Fuel Cells
Production methods for MEAs
Thomas Kolbusch, Vice President
## Summary

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<th>Coating systems</th>
<th>Drying &amp; curing</th>
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</table>
Coating, Printing & Laminating

Connect
Like
Follow
Vision

From Lab2Fab

Lab → Pilot → Production

Process development → Pilot production → Production line

Custom made

Coatema equipment platform strategy for Lab2Fab
R&D Services

R&D centre

Coating
Printing
Laminating
Imprinting
Pretreatment
Drying
Curing
Crosslinking
Cutting

10-12 units on 1.200 sqm

Sheet to Sheet
up to 300 x 500 mm
Roll to Roll
up to 700 mm width

Operation Speed
0.1 to 200 m/min
## R&D Services

### Process Development
- Feasibility study
- Ink – process study
- Process analysis
- Proof of concept
- Small scale prototype

### Test Production
- Prototyping
- Near to market testing
- TRL evaluation
- Training of staff

### Education
- Coatema Conference
- Training of customers
- Education of students

### After sales service and ramp up of processes
- of Coatema units

### Development of custom made design for equipment
- Prototyping
- Proof of concept

### Funded Research Projects
- German funded
- Horizon 2020
- Global 2+2 projects
Equipment
Products

Lab units
Products

Pilot lines

Pilot
Products

Production lines

Production
Products

Production systems

Production
Products

Bespoke equipment

Custom made
Scaling up new technologies

Tools for Lab2Fab
Our markets
Markets

Smart Textiles
Printed electronics
Prepreg
Batteries
Solar Cells
Membranes
Medical/Pharmaceutical
Fuel Cells
Smart Textiles
Markets

Fuel Cells
R&D Projects
R&D Associations

- oe-a
- COPT.NRW
- IVAM
- NMWP.NRW
- FlexTech Alliance
- PrintoCent
- SEMI
- HOPE-A
R&D customers
R&D Projects

Currently 14 Projects in operation

Coatema follows “Open Pilot Line Philosophy”
Proof of concept
Industrial References
Introduction Coatema

Our latest awards
Upscaling from Lab2Fab

Overview on the basics
Overview on the basics
MEA-components

Diffusion layer
Anode

- Methanol
- Carbon cloth, Carbon paper (Substrate)
- Carbon dioxide

Diffusion layer
Cathode

- Air
- Carbon cloth, Carbon paper (Substrate)
- Water

Anode
- Micro layer: PTFE + Carbon
- Catalyst layer: Pt + Naf.
- Nafion-membrane

Cathode
- Micro layer: PTFE + Carbon
- Catalyst layer: Pt-Ru + Naf.
- Nafion-membrane
MEA production technology

Structure of an MEA

- Catalyst ink
- Coating on GDL or Membrane (Spraying, screen printing, ink jet, knife ⋯⋯)
- Hot pressing
- MEA

Catalyst, ionomer colloid, solvent mixture, additives mixing

- Polymer electrolyte (Nafion)
- Carbon particles (20-40 nm)
- Pt particles (2-3 nm)
- Backing layer

Quelle: Institute of Energy Research - Fuel Cells (IEF-3), Juelich Research Center part of Helmholtz-Community
Overview on the basics

Manufacturing methods

MEA: Membrane-Electrode-Assembly
GDL: Gas Diffusion Layer
GDE: Gas Diffusion Electrode
PEM: Polymer Electrolyte
Membrane
CCM: Catalyst Coated Membrane
MEA production technology

Status MEA 1999-2010

CCM Method
- Application of catalyst layer to membrane by direct coating or decal, transfer by hot pressing
- Laminating GDL to CCM

GDE Method
- Application of catalyst layer to Gas Diffusion Layer (GDL)
- Laminating GDE to Membrane

✓ Easy to transfer from laboratory scale to mass production scale
✓ Flexibility in MEA Flexibility in MEA configuration & dimension change

- Membrane dimension instability
- Reinforced membranes needed
- Less flexibility to GDE/MEA configuration or dimension change
- Difficult to scale up for mass production
- expensive laboratory instrument investment and expensive to scale up
- Difficulty in catalyst layer thickness (low catalyst loading)

Quelle: Institute of Energy Research - Fuel Cells (IEF-3), Juelich Research Center part of Helmholtz-Community
Overview on the basics

Manufacturing Methods

Parts of an MEA
a) b) c) d)
Equipment in 1999

Deskcoater

Quelle: Juelich Research Center part of Helmholtz-Community
Conclusion in 1999

Overview on the basics

Common points for Fuel cell development are:

Thinner coatings with defined edges for the CCM are needed – thin film coating methods, intermittend coatings etc.

Laminating of GDL/GDE with CCM/Membran - Research on parameters in the continuous laminating process has to be focused

New developments of reinforced membranes are needed to get higher production speed

Where are the mass markets for fuel cell application?
The vision in 1999

Overview on the basics

Impregnation- & Coating Plant: GDE
Realization in 2008

Overview on the basics
Coatema`s today products

Overview on the basics

Membrane

GDE method

CCM direct

CCM indirect

Gasket
Coatema`s today products

Overview on the basics

GDE method
CCM direct
CCM indirect
Membrane Manufacturing

Coatema's today products
Coatema`s today products

Overview on the basics

GDE method

Coating Area / working width (ww)

- EC Fuel Cell (A4/A3)
- Test Solution Fuel Cell ww 100 mm
- Basecoater Fuel Cell ww 300 mm / 500 mm
- Smartcoater Fuel Cell ww 300 mm
- Linecoater Fuel Cell ww 500 mm / 1,000 mm
- Production Line Fuel Cell ww 1,500 and on request

- GDL Sintering station available in different ww

- Mixer for microporous and catalyst layer available

- Hotpressing of GDE to membrane available in different ww
## Coatema`s today products

### Overview on the basics

**CCM method**

<table>
<thead>
<tr>
<th>Coating Area / working width (ww)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC Fuel Cell (A4/A3)</td>
</tr>
<tr>
<td>Smartcoater Fuel Cell ww 300 mm</td>
</tr>
<tr>
<td>Linecoater Fuel Cell ww 500 mm / 1.000 mm</td>
</tr>
<tr>
<td>Double side coating CCM unit available in different ww</td>
</tr>
<tr>
<td>Mixer for catalyst layer available</td>
</tr>
<tr>
<td>Quality control system</td>
</tr>
</tbody>
</table>
Coatema`s today products

Overview on the basics

Indirect CCM Method

Coating Area / working width (ww)

- EC Fuel Cell (A4/A3)
- Test Solution Combi ww 100 mm
- Basecoater Combi ww 300 mm / 500 mm
- Smartcoater Combi ww 300 mm
- Linecoater Combi ww 500 mm / 1.000 mm
- Production Combi ww 1.500 and on request

- Hot pressing station available in different ww
Coatema`s today products

Overview on the basics

Membrane production

• Basecoater Combi      ww 300 mm / 500 mm
• Smartcoater Combi     ww 300 mm
• Linecoater Combi      ww 500 mm / 1.000 mm
• Production Combi      ww 1.500 and on request

Coating Area / working width (ww)
Coating Systems
Coating & Printing systems

Versatility

Knife  Double Side  Commabar  Case Knife  Slot Die  Hotmelt Slot Die

Engraved Roller  Powder Scattering  3 Roller Combi  Micro Roller  5 Roller  Reverse Roll

Double Knife  Curtain Coating  2 Roller Combi  Dipping  Rotary Screen

>30 application systems
## Processes

### Definition of Coating Systems

<table>
<thead>
<tr>
<th>Category of coating methods</th>
<th>Examples of coating methods belong to the category</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Self-metered                | - Dip roll  
- Nip forward roll  
- Reverse roll              | Wet thickness is determined the conditions of the coating meniscus |
| Doctored                    | - Mayer rod  
- Blade/knife  
- Air knife  
- Dip & scrape              | Post applicator device determines the wet thickness |
| Pre-metered                 | -Slot die  
- Slide curtain  
- Spray                  | All the ink fed into an applicator is transferred to the web |
Technologies & Processes

Process Parameters

Process Parameters are:

✓ Operation speed
✓ Rheology of coating and printing inks
✓ Substrate condition
✓ Tension control MD/CD
✓ Edge control
✓ Resolution and registration accuracy of printing/laminating systems
✓ Precision of coating operations
✓ Curing / drying / crosslinking
# Coating Systems

## Coating Parameters

<table>
<thead>
<tr>
<th>Coating Chemistry</th>
<th>Coating Processes</th>
<th>Process control</th>
<th>Drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Rheology</td>
<td>✓ Coating systems</td>
<td>✓ Process layout</td>
<td>✓ Convection drying</td>
</tr>
<tr>
<td>✓ Viscosity</td>
<td>✓ Single or Multilayer coatings</td>
<td>✓ Tension control system</td>
<td>✓ Contact drying</td>
</tr>
<tr>
<td>✓ Viscoelasticity</td>
<td>✓ Direct coatings</td>
<td>✓ Material guiding system</td>
<td>✓ Infrared drying</td>
</tr>
<tr>
<td>✓ Type of solvents</td>
<td>✓ Transfer (indirect) coatings</td>
<td>✓ Inline parameter control</td>
<td>✓ Sintering</td>
</tr>
<tr>
<td>✓ Amount of solids</td>
<td>✓ Substrate speed</td>
<td>✓ Quality control</td>
<td>✓ NIR</td>
</tr>
<tr>
<td>✓ Van der Waals force</td>
<td>✓ Layer Thickness</td>
<td></td>
<td>✓ High Frequency</td>
</tr>
<tr>
<td>✓ Sheer ratio</td>
<td>✓ Coating accuracy</td>
<td></td>
<td>✓ UV crosslinking systems</td>
</tr>
<tr>
<td>✓ Adhesion/Cohesion</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Pretreatment</th>
<th>Environment</th>
<th>Finishing</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Surface tension</td>
<td>✓ Corona</td>
<td>✓ Humidity</td>
<td>✓ Calendaring</td>
</tr>
<tr>
<td>✓ Dimension stability</td>
<td>✓ Plasma</td>
<td>✓ Temperature</td>
<td>✓ Embossing</td>
</tr>
<tr>
<td>✓ Surface structure</td>
<td>✓ Cleaning</td>
<td>✓ Inert Conditions</td>
<td>✓ Slitting</td>
</tr>
<tr>
<td>✓ Contact angle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Coating Systems

Dipping System

Variation of the Coating Weight
- Depending on the textile

Range of Viscosity (mPas)
- 1 – 10 000
Coating Systems

Knife Coating

**Variation of the Coating Weight**
- Roller knife 10 to 1.250 g/m²
- Air knife 5-6 to 60 g/m²

**Range of Viscosity (mPas)**
- Paste (1000) 100 – 50 000
- Foam 10 000 – 25 000
- Air knife 5 – 10 000
Coating Systems

Commabar Coating

**Variation of the Coating Weight**
- Air Knife 5-6 to 1.250 g/m²

**Range of Viscosity (mPas)**
- Paste 5-6 to 60 g/m²
- Foam 10 000 – 25 000
Variation of the Coating Weight

- 2 to 200 g/m²

Range of Viscosity (mPas)

- 1 – 15 000
Coating Systems

Micro Roller Coating

Variation of the Coating Weight

- 2 to 100 g/m²

Range of Viscosity (mPas)

- 1 – 15 000
Coating Systems

Rotary Screen Coating

**Variation of the Coating Weight**
- 10 to 300 g/m²

**Range of Viscosity (mPas)**
- Paste 10 000 – 80 000
- Paste 10 000 – 25 000
Coating Systems

Powder Scattering Coating

Variation of the Coating Weight

- 10 to 300 g/m²

Range of Viscosity (mPas)

- Application of powdery materials
Technologies & Processes
Slot Die System
Coating Systems

Slot Die Coating

Variation of the Coating Weight
✓ < 1 to 200 g/m²

Range of Viscosity (mPas)
✓ 1 – 30 000
Operating a slot die

- meniscus is formed between die lips and substrate
- adhesive stabilization of meniscus by die lips
- very low minimum flow rate possible
- range of rheological parameters limited for stability
Technologies & Processes

Intermittent slot die coating
Drying & curing
# Coating Parameters

## Coating Chemistry
- Rheology
- Viscosity
- Viscoleasticity
- Type of solvents
- Amount of solids
- Van der Waals force
- Sheer ratio
- Adhesion/Cohesion

## Coating Processes
- Coating systems
- Single or Multilayer coatings
- Direct coatings
- Transfer (indirect) coatings
- Substrate speed
- Layer Thickness
- Coating accuracy

## Process control
- Process layout
- Tension control system
- Material guiding system
- Inline parameter control
- Quality control

## Drying
- Convection drying
- Contact drying
- Infrared drying
- Sintering
- NIR
- High Frequency
- UV crosslinking systems

## Substrate
- Surface tension
- Dimension stability
- Surface structure
- Contact angle

## Pretreatment
- Corona
- Plasma
- Cleaning

## Environment
- Humidity
- Temperature
- Inert Conditions

## Finishing
- Calendaring
- Embossing
- Slitting
Technologies

Drying Technologies

Drying with hot air technology
Technologies

Drying Technologies
Drying Topics

General tasks of drying

1.) transfer the drying energy into solids and solvent to achieve the drying temperature
2.) evaporate the solvent
3.) remove the solvent vapor

Substrate
Coating
Heat transfer
Vapor removal

dryer technology
solid heat capacity
Drying Topics

Drying systems: hot air technology

Floatation dryer

single nozzle
Technologies

Drying Technologies

IR-Sinter unit
Drying Topics

Infrared dryers

Combined hot air / IR dryer
MEA production technology
GDE approach

Production steps for MEAs

1st production step: **hydrophobization**
- Impregnation of carbon substrate by dipping into a PTFE solution

Quelle: Institute of Energy Research - Fuel Cells (IEF-3), Juelich Research Center part of Helmholtz-Community
GDE approach

Production steps for MEAs

1st production step: **hydrophobization**

PTFE content adjustable by PTFE concentration of the solution
1st sub-step: impregnation + drying
2nd sub-step: sintering

Quelle: Institute of Energy Research - Fuel Cells (IEF-3), Juelich Research Center part of Helmholtz-Community
GDE approach

Production steps for MEAs

2nd production step: micro layer

Quelle: Institute of Energy Research - Fuel Cells (IEF-3), Juelich Research Center part of Helmholtz-Community
GDE approach

Production steps for MEAs

2nd production step: **micro layer**

1st sub-step: coating and drying
2nd sub-step: sintering

Quelle: Institute of Energy Research - Fuel Cells (IEF-3), Juelich Research Center part of Helmholtz-Community
GDE approach

Production steps for MEAs

2nd production step: **micro layer**

1st sub-step: coating and drying
2nd sub-step: sintering

Dispersed in Dissolver –
Adjustment of speed and dispersing time

- great agglomerates of 50 µm
- small aggregates with a few µm in diameter
Production steps for MEAs

3rd production step: **catalyst layer**

Quelle: Institute of Energy Research - Fuel Cells (IEF-3), Juelich Research Center part of Helmholtz-Community
GDE approach

Production steps for MEAs

3rd production step: catalyst layer

The structure of catalyst layer depends on:
- catalyst paste
- coating technique / coating speed
- drying conditions
GDE approach

Production steps for GDE

3rd production step: **catalyst layer**

The structure of catalyst layer depends on
- catalyst paste
- coating technique / coating speed
- drying conditions

The viscosity of catalyst depends on
- catalyst
- dispersing agent
- dispersing method
GDE approach

Production steps for GDE

4th production step: laminating / sealing

GDE Cathode

GDE Anode

PEM = Nafion or other membranes

MEA & GDE
GDE approach

Production steps for GDE

4th production step: laminating / hot pressing

Quelle: Juelich Research Center part of Helmholtz-Community
GDE approach

Deskcoater

Quelle: Juelich Research Center part of Helmholtz-Community
CCM approach
CCM approach

Production steps

1st step: coating / drying / cooling
CCM approach

Production steps

Single side step: coating / drying / cooling
CCM approach

Production steps

Double side step: coating / drying / cooling
Upscaling from Lab2Fab
Todays equipment

The Basecoater

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating width</td>
<td>500 mm</td>
</tr>
<tr>
<td>Roller width</td>
<td>500 mm</td>
</tr>
<tr>
<td>Machine speed, mechanical</td>
<td>1-10 m / min</td>
</tr>
<tr>
<td>Web tension</td>
<td>25 - 250 N</td>
</tr>
</tbody>
</table>
Todays equipment

The Basecoater
Todays equipment

The Basecoater
Todays equipment

The Basecoater 3rd Generation
Todays equipment

The Basecoater 3rd Generation

**Facts**

- Cantilever Rollers
- Delamination / Lamination
- Contact cleaning
- Corona station
- Slot Die System
- Rotary Screen System
- 2 Roller System
- Hot Air Dryer
- IR Dryer
- UV unit
- Edge sealing & glue application
- Cross-directional cutting system
Todays equipment

The Basecoater Hot pressing
Todays equipment

The Basecoater Hot pressing
Todays equipment

The Linecoater
Todays equipment

The Linecoater
Todays equipment

The Click&Coat
Click&Coat

Overview drawing
Click&Coat
Todays equipment

The Click&Coat
Click&Coat™ Steel layout
Click&Coat™ Steel layout
Click&Coat™ Steel layout
Click&Coat™ Steel layout
Click&Coat™ Steel layout
Click&Coat™ Steel layout
Production line for MEAs

Production line for Fuel cells

1000 mm working width
Today's equipment
The pathway to production

- Single side coating of catalyst layer
- Single side coating of gasket
- Coating of second side catalyst
- Coating of second side gasket
- Die cutting of the MEA and stapling
- Included are mixers, registration control and splicing table

- Missing – automated assembly of CCM with GDL
- and hotpressing in a discontinuous step
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