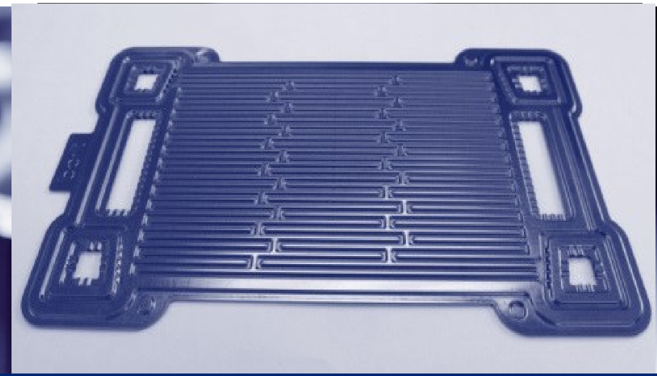
International Workshop, Sattledt, Austria, May 20th 2015

Innovation in Motion

Developments in PVD Coatings for PEMFC Bipolar Plates



'No powertrain without Miba Technology'

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Teer Coatings Ltd, Miba Coating Group, UK
www.teercoatings.co.uk, www.miba.com

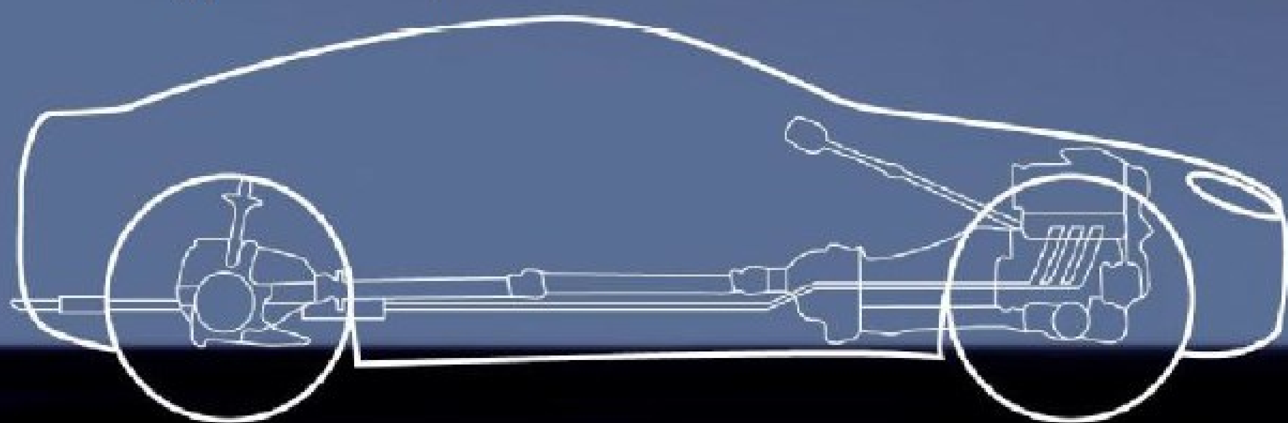
Contents

Miba Group

Snapshot

Innovation in Motion Miba

- Foundation: 1927
- Sales: >600 Mio. €
- Employees: >5000
- Global Presence, 20 production sites
- Family owned, listed on Vienna Stock Exchange
- Technology Leadership as the Core Value



What does Miba do?

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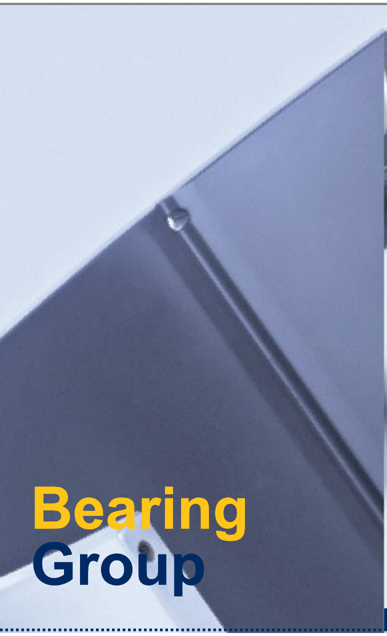
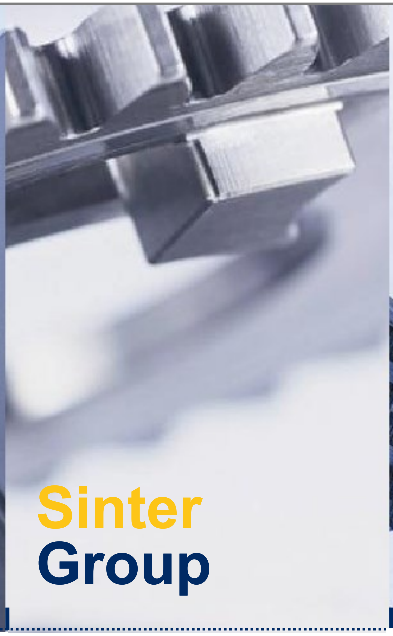
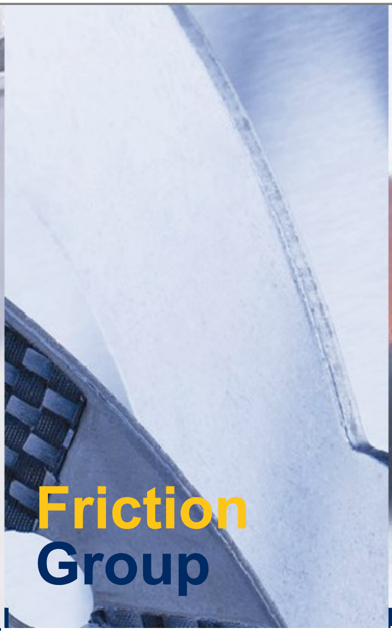


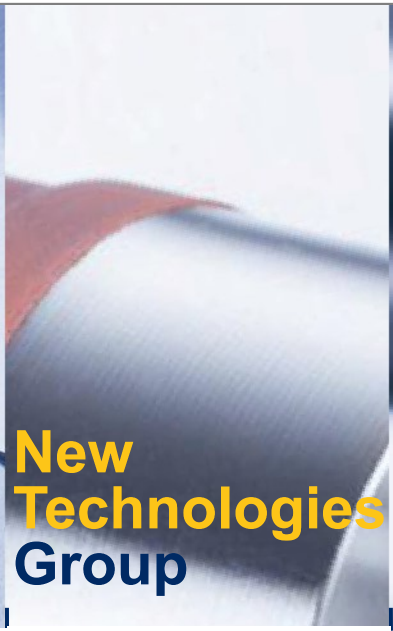
Miba bearings support crankshafts in diesel and gas engines of heavy commercial vehicles, locomotives, power plants and ships.



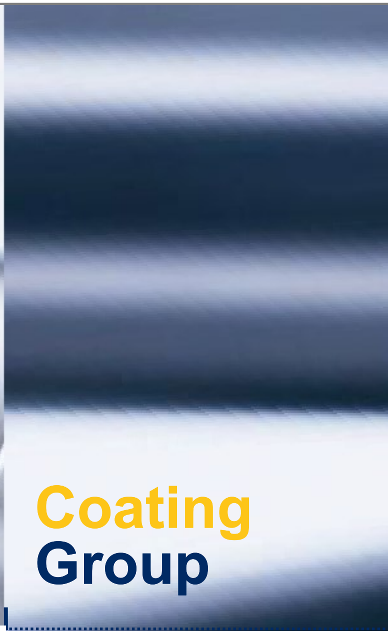
Miba sintered components are high-precision and high-strength parts. They are used in engines, transmissions, steerings, brakes and shock absorbers of passenger vehicles.



Miba friction materials determine the performance of clutches and brakes. Used in construction machines, tractors, trucks, cars, trains, motorcycles, aircrafts and wind turbines.



High-performance components for power electronics are a key to more efficient power trains as well as to the efficient and effective use of regenerative energy sources.



Miba coatings are used in components for engines, transmissions and other high-stress applications. They improve performance and energy efficiency and also save costs.

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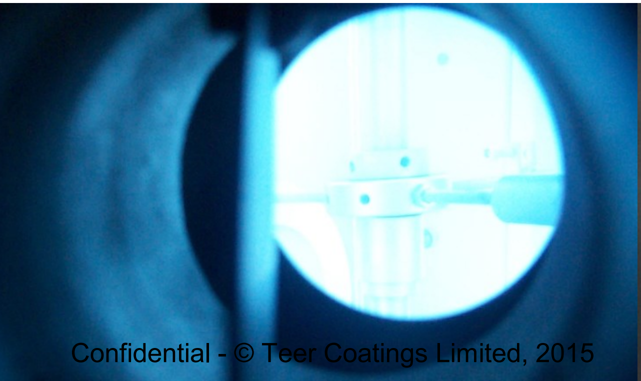
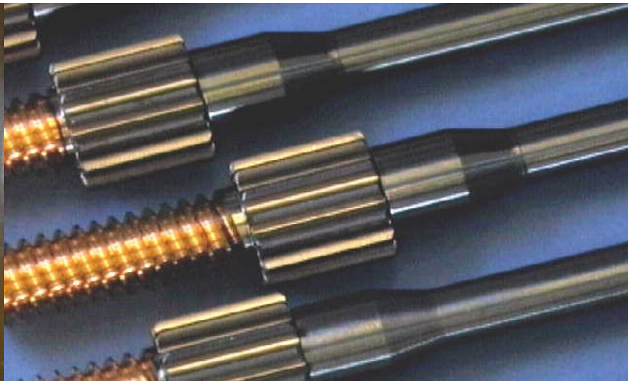
Teer Coatings – Miba Coating Group

- ~55 Staff, founded in 1985, acquired by Miba in 2010. Pioneered a patented magnetron sputtering technique.
- Track record of innovation. Projects relevant to the hydrogen economy include
  - FCH JU projects **STAMPEM** (PEMFC BPPs), **NOVEL** (electrolysers) and **SCoReD2.0** (SOFC interconnects) UK TP project, **HydroGEN** (alkaline electrolysers).
- Supplying coatings to fuel cell manufacturers for trials and/or production since 2003 including;
  - major automotive OEMs, Tier 1 & 2 suppliers & many other smaller companies





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PEMFC Bipolar Plate Coating Activities

2004 › 2006 › 2007 › 2009 › 2010 › 2011 › 2012 › 2013 › 2014 › 2015

Customer Activities

- OEM development work
- Miba acquire TCL
- Trials with OEM's, plate manuf.

Collaboration Activities

- Sponsored Student UoB
- 3 x UK TSB FC manufacturing and supply chain projects
- EU FCH JU STAMPEM

R&D Development

- Coating Development
- Scale-up preparation

Patents and Publications

- Base carbon coating filed
- Carbon and PMG coating filed
- Paper published, conferences

PEM Fuel Cell/Electrolyser Partners

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STAMPEM Consortium Partners (PEMFC)

SINTEF
Fraunhofer ISE
UNIVERSITY OF BIRMINGHAM
elringklinger
Fronius

NOVEL Consortium Partners (PEMWE)

SINTEF
Fraunhofer ISE
AREVA
cea
Johnson Matthey
Beneq
PAUL SCHERRER INSTITUT PSI

Previous PEMFC Project Partners

TATA
Intelligent Energy
borit®
ITM POWER Energy Storage | Clean Fuel

Bipolar Plates

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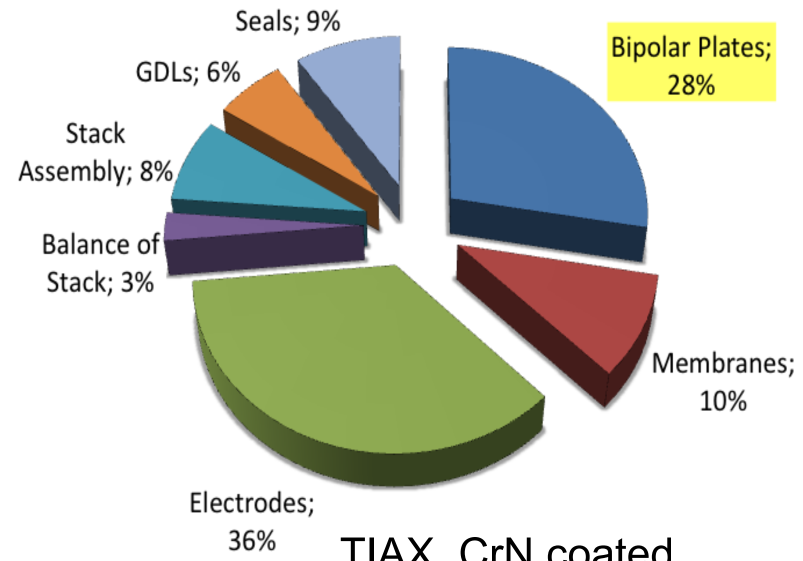
- Function
  - Separating gases between cells
  - Providing a conductive medium between the anode and cathode
  - Providing a flow field channel for even distribution of reaction gases (and potentially coolant)
  - Providing a solid structure for the stack
  - Facilitating water and heat management
- Materials
- US DoE targets



TIAX, CrN coated 0.1mm foil, \$6.2 kW^{-1}

Properties	Units	2015
Cost (@500,000 stacks per year)	$\$kW^{-1}$	3
Electrical Conductivity	mohm cm^2	<20
Corrosion	μAcm^{-2}	<1
Formability	%	40

PVD Coating Process?

How does the process work?

1. Pre-cleaning process

⬇

2. Pumping down

⬇

3. Plasma/Ion Cleaning process

⬇

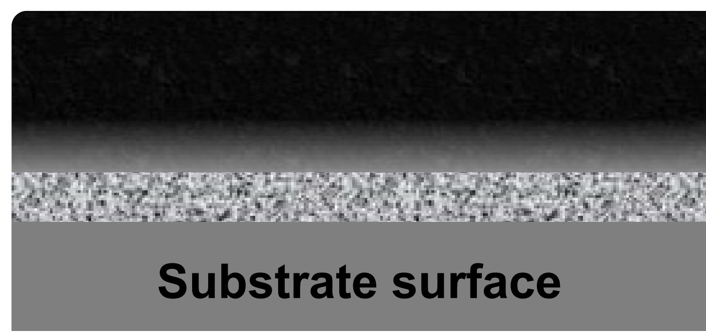
4. Coating Deposition

Coating options include
- Adhesion & graded layers
- Single or multilayer
- Materials – metal oxides, nitrides, carbon, PGMs etc
- Thickness range – nm to µm

⬇

5. Cooling down and venting

Batch Coating system



Is PVD suitable for fuel cells?

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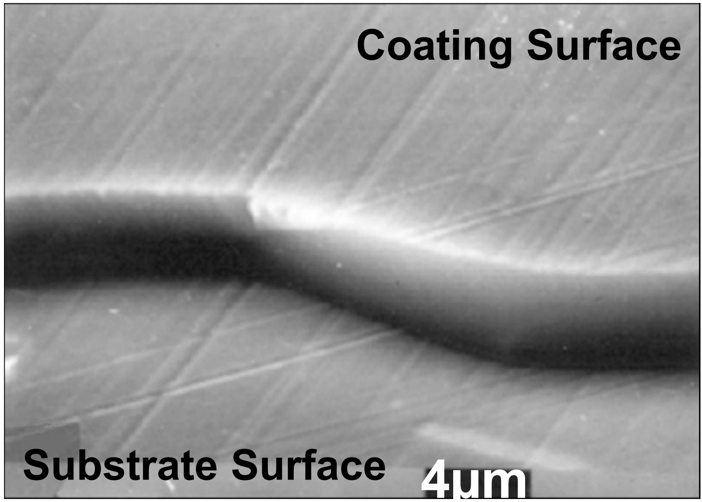
- Advantages of MS-PVD
  - ✓ **Ion cleaning prior to deposition reduces the resistive surface oxide layer** (no need for pickling)
  - ✓ **Better coating adhesion** (compared to carbon/polymer coatings)
  - ✓ **Lower temperature process** (compared to EB-PVD or nitriding)
  - ✓ **Wide range of coatings options including multilayers**
  - ✓ **Fewer defects** (compared to Arc-PVD)
  - ✓ **Environmental benefits** (compared to electroplating)
  - ✓ **Thinner coatings reduce material costs**



- Concerns?
  - ! High capital expenditure
  - ! Vacuum process
  - ! Deposition rate?

Typical Coating Groups (Patents)

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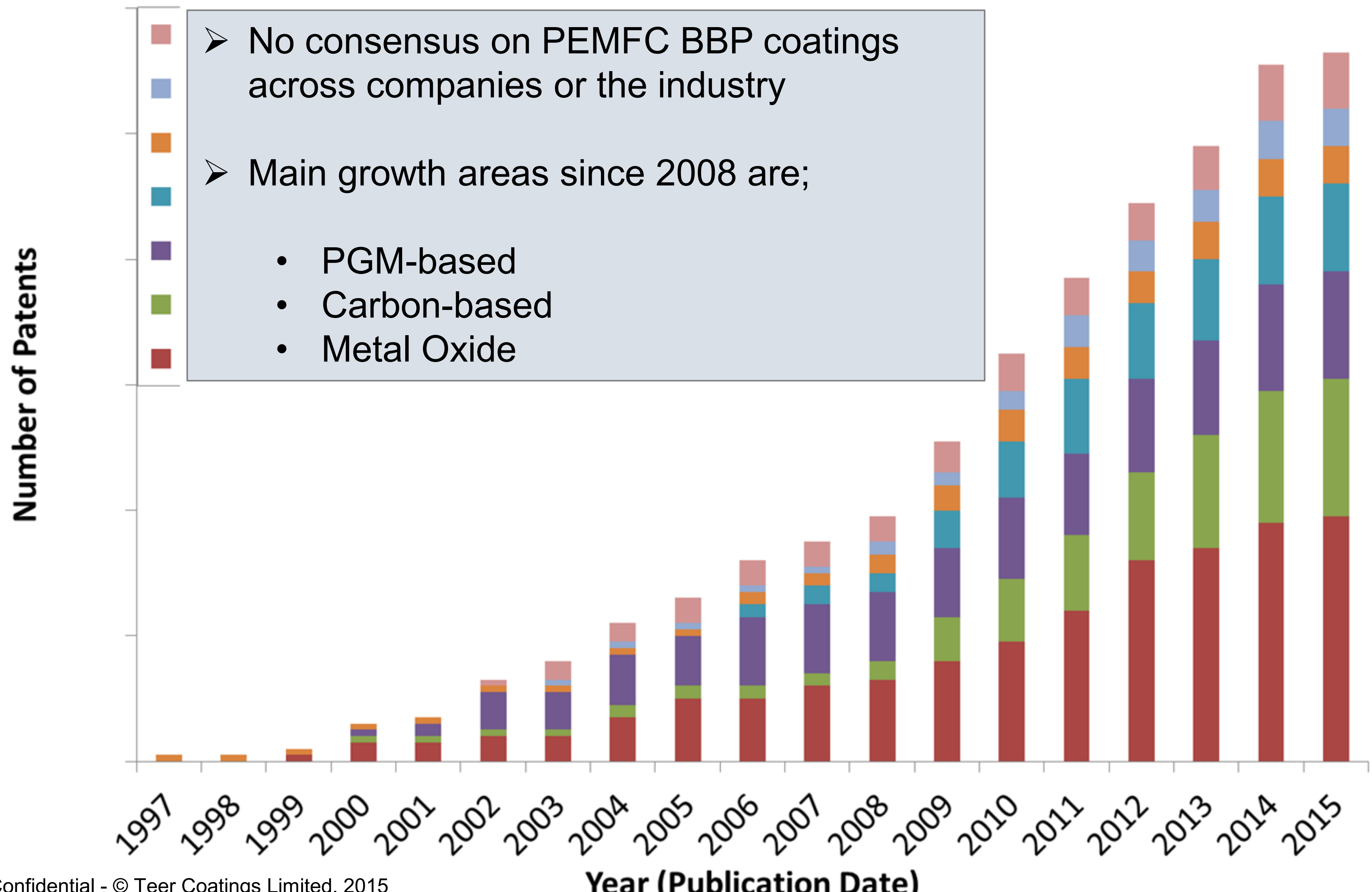

- No consensus on PEMFC BBP coatings across companies or the industry
- Main growth areas since 2008 are;
  - PGM-based
  - Carbon-based
  - Metal Oxide

Coating Characterisation

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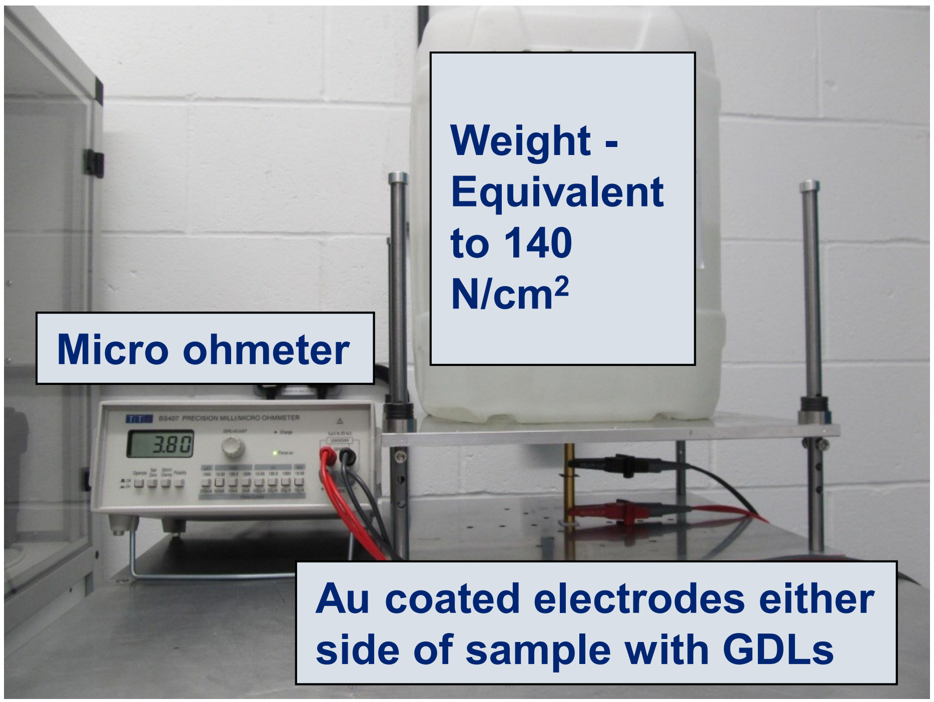
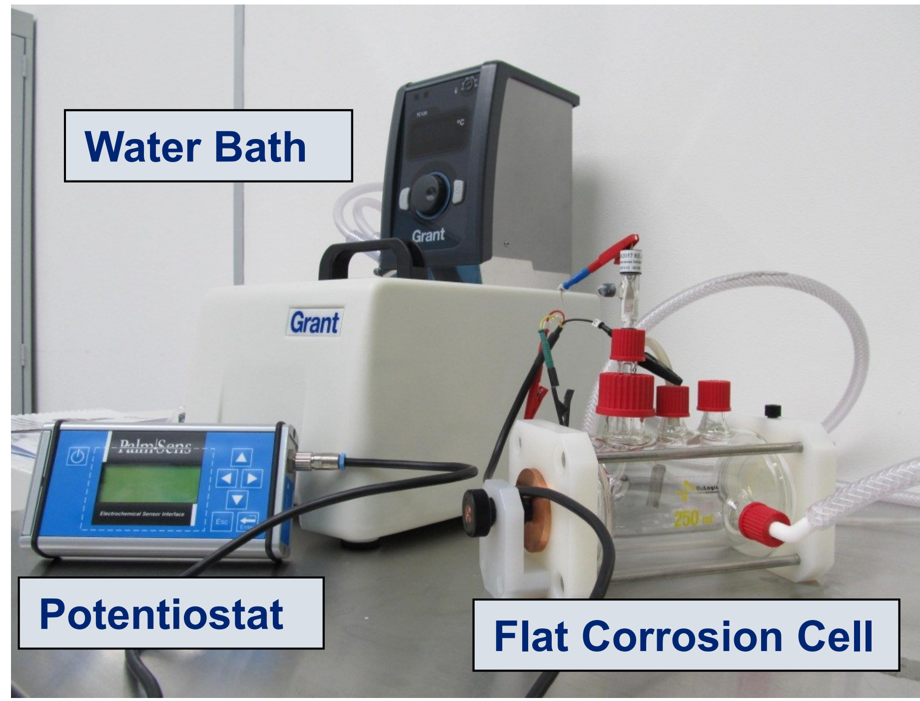
Interfacial Contact Resistance



Target - ICR of <20 mohm cm^2 at 140 N cm^2, Freudenberg H2315 I2C6 with microporous layer

Corrosion Resistance



Target - Corrosion <1 µA/cm^2
Potentiostatic tests at 1.4V in 1 mM H_2SO_4 (pH3) at 80 C

Corrosion Resistance

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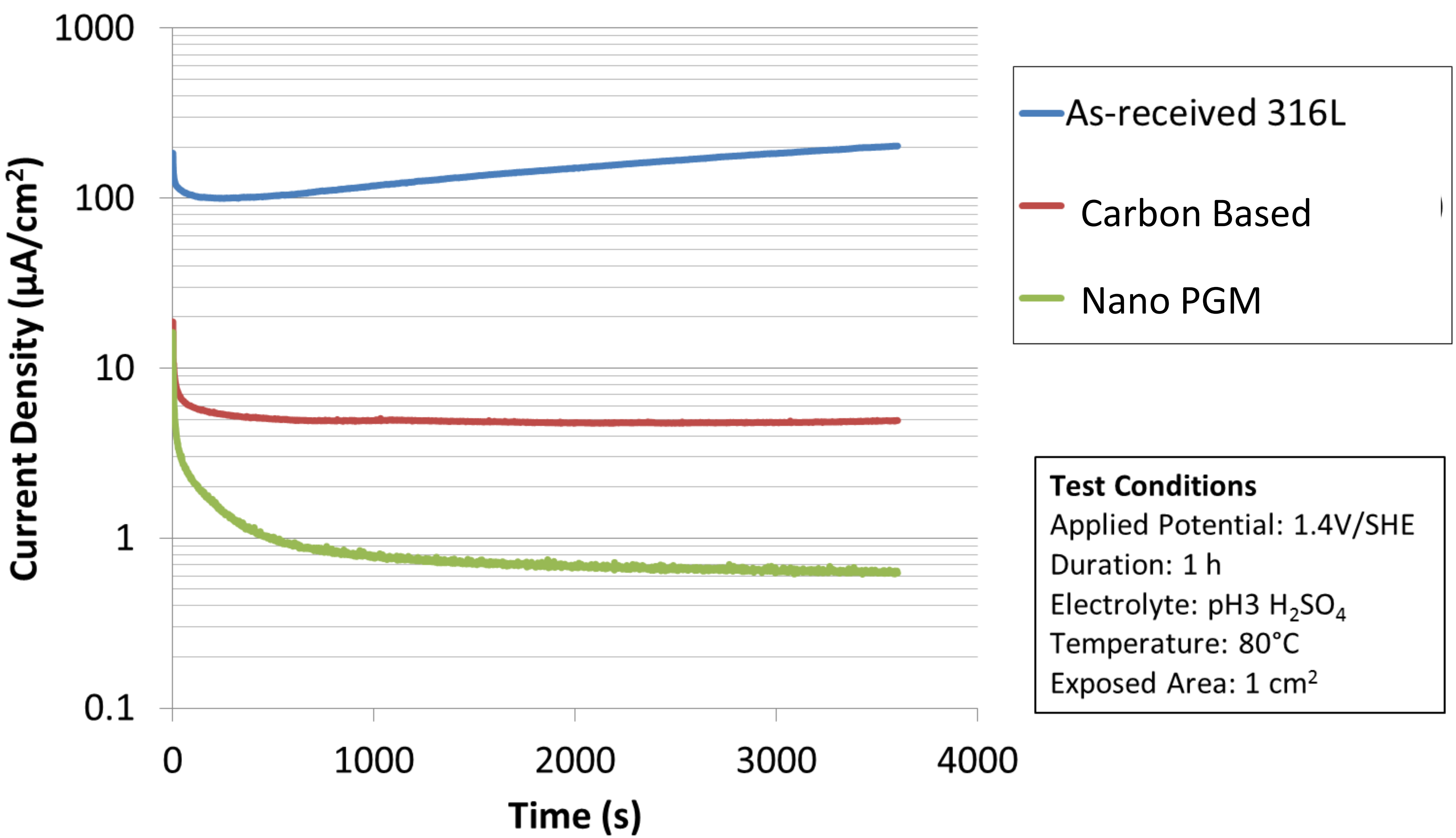

Test Conditions
Applied Potential: 1.4V/SHE
Duration: 1 h
Electrolyte: pH3 H_2SO_4
Temperature: 80°C
Exposed Area: 1 cm^2

Interfacial Contact Resistance

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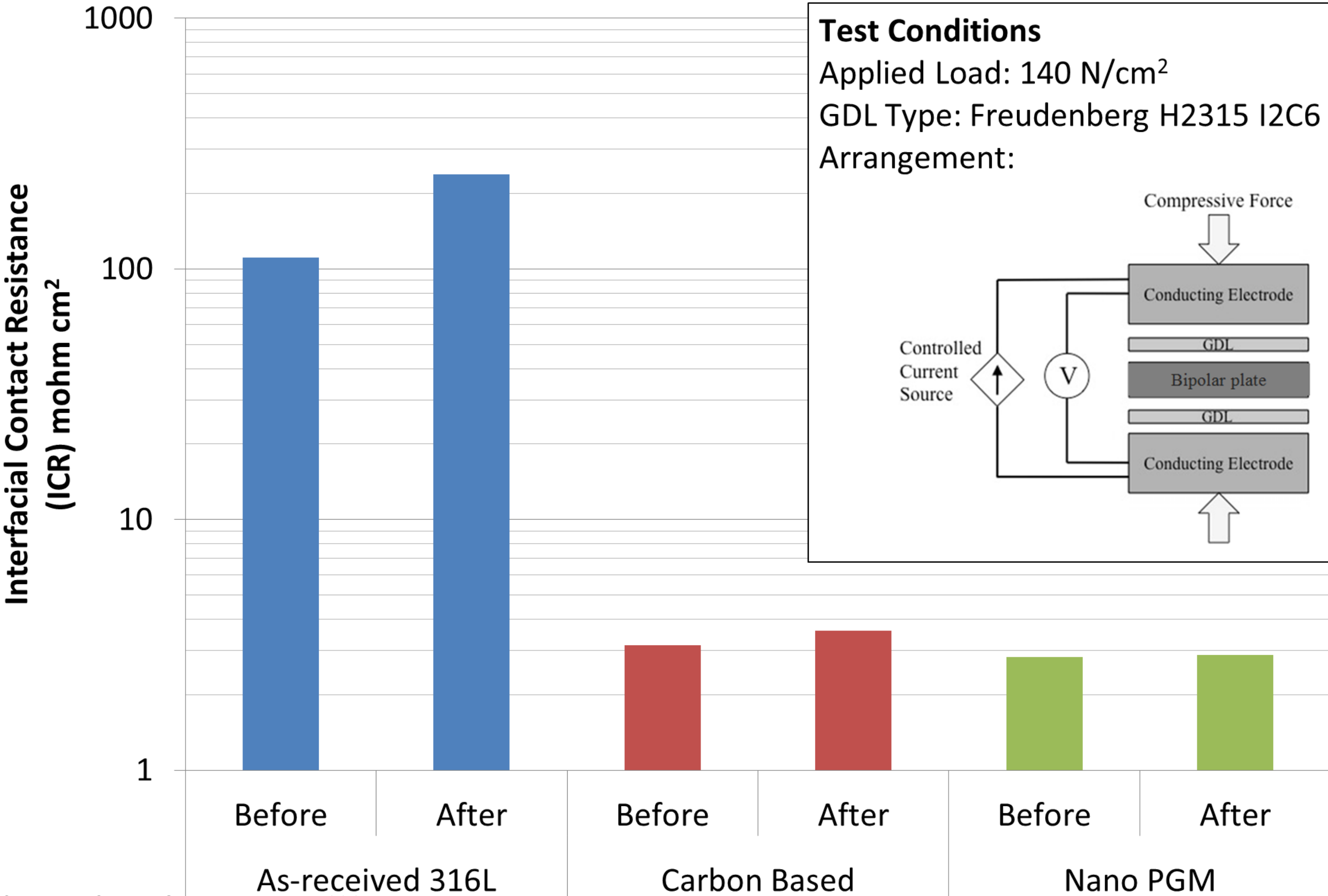

Test Conditions

Applied Load: 140 N/cm^2

GDL Type: Freudenberg H2315 I2C6

Arrangement:

Ex-situ vs In-situ realities?

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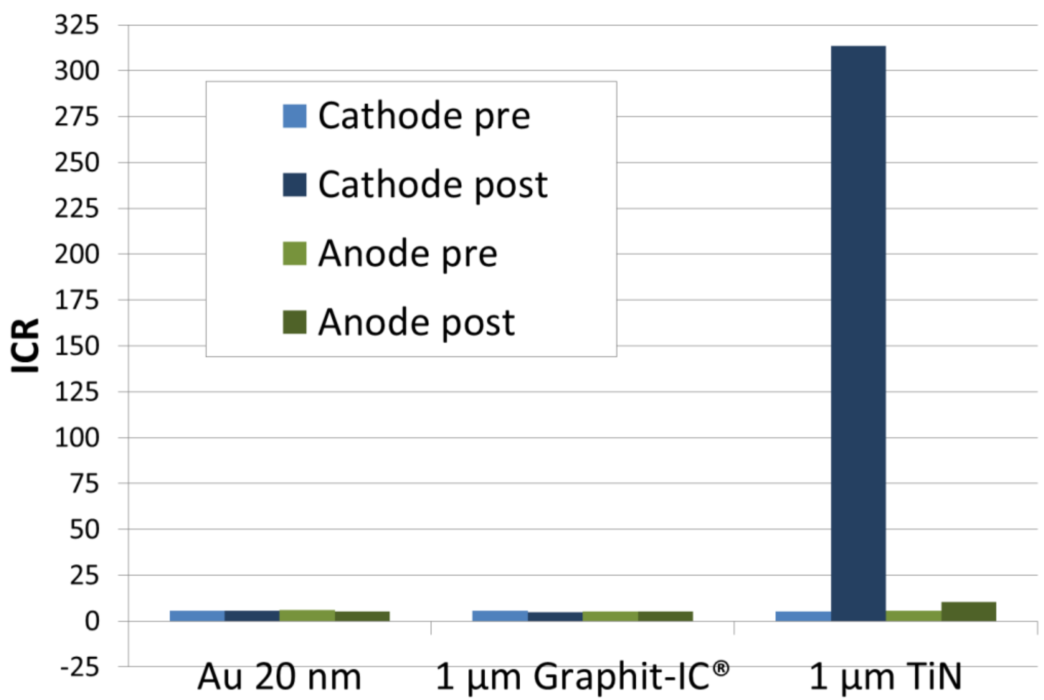
- Fuel Cell Accelerated Stress Test (No. 1) carried out by SINTEF – 70°C, 100% RH, cycling between 0.4V & OCV every 20mins for 100 h. Suspect frequent fuel starvation with selected stoichiometries.
- Significant degradation of the MEA occurs using this protocol.



Failure Modes

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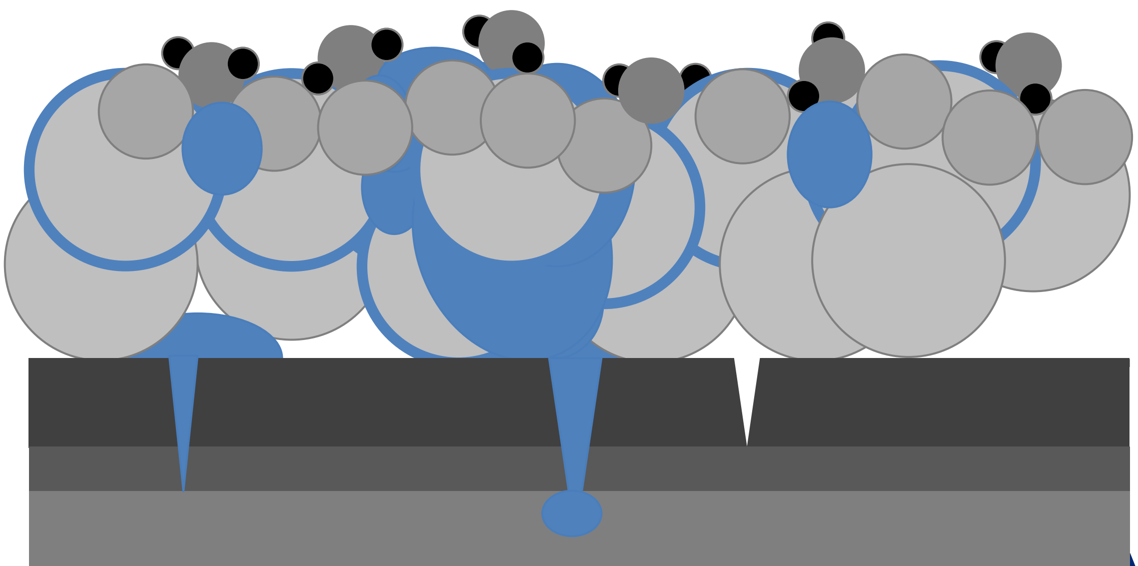
Environmental Bipolar Plate Degradation Factors

- Load profile
- Relative Humidity
- Temperature
- Stoichiometry
- Compression
- SU/SD strategies

All parameters controlled/imposed by the fuel cell system

Upscaling also reduces homogeneity
– larger cell areas
– cell to cell level

Localised Corrosion Processes



- Galvanic and crevice corrosion mechanisms (where the interface is wetted)
- New experimental data from NPL suggest high potentials may not be transferred to BPP

Coating Durability Factors?

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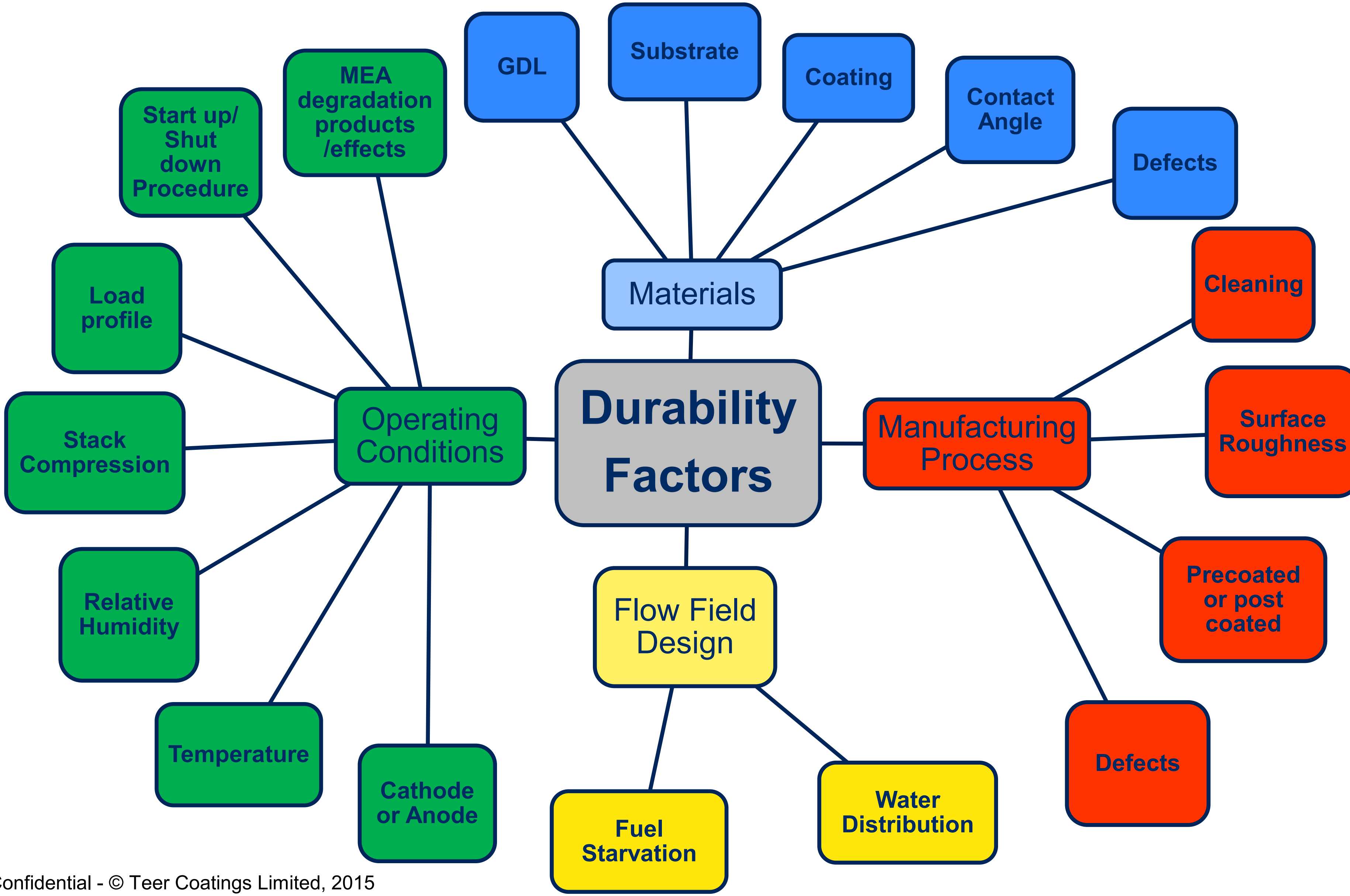

Manufacturing Variables

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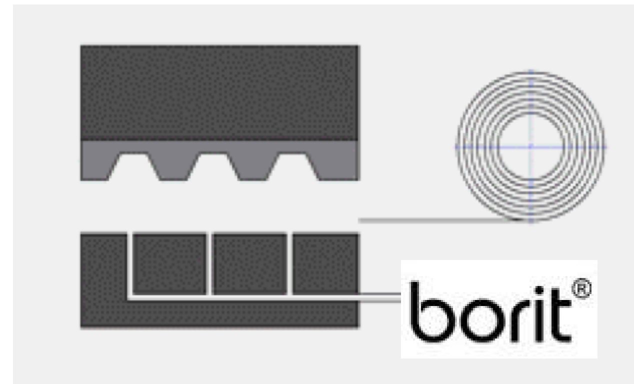
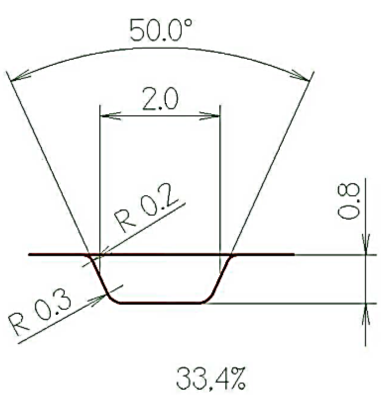
Using a proprietary metal hydroforming process by Borit

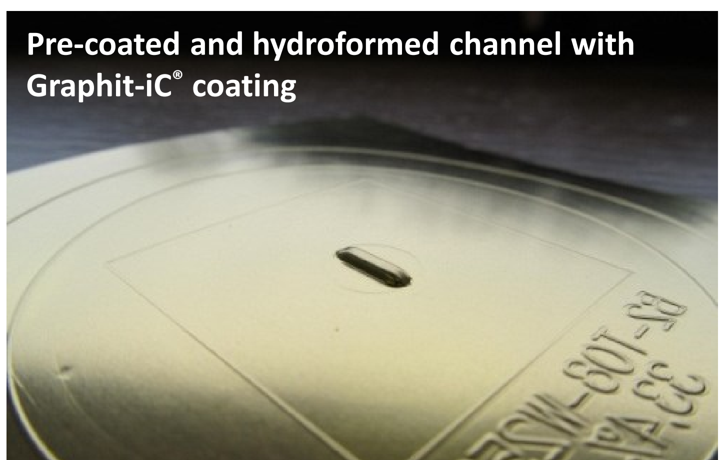
Benefits include

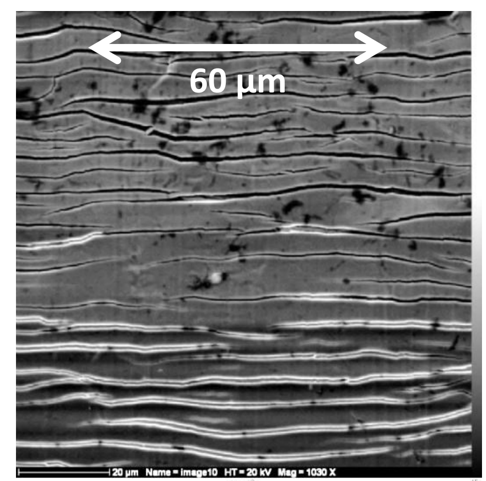
- Greater range of extreme geometries
- Lower tooling costs (single die)
- Reduced residual stresses



Single channel created in order test corrosion resistance in ex-situ experiments







Implications for Manufacturing Route

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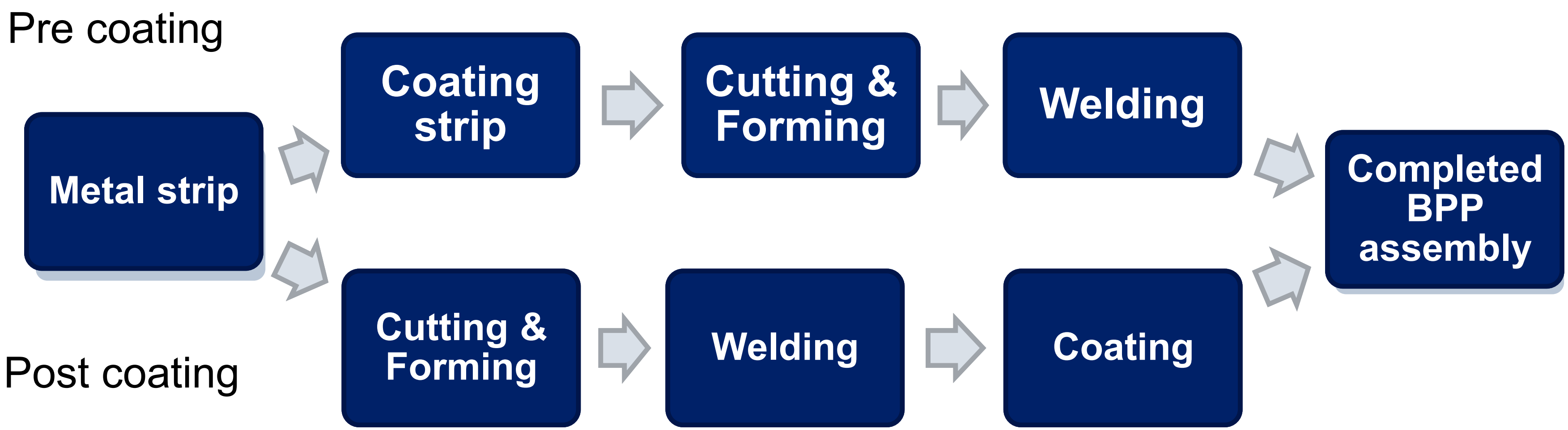

	Pre Coating (R2R)	Post Coating (In-line)
Coating cracking/damage in active area	Yes	No?
Welding or punching inlet/outlet holes	Will damage coating	Issue in welding areas?
Cost	Cheaper	More expensive

BPP manufacturing and coating process route is still unclear - no concensus
Key question: Does pre-coated material give sufficient durability?

High Volume Cost Indications

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- Existing R&D In-line System used for high volume process development and validation of cost assumptions

- DoE Target \$3/kW @ 500,000 stacks (185Mio BPPs)
- ~\$0.2 / BPP coating (assuming ~25% of BPP assembly cost)

- Miba In-line Concept (post coating)
  - Carbon based (<100 nm) or Nano PGM (<5 nm)
  - \$0.5-1.0 / plate @ 10 Mio. p/a

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Summary & Conclusions

- Several PVD coating architectures show promise for fuel cell applications
- Coatings are often tailored to particular fuel cell operational conditions
- Traditional ex-situ methods do not replicate in-situ failure modes
- Manufacturing process route (pre or post coating) is still unclear

What we offer…

- Experience built up over >10 yrs in the FC industry
- Flexibility of coating architecture – PGM, Carbon-based, Metal oxide
- Research & Development capabilities
- High volume PVD experience from Miba (1.5 - 2M parts p/a)

Thank you for listening – Any questions?

'No powertrain without Miba Technology'

Acknowledgments

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