle size and thickness of the catalyst layer. This can take place using infrared/direct current (IR/DC) and/or X-ray fluorescence (XRF) systems.

Process parameters & requirements

- Coating thickness (anode): 3 - 15 µm
- Coating thickness (cathode): 10 - 30 µm
- Belt speed: 0.1 - 1 m/min
- Drying time: approx. 4 min
- Drying temperature: approx. 30°C - 70°C (air) 120°C - 160°C (heated rollers)

Alternative technologies

- Transfer roller
- Screen printing, inkjet printing, gravure printing
- Squeegee
- Infrared drying, laser drying
- Extrusion

Quality influences

- Viscosity of the catalyst ink
- Application tool
- Oven temperature

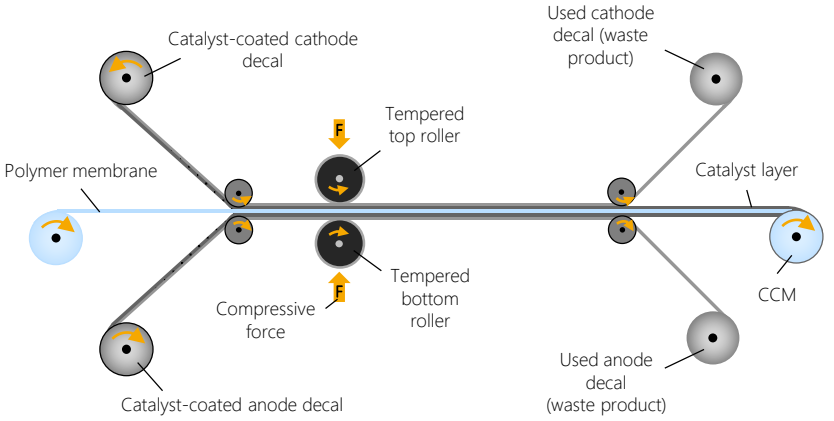
Quality characteristics

- Layer homogeneity
- Particle size
- Layer thickness
- Residual moisture after drying

Production costs [excerpt] Invest for machinery and plant: € 0.8 - 1.2 m

Hot Pressing & Decal Removing

CCM production



Component production | Stack production | System production

- The transfer of the dry catalyst layer from the decal to the polymer membrane is done by hot pressing process. Since the productivity of this step is largely dependent on the hot pressing method, a roll-to-roll process is recommended.
- Cathode and anode decal are fed to the top and bottom of the polymer membrane simultaneously and placed between the pair of rollers.
- For good transferability of the catalyst layer, the temperature-controlled roller pair (100°C to 170°C) brings the polymer membrane to glass transition temperature and generates a constant line pressure.
- The cathode and anode decal are then peeled off, analogous to the removal of a decal, to form a waste product.
- The CCM is finished and wound onto a coil.

Process parameters & requirements

- Line force: 150 - 250 N/cm
- Temperature: 100°C - 170°C

Alternative technologies

- ***Direct membrane coating***
- Screen printing, inkjet printing, gravure printing, squeegee, additive layer production
- ***Indirect membrane coating***
- Transfer roller
- Coating of GDL (GDE approach)

Quality influences

- Decal quality
- Combination of roller temperature, feed speed, and contact pressure
- Duration of active force application

Quality characteristics

- Residue free decal
- Non-destructive catalyst layer and polymer membrane
- Uniform adhesion of catalyst layer

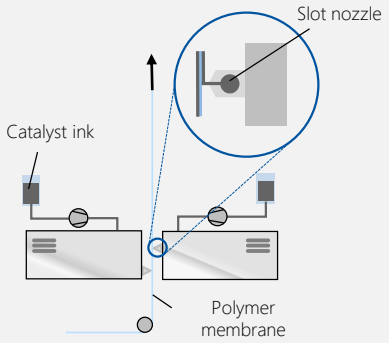
Production costs [excerpt] Invest for machinery and plant: € 0.3 - 0.6 m

Alternative Catalyst Application

Coating concepts and research approaches

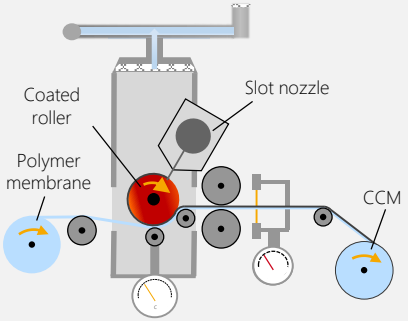
The decal method shown previously is considered a possible option for membrane coating. Alternatively, the following procedures are conceivable:

CCM direct coating:



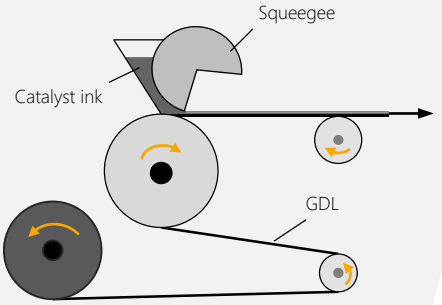
- The polymer membrane is coated on both sides in a vertical direction using slot nozzles.
- The vertical orientation saves installation space and allows coating on both sides with the same layer quality.
- Due to the high moisture sensitivity of the polymer membrane, cracking and wave formation must be counteracted.

Indirect coating by transfer roller:



- The catalyst ink is applied to a teflon-coated intermediate element (e.g. a roller) and (partially) dried.
- The transfer takes place along the lines of hot pressing on the underside of the intermediate element where the polymer membrane is guided along.
- The intermediate element must be cleaned before it is coated again.

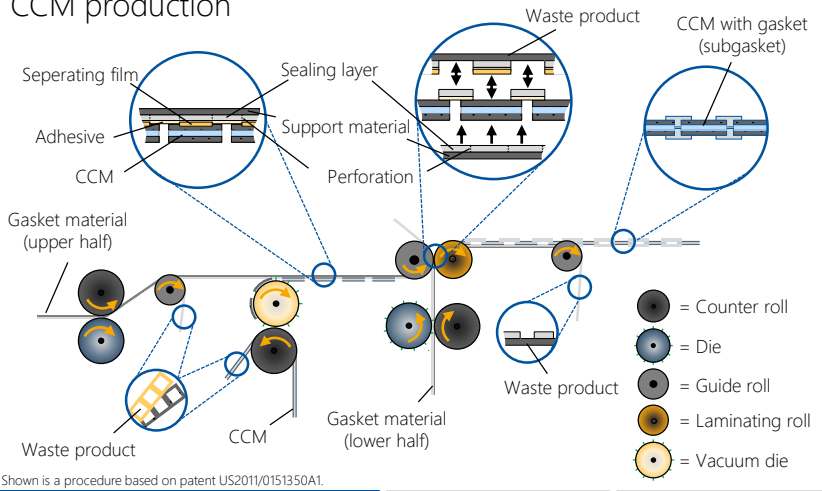
GDE approach:



- The catalyst ink is applied directly to the GDL, forming a so-called gas diffusion electrode (GDE).
- The GDE is then applied to the top and bottom of a polymer membrane and laminated to form the MEA.
- Depicted is the coating by squeegee, where the thickness of the catalyst ink can be precisely adjusted.

Subgasket Application

CCM production



Shown is a procedure based on patent US2011/0151350A1.

Component production | Stack production | System production

- The upper half of the subgasket, consisting of carrier material, adhesive, PET sealing layer and release film, is first perforated by means of a die. Afterwards, excess release film is removed.
- From the supplied CCM, material is separated in a specified shape by means of a vacuum die and stapled to the upper half of the gasket.
- The lower half of the gasket, consisting only of carrier material and PET sealing layer, is also first perforated and pressed onto the underside of the CCM material by laminating roller.
- At the same time, the perforated part of the upper carrier material, including the release film, is removed and disposed.
- Finally, the perforated part of the lower carrier material is removed.

Process parameters & requirements

- Belt speed: 30 m/min
- Die geometry: Product-dependent
- Contact pressure during joining process: Material-dependent

Alternative technologies

- Injection molding of a framegasket
- Application of the subgasket by robot

Quality influences

- Axial, radial and angular misalignment of the rolls relative to each other
- Position tolerance between seal and CCM

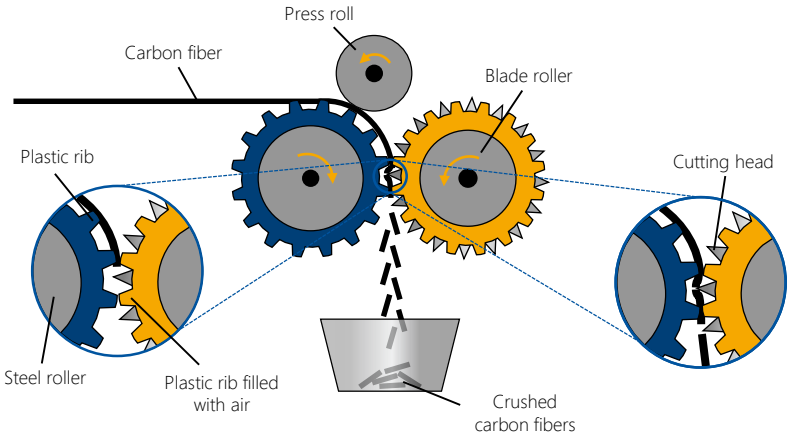
Quality characteristics

- Accurate positioning of the gasket
- No contamination on the MEA surface
- Strength of the joint

Production costs [excerpt] Invest for machinery and plant: € 0.8 - 1.0 m

Carbon Fiber Chopping

GDL production



Component production | Stack production | System production

- Dry carbon fibers are shredded to produce the GDL.
- The fiber ribbon is guided over a steel roller with plastic ribs (blue) and held in position by a press roller.
- The cutting heads of the rotating blade roll apply pressure to the fiber ribbon in the transverse direction, causing the fiber filaments to break until the fiber is completely severed. In the process, air-filled plastic ribs (orange) eject the cut fibers silently.
- The rotary cutting tool is capable of operating at high speed. The cutting head wear typical of the process is minimized by cutting "into the void".
- The six to twelve millimeter fibers are collected in a collection bin and used for subsequent carbon paper production.

Process parameters & requirements

- Cutting rate: 9 m/min
- Particle size: 6 - 12 mm
- Contact pressure of the press roll: 0.1 MPa

Alternative technologies

- Guillotine cutting

Quality influences

- Sharpness of the cutting heads
- Shape of the cutting heads
- Material of the cutting heads

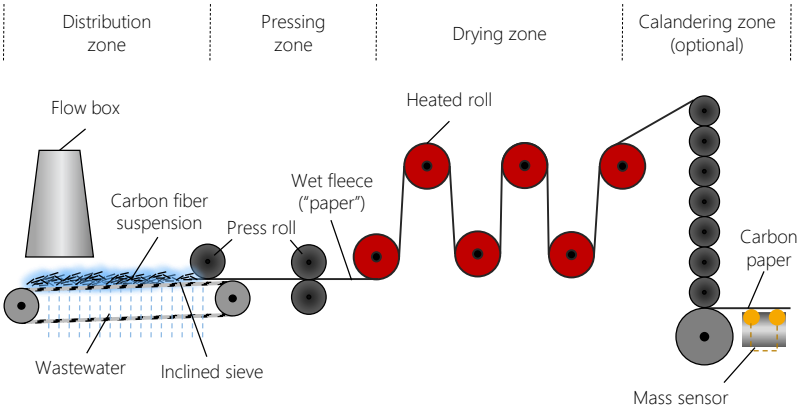
Quality characteristics

- Particle shape
- Surface morphology

Production costs [excerpt] Invest for machinery and plant: € 0.05 - 0.1 m

Forming Carbon Paper

GDL production



Component production | Stack production | System production

- Chopped carbon fibers are processed together with a binder polymer inside a "flowbox" to form a suspension and uniformly applied to an inclined wire.
- The inclined wire is covered with plastic fabric and allows water to drain off, but retains the carbon fibers.
- During subsequent pressing, further removal of water increases the solids content of the paper suspension. Wet laid nonwoven ("paper") is produced.
- While retaining the sheet structure, the volume of the paper is reduced in the drying unit and the binder is hardened.
- Optionally, the surface structure is fixed by calendering. Cooled rolls compress the carbon paper and remove last fibers and sponge structures.

Process parameters & requirements

- Productivity: 300 - 320 m²/h
- Basis weight: 15 - 70 g/m²
- Material thickness: 150 - 300 µm
- Binder content: <25%

Alternative technologies

- Spunlace fleece production
- Fabric manufacturing

Quality influences

- Water content of the suspension
- Height or force measurement during calendering
- Quality of the fiber dispersion
- Homogeneous binder distribution
- Web tension

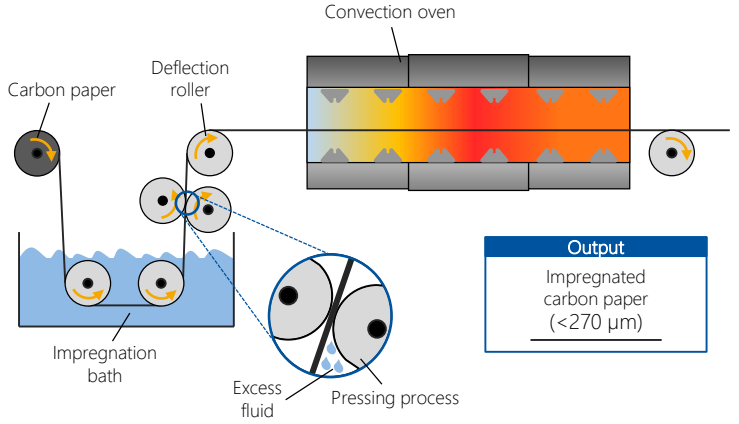
Quality characteristics

- Uniform thickness of the material
- Smoothness of the material
- Wet strength of the paper
- Damage-free surface

Production costs [excerpt] Invest for machinery and plant: € 0.5 - 1.0 m

Impregnating

GDL production



Component production | Stack production | System production

- The carbon paper is impregnated with a thermosetting resin (e.g. phenolic resin) so that a desired material strength as well as porosity are achieved. In addition, the electrical and thermal conductivity are increased after passing through the graphitization process.
- After passing through the impregnation bath, excess liquid is removed by a pressing process.
- Remaining solvents are evaporated inside a convection oven at about 150°C, and the resin is cured.
- As an alternative to the continuous process, after drying, the carbon paper is stacked individually alternating with separator paper at elevated temperature and then pressed.

Process parameters & requirements

- Drying temperature: 150°C
- Material thickness: 200 - 270 µm

Alternative technologies

- Infrared drying
- Stacking with separator paper

Quality influences

- Composition of the impregnation material
- Drying temperature
- Drying period

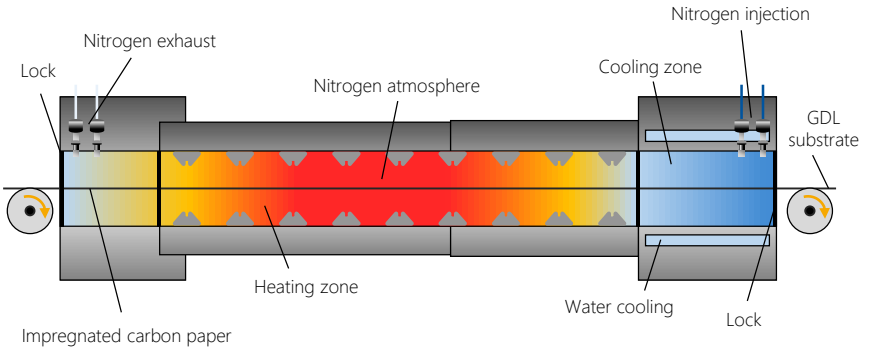
Quality characteristics

- Material thickness
- Material density

Production costs [excerpt] Invest for machinery and plant: € 0.35 - 0.7 m

Graphitizing

GDL production



Component production | Stack production | System production

- Graphitization (also high-temperature carbonization) of the thermosetting resin results in a higher modulus of elasticity, increased electrical and thermal conductivity, and oxidative resistance.
- The carbon paper is heated in a furnace under an inert gas atmosphere (nitrogen, argon) or in a vacuum to temperatures of about 1,400°C to 2,000°C (in batch processes: more than 2,000°C).
- The strip material passes through different temperature zones within the heating zone and is finally cooled to room temperature in a cooling zone.
- The end product has a material thickness of 150 to 300 µm.

Process parameters & requirements

- Process temperature: 1,400°C - 2,500°C
- Material thickness: 150 - 300 µm
- Density of paper: 0.2 - 0.3 g/cm³
- Process time <5 min. (< 15 min. for batch process)
- Vacuum or inert gas atmosphere

Alternative technologies

- Graphitization under inert gas atmosphere
- Batch carbonization under vacuum or inert gas

Quality influences

- Temperature profile
- Smoldering gas duct (removal of pyrolysis products)
- Inerting of the furnace

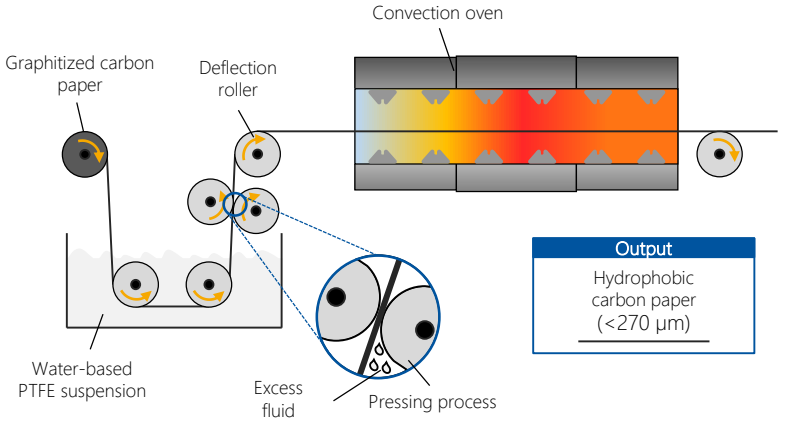
Quality characteristics

- Degree of pyrolysis of the resin >99.5%
- Deposit free product
- Conductivity of the material
- Carbon content

Production costs [excerpt] Invest for machinery and plant: € 0.35 - 0.7 m

Hydrophobing

GDL production



Component production | Stack production | System production

- The GDL substrate is immersed in an aqueous polytetrafluoroethylene (PTFE) suspension, with excess suspension removed by a pressing process. This process helps improving the hydrophobic properties.
- The PTFE content of the subsequent GDL is adjusted by the amount of PTFE in the suspension.
- Remaining solvents are removed by oven drying, and the PTFE particles are bonded to the base material by sintering at about 300°C to 350°C.
- The speed of the drying process influences the PTFE distribution in the material. Fast drying causes the PTFE to remain in surface zones, while slow drying ensures holistic distribution.

Process parameters & requirements

- Drying temperature: 300°C - 350°C
- PTFE mass fraction: 5 - 10 wt.%
- Paper thickness: 200 - 270 µm
- Material alternative: Fluoroethylene propylene (FEP)

Alternative technologies

- Infrared drying
- Air drying
- Spraying
- Brush application

Quality influences

- Composition of the impregnation material
- Drying temperature
- Drying period

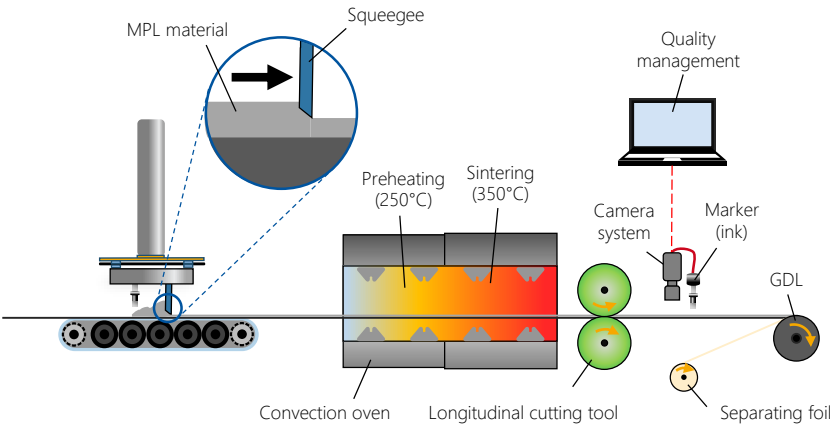
Quality characteristics

- Homogeneous PTFE distribution

Production costs [excerpt] Invest for machinery and plant: € 0.35 - 0.7 m

MPL Application & Sintering

GDL production



Component production | Stack production | System production

- The microporous layer (MPL), consisting of carbon or graphite particles and polymeric binder (e.g. PTFE), has a pore size between 100 and 500 nm, while the carbon paper has a pore size of ten to 30 µm.
- The primary function of the MPL is water management, as it effectively removes liquid water from the catalyst layers.
- Here, the MPL is applied to the carbon paper via a squeegee process with a layer thickness of less than 50 µm.
- To reduce cracking, the solvent is slowly evaporated. Sintering enables sufficient adhesion of the MPL.
- Finally, the material is trimmed, inspected for quality defects and marked. Winding is carried out with the aid of release film.

Process parameters & requirements

- Pore size: 100 - 500 nm
- Layer thickness: <50 µm
- Duration of the sintering process: <10 min.
- Sintering temperature: approx. 300°C - 350°C

Alternative technologies

- Slot nozzle
- Screen printing
- Spray application
- Roll up

Quality influences

- Sintering time
- Temperature curve during sintering
- MPL material

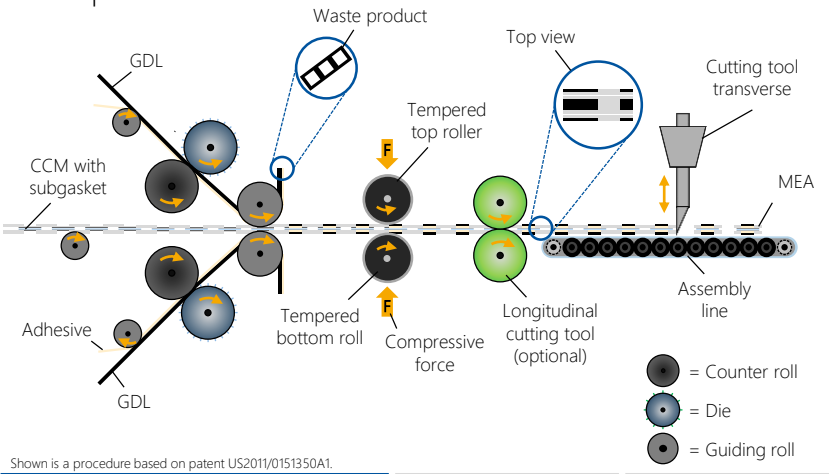
Quality characteristics

- Adhesion of MPL to carbon paper
- No exceeding of the melting point
- Damage-free MPL surface
- Smoothness

Production costs [excerpt] Invest for machinery and plant: € 0.9 - 1.8 m

Joining & Separating

MEA production



Shown is a procedure based on patent US2011/0151350A1.

Component production | Stack production | System production

- The CCM is connected to the GDL on both sides and then separated. An MEA with a seal is created.
- The GDL is provided with adhesive and perforated according to the specified geometry.
- The perforated GDL is stapled to the top and bottom of the MEA with a seal.
- Joining is then carried out by means of a hot pressing process.
- The process step is completed with the separation. In addition to transverse separation, longitudinal separation is also possible at this point, depending on the product and process design.
- Since the MEA is the "less precise" component compared to the bipolar plate, it requires special attention in tolerance management.

Process parameters & requirements

- Hot pressing temperature: 100°C - 160°C
- Contact pressure: 1,000 - 10,000 kg/cm²

Alternative technologies

- Discontinuous hot pressing process
- Additive layer production

Quality influences

- Axial, radial and angular misalignment of the rolls
- Combination of roll temperature, feed speed, and contact pressure
- Duration of active force application
- Thickness variations and irregular cut edges of the porous GDL

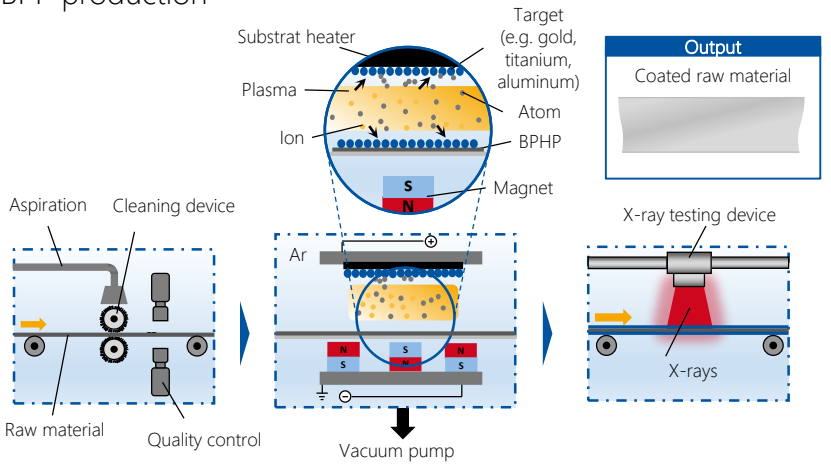
Quality characteristics

- Positional accuracy of the GDL
- Strength of the joint
- Dimensional accuracy of the cutting geometry

Production costs [excerpt] Invest for machinery and plant: € 1.2 - 1.8 m

Coating

BPP production



Component production | Stack production | System production

- The coating of the raw material for the bipolar half plates is carried out using the PVD process (physical vapor deposition, CVD).
- The surface of the raw material is first cleaned from both sides. Afterwards, its quality is checked.
- The raw material is positioned inside a vacuum chamber filled with inert gas (e.g. argon). The inert gas is ionized and forms a plasma.
- The target (coating material, e.g. gold, titanium, aluminum) is fired at with ions formed by the plasma. Atoms of the target are dissolved. They move to the substrate (here: the raw material) and diffuse into its surface.
- After the coated raw material exits the vacuum chamber, its wall thickness is measured using X-rays.

Process parameters & requirements

- Temperature: 450°C - 500°C
- Vacuum pressure: $1*10^{-1}$ – $1*10^{-7}$ mbar
- Layer thickness: 0,1 - 6,3 µm
- Cycle time: approx. 2 - 5 min.

Alternative technologies

- Alternative coating materials: titanium nitride, chromium nitride, amorphous carbon
- Chemical vapour deposition (CVD)
- Nitriding
- Electroplating

Quality influences

- Inert gas
- Coating material
- Substrate shape

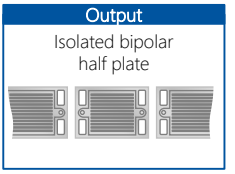
Quality characteristics

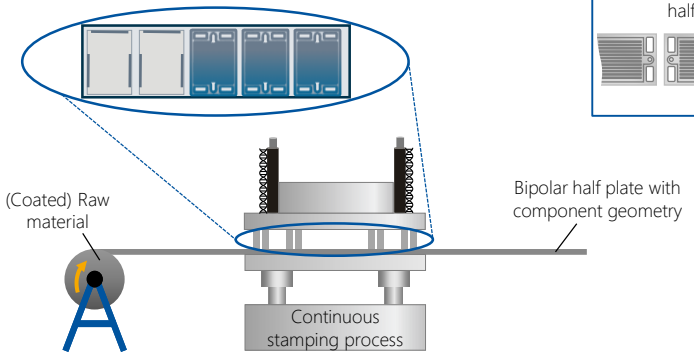
- Electrical conductivity
- Corrosion resistance

Production costs [excerpt] Invest for machinery and plant: € 1.8 - 2.0 m

Stamping

BPP production





Component production | Stack production | System production

- The (coated) raw material for the bipolar half plates (e.g. 1.4301, 1.4404) is unwound from a coil and fed into the stamping line.
- The high-precision transfer positions the material below the forming tool and applies the pressing force.
- The application of the pressing force results in plastic deformation of the material and cutting of free contours.
- Different deformations and free contours of the bipolar half plates are possible; these are realized by different tool stages.
- Advantages of forming stamping are a high repeatability and a high cycle time.

Process parameters & requirements

- Cycle time: 30 - 50 BPP/min
- Pressing force: 460 - 11,000 kN (46 - 1,100 t)
- Stroke path: 200 - 600 mm
- Minimum number of pressure points: 4
- Possible material thickness: 0.05 - 1 mm
- Material thickness tolerance: approx. 0.01 mm

Alternative technologies

- Deep drawing
- Injection molding
- Rubber cushion pressing
- Roll-to-roll molding
- Hydroforming

Quality influences

- Forming pressure
- Clamping force
- Forming properties of the base material
- Component geometry
- Machine stiffness

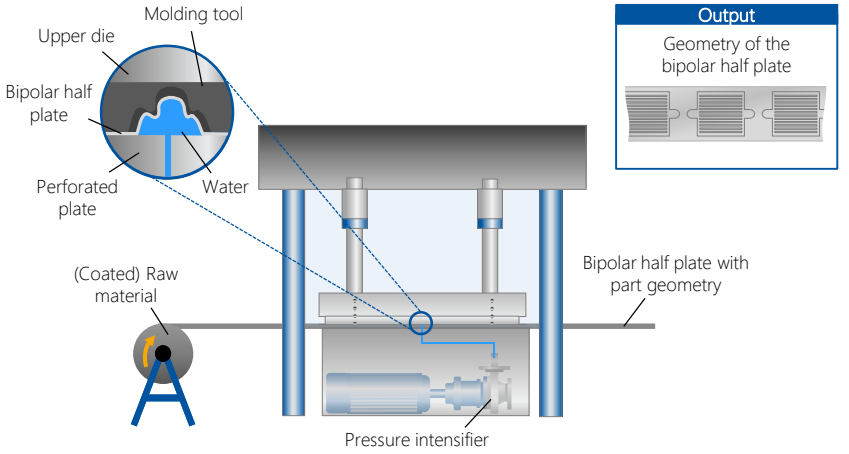
Quality characteristics

- High cycle time
- Freedom from breakage and damage
- Uniform flowfield structure
- High repeatability

Production costs [excerpt] Invest for machinery and plant: € 1.5 - 2.0 m

Hydroforming

BPP production



Component production | Stack production | System production

- The (coated) raw material for the bipolar half plate (e.g. 1.4301, 1.4404) is unwound from a coil, fed into the hydroforming system and positioned under the forming die.
- By lowering the upper die, a contact pressure (also clamping force) is applied to the material, forming die and lower die.
- Water is then brought under high pressure by means of a pressure intensifier and passed through the die plate. This leads – predetermined by the design of the forming die – to plastic deformation of the material and thus to the formation of the component geometry.
- To increase the output rate, several component geometries can be formed simultaneously.
- A final cleaning process removes residues from the formed material.

Process parameters & requirements

- Forming pressure: 1,000 - 4,000 bar
- Process time: approx. 5 - 10 sec. per plate
- Working medium: water
- Possible material thickness: 0.05 - 1 mm
- Material thickness tolerance: approx. 0.01 mm

Alternative technologies

- Punching
- Deep drawing
- Injection molding
- Embossing
- Rubber cushion pressing
- Roll-to-roll molding

Quality influences

- Forming pressure
- Clamping force
- Forming properties of the base material
- Component geometry
- Machine stiffness

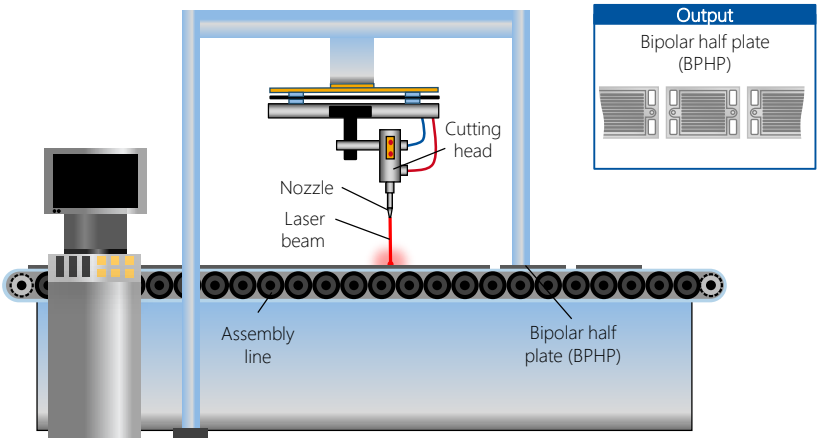
Quality characteristics

- Freedom from breakage and damage
- Uniform flowfield structure
- High repeatability
- Very low springback

Production costs [excerpt] Invest for machinery and plant: € 1.5 - 1.8 m

Separating

BPP production



Component production | Stack production | System production

- The production step of "separating" is only necessary in the case of hydroforming. For "stamping" it is obsolete.
- Bipolar half sheets are separated and brought into the desired geometry by means of laser trimming.
- Inside the cutting head, the laser beam is focused by a lens and projected onto the sheet. The high energy input leads to a separation of the material.
- The cutting optics are mounted on a so-called XY gantry, allowing precise movement of the cutting head within a predefined range.
- Coated as well as uncoated materials can be processed.

Process parameters & requirements

- Working range: 500 - 1,500 mm
- Laser output power: 500 - 2,000 W
- Feed rate: 20 to max. 300 m/min at 0.2 mm wall thickness
- Accuracy: 10 - 50 µm

Alternative technologies

- Punching
- Fine cutting, shear cutting
- Remote laser cutting

Quality influences

- Type of laser
- Cutting speed
- Focusing
- Process-related impurities

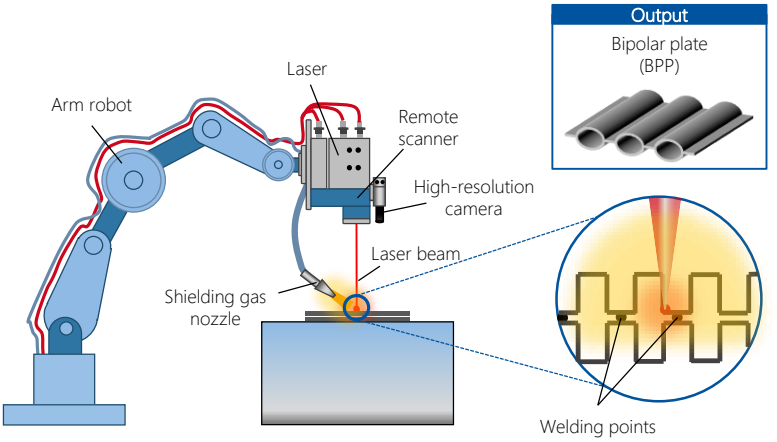
Quality characteristics

- Burr-free edges
- No impairment of the coating
- Distortion-free trimming

Production costs [excerpt] Invest for machinery and plant: € 0.5 - 0.6 m

Joining

BPP production



Component production | Stack production | System production

- In the joining process, two bipolar half plates are welded to form a bipolar plate.
- The focusing of the laser beam and the resulting high energy input into the metal surface heats the metal to melting temperature and creates a material bond.
- To avoid oxidation, the welding process is carried out in an inert gas atmosphere.
- For process monitoring and quality assurance, the welding process can be recorded and evaluated by means of sensors.

Process parameters & requirements

- Cycle time: 10 - 120 sec.
- Feed rate: <60 m/min
- Laser power: approx. 500 - 1,000 W
- Material thickness: approx. 100 - 250 µm

Alternative technologies

- Adhesive technology
- Brazing
- Additive manufacturing

Quality influences

- Positioning and bracing of the bipolar half plates
- Size of the heat-affected zone
- Process temperature in the weld spot
- Wavelength of the laser beam
- Type of shielding gas

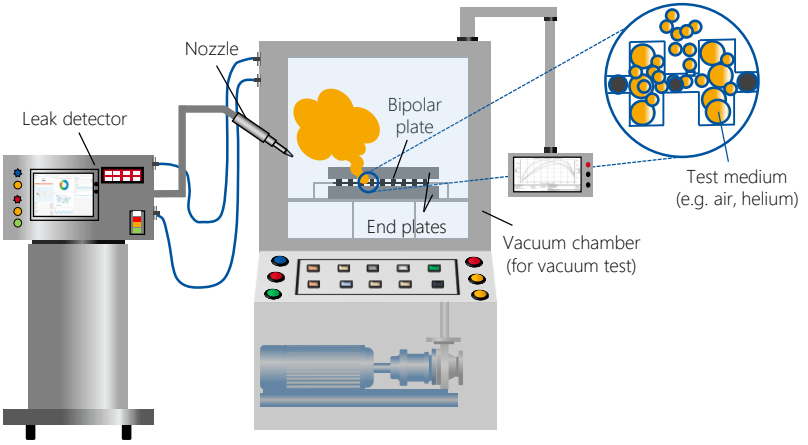
Quality characteristics

- Component distortion
- Strength of the weld spots
- Media tight welding
- No flash

Production costs [excerpt] Invest for machinery and plant: € 0.8 - 0.9 m

Leakage Testing

BPP production



Component production | Stack production | System production

- Eventually, the bipolar plates are checked for leakages.
- In the vacuum test, they are placed inside a vacuum chamber, filled with a test medium (e.g. helium) and its partial pressure is measured in a vacuum chamber.
- If the test medium's partial pressure in the chamber is elevated, leakage from the bipolar plates can be identified using a mass spectrometer leak detector (MSLD). This method can be used for more stringent test specifications.
- In the pressure decay test, air is introduced into the device under testing (DUT) as the test medium. Leaks are detected by a drop in air pressure in the system.
- The general conditions for passing the leakage test are to be determined by the manufacturer. After passing the leakage test, the production of the bipolar plate is completed.

Process parameters & requirements

- Test pressure: approx. 1 - 1.5 bar
- Cycle time: approx. 40 sec.
- Test sensitivity: $3*10^{-2}$ mbar l/s (air) $2*10^{-6}$ mbar l/s (helium)
- Test gas: **air**, helium, nitrogen, hydrogen

Alternative technologies

- Flow measurement
- Ultrasonic detection
- Outside-in method

Quality influences

- Test pressure
- Accuracy leak detector
- Geometry of the fuel gas channels

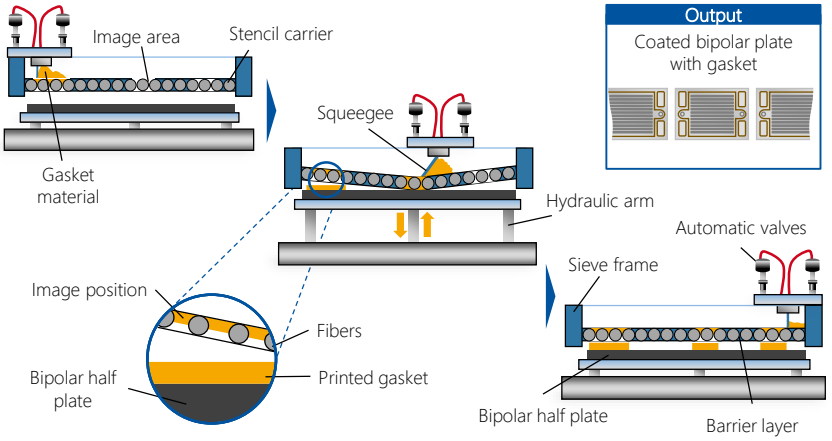
Quality characteristics

- No deformation or destruction of the bipolar plate
- Leak tightness of the bipolar plate

Production costs [excerpt] Invest for machinery and plant: € 0,2 - 0,4 m

Gasket Application

BPP production



Component production | Stack production | System production

- The BPP seals are applied to the bipolar plate by means of screen printing.
- The sealant is applied to the stencil carrier by a nozzle and pressed through the image areas by the movement of the squeegee.
- While the barrier layers cannot transfer any sealing material to the bipolar plate, the image zones of the stencil carrier are permeable. These zones can be individually adjusted.
- The bipolar plate is brought into close proximity of the stencil carrier by means of a hydraulic arm, so that perfect application of the seal is possible.
- The excess printing substance is transported by the squeegee to the edge of the printing form and used for the next printing process.

Process parameters & requirements

- Cycle time: <3 sec.
- Wall thickness seal: 0.3 – 0.5 mm
- Belt speed: 50 mm/s

Alternative technologies

- Dispensing
- Formed in-place foam gasket (FIPFG)
- Insert molding
- Punching

Quality influences

- Process speed
- Distance between the fibers of the stencil carrier
- Dosing quantity

Quality characteristics

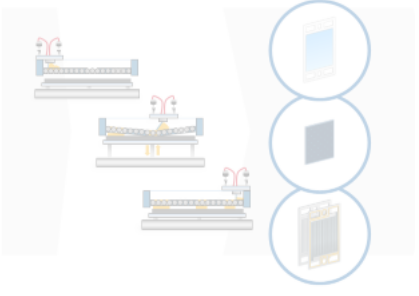
- Positional accuracy of the seal
- Uniform sealing ring

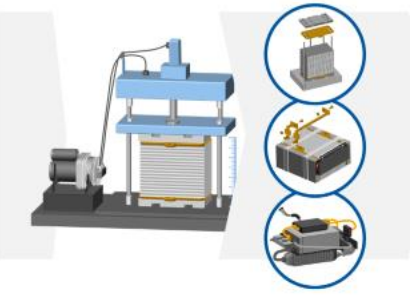
Production costs [excerpt] Invest for machinery and plant: € 1.2 - 1.5 m

Further Information

on fuel cell stacks and systems

The production chain of the fuel cell components explained in the context of this guide is continued by the production of the stack and the system. For more information on this, please refer to the guide listed below. It further details the production steps for the assembly of the stack as well as the system and the associated total costs.





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