NRC·CNRC

NRC.CANADA.CA

Development of book of attributes for PEM fuel cell components

Xiao-Zi (Riny) Yuan

QC workshop, NREL

May 5-6, 2021

Why book of attributes?

Results of the previous QC workshops to establish a complete book of attributes for main fuel cell components.

- ✓ Harmonize the language of QC for fuel cells.
- ✓ Describe specifications, definitions and standardizations for fuel cell components/sub-components.
- ✓ Identify critical parameters for components QC.
- ✓ Identify a number of areas that can be further improved
- ✓ Develop QC tools for fuel cell components/sub-components.
- ✓ Strengthen the international collaboration around QC.

What is book of attributes ?

A functional analysis by breaking down functions, attributes and properties for each components/subcomponents

Functions:

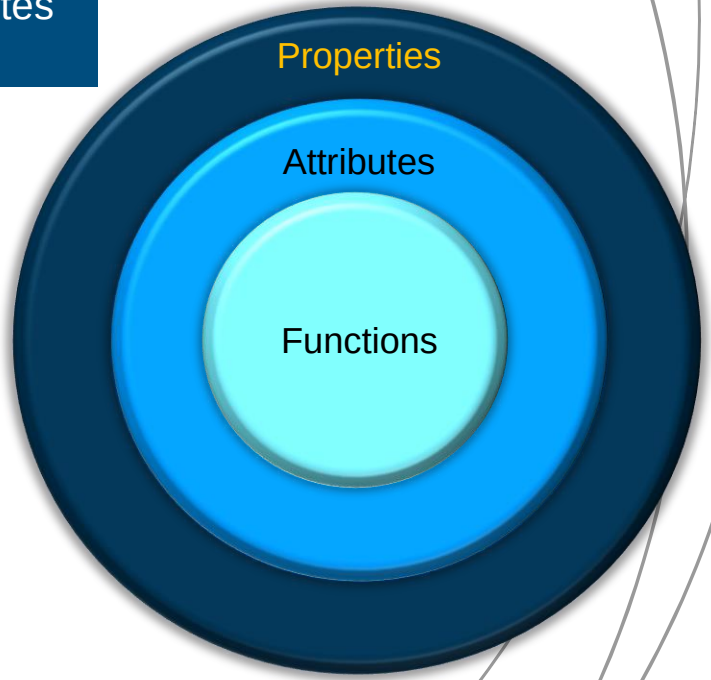
Roles the component needs to perform in a fuel cell stack operation

Attributes:

Qualities the component needs to have to perform its functions

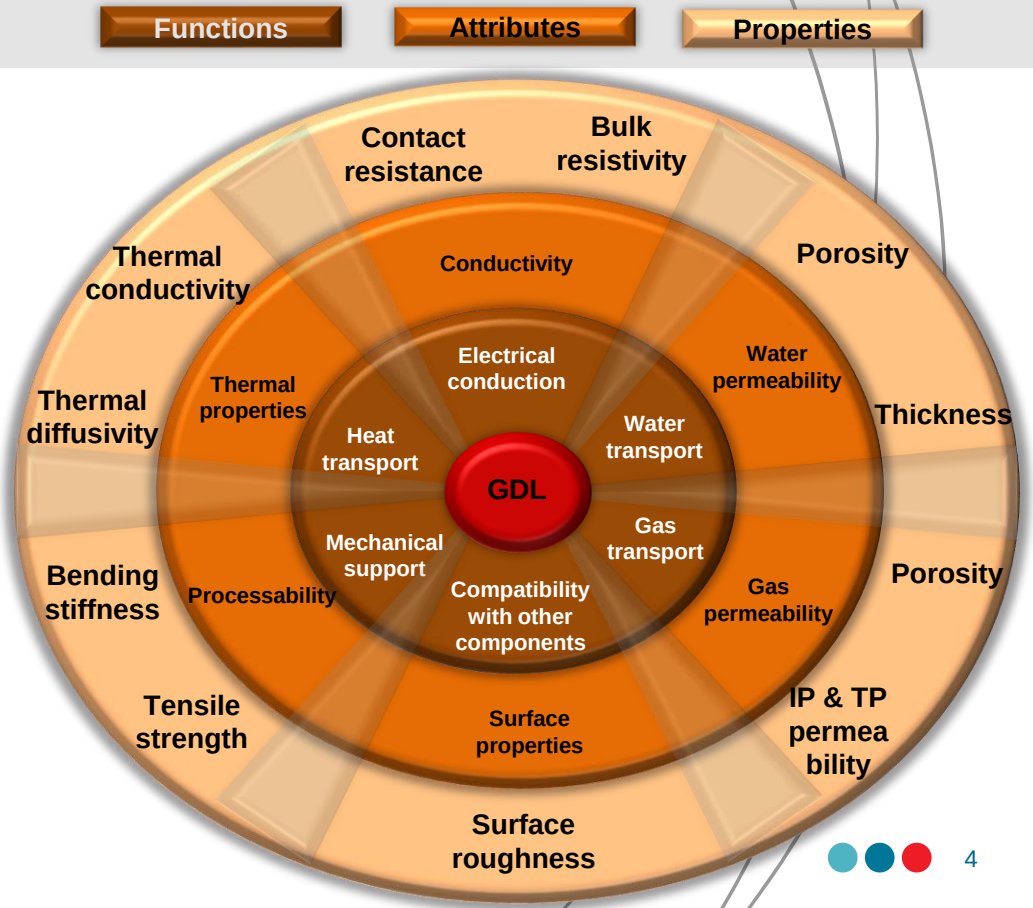
Properties:

Experimentally measurable qualities that quantify the attributes



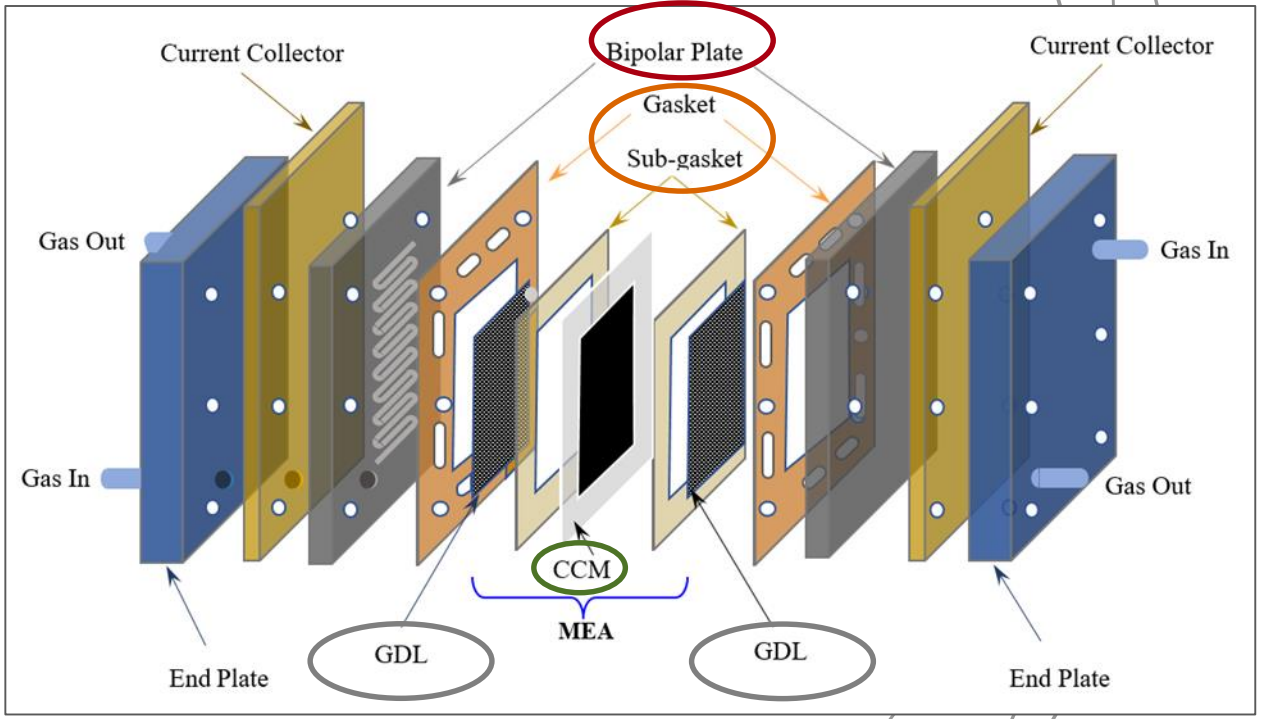
Main objectives

- Review and categorize the main attributes/properties that determine the functionalities of key fuel cell components.
- Identify existing test for each properties, including if it is a standard test, destructive or not and where the capability to measure such property resides.
- Prioritize each properties for QC.

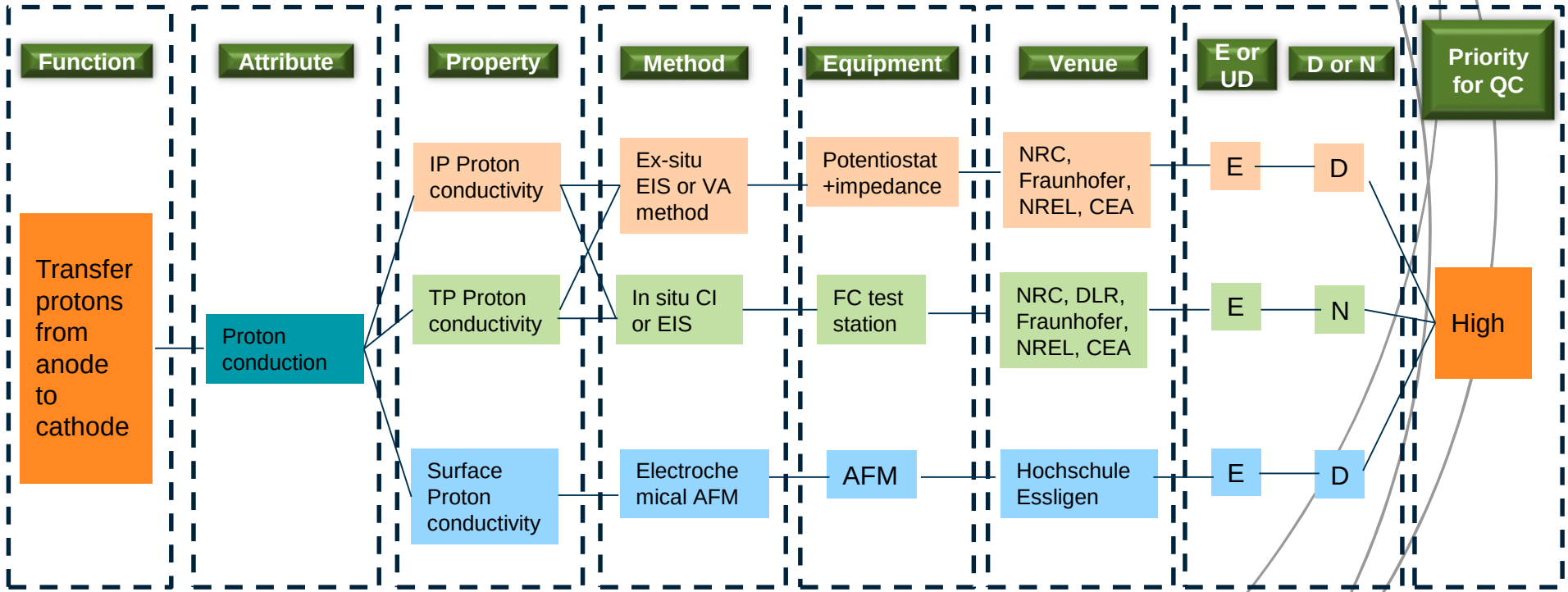


Main components of the compendium

- Main components include BP, GDL, CCM and gasket.
- The CCM book includes membrane, CL, ink and CCM as a whole
- Gasket/sub-gasket was included to make a full spectrum of fuel cell components



Matrix of book of attributes



Final book of attributes for GDLs

Function	Attribute	Property	Note on why or why not the property is downselected	Measurement					Priority for QC
				Method	Tool or equipment	Venue	Existing or under development	Destructive or not	
Mechanical support	Processibility	Tensile strength (N/m^2)	The MEA processes do not seem to change tensile strength. It is suggested as an inbound material parameter (need to develop a lower specification limit)	Stretching test (ISO 1798, ASTM D3574-E)	Universal mechanical tester (e.g., Instron, Zwick/Roell, 3R Company)	NRC-Vancouver; ElringKlinger; Freudenberg PM; ZSW	E	D	Medium: Devices and standards available
		Tear strength (N/m)		Tear strength test (ISO 8067, ASTM D3574-F)					
	Pressure distribution	Bending stiffness (N/m)	Suggested as an inbound material parameter (need to develop a window)	Flexural test/3 point bending test (ISO 178, ASTM D790)					
				Taber bending test (ASTM D5650, D5342 and ISO 2493)	Taber stiffness tester	ZSW			
				Cantilever bending test (ASTM D 5732, DIN 53362)	Cantilever tester (e.g., TG-79-12 Cantilever Fabric Stiffness Tester)	Freudenberg PM			
		Shear Modulus/strength (Pa) [1]	It is believed to be linked to GDL/CCM contact pressure distribution at mid-channels. During compression, the GDL has to withstand a shear load in some areas due to flowfield geometry.	Shear strength test (ASTM D1002)	Shear tester or universal mechanical tester	Freudenberg PM	E	D	Low: Not clear if this is an important property
	Compressibility	Compression properties	Can be coupled with thickness measurement	Compression load vs. thickness	TUC tester	NRC-Vancouver; ElringKlinger	E	D	High: Simple and fast for QC
					Pneumatic clamps with pressure control	NRC-Vancouver; ElringKlinger; Freudenberg PM			
			SEM is not quantitative and not feasible for onsite test	Surface morphology	SEM	NRC-Vancouver; Frauhofer ISE; ElringKlinger; CEA	E	D	Low: Device available, measurement standard not necessary as every company uses different compression procedures and therefore measures different compressibilities
			Penetration in flow field (μm)	μ-CT at different pressures	μ-CT	ZSW			
		Compression set	Compression variations in fuel cell stacks will lead to plastic GDL deformations and loss of	Change in thickness over time or over several compression cycles	TUC tester	NRC-Vancouver; ElringKlinger; Freudenberg PM	E	D	High: A good indicator for thickness loss over time.
			Compression curve: Compression rate vs. stress strain coupled with ICR vs. stress strain gives information on compression rate in stack to ensure a low contact	Compression set test (cylindrical disc samples)	Universal mechanical tester	CEA	E	D	

Final book of attributes for GDLs – cont'd

Function	Attribute	Property	Note on why or why not the property is downselected	Measurement					Priority for QC
				Method	Tool or equipment	Venue	Existing or under development	Destructive or not	
	Heat capacity	Specific heat capacity (J/g·K)	The specific heat capacity is an important, temperature-dependent material property and can be conveniently and reliably measured by DSC.	DSC (ISO 11357-4)	DSC	ElringKlinger	E	D	Low
Compatibility with other components	Surface properties	Surface defects (number/size)	Optical inspection is an easy and fast way to inspect surface quality.	Optical inspection	Optical inspection system	-	E	D	High: Easy and fast
		MPL roughness (Ra, Rz)	Increased MPL roughness can lead to mechanical stress of the membrane and therefore to reduced cell durability. Therefore this parameter is considered very important. Different methods can be used to assess this property.	Line roughness measurement (ISO 4287,4288)	Mahr Surf profiler; Perthometer	Freudenberg PM	E	D	Low: Complex and time consuming for real QC.
				3D surface roughness measurement	Surface roughness profiler (WYKO) [8]	NRC-Vancouver	E	D	
				Break-down voltage	Customized equipment: foil between two GDLs – Pressure applied; voltage+current increased until breakthrough	ElringKlinger	E	D	Low: MPL surface properties are important factors, however, not suitable for QC
				Shorting current measurement	Customized equipment: foil between two GDLs – Pressure applied; voltage increased and current monitored				
				Probability of electric shortcut	Customized equipment: foil between two GDLs – Pressure and current applied; resistance measured and evaluated statistically				
	Dimensioning properties	Areal size (cm^2)	Proper thickness (also under compression) and areal dimensions are fundamental to make the GDL compatible with a given gasket and cell design.	Length measurements	Optical area measurement	DLR-TT and everywhere	E	N	Low: Areal size is not that important, because GDL is mostly sold and bought as roll good.
	Contaminations	Metal impurities (ppm)	Contaminants may leach out and trigger unwanted chemical processes	Elemental analysis techniques	ICP-OES (DIN EN 11885) e.g., Agilent 5110	ZSW	E	D	Low: Devices and standards available
		Halogen impurities (ppm)			Ion Chromatography (DIN EN ISO 10304-1) (e.g. ThermoFisher Scientific)	-	E	D	

Publication

- Contributors:
  - *NRC*
  - *CEA*
  - *ElringKlinger AG*
  - *Frauhofer ISE*
  - *DLR*
  - *NREL*

Journal of Power Sources 491 (2021) 229540

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

A review of functions, attributes, properties and measurements for the quality control of proton exchange membrane fuel cell components

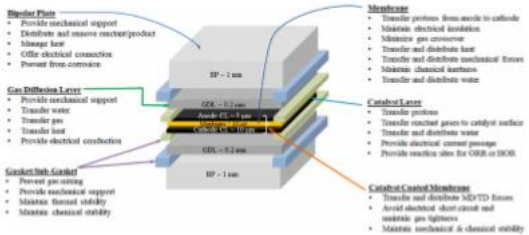
Xiao-Zi Yuan [a,*], Christine Nayoze-Coynel [b], Nima Shaigan [a], David Fisher [c], Nana Zhao [a], Nada Zamel [d], Pawel Gazdzicki [e], Michael Ulsh [f], Kaspar Andreas Friedrich [e], Francois Girard [a], Ulf Groos [d]

[a] National Research Council Canada, 4250 Wesbrook Mall, Vancouver, BC, V6T 1W5, Canada
[b] CEA Grenoble, DRT / LITEN / DEHT / STP / LCP, 17 Rue des Martyrs, 38 054, Grenoble, Cedex 9, France
[c] ElringKlinger AG, Max-Eyth-Straße 2, D-72581, Dettingen, Erms, Germany
[d] Fraunhofer Institute for Solar Energy Systems, Heidenhofstr. 2, 79110, Freiburg, Germany
[e] Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institute of Engineering Thermodynamics, Pfaffenwaldring 38-40, 70569, Stuttgart, Germany
[f] National Renewable Energy Laboratory, 15013 Denver W Pkwy, Golden, CO, 80401, USA

HIGHLIGHTS

- Compendia or books of attributes are established for key PEM fuel cell components.
- The books of component attributes include GDL, CGM, BP and gasket/sub-gasket.
- Functions and attributes/properties of each component are identified and categorized.
- Methods/devices existing or under development to measure the properties are listed.
- Identified properties of each component/sub-component are prioritized for QC.

GRAPHICAL ABSTRACT



book of attributes with high QC priority

GDL	**Function**	Michanical support	Water transport	Gas transport	Electrical conduction	Heat transport	Compatibility with other components
	Property	Compression Compression set	Thickness Water vapor diffusivity	MPL porosity Gas permeability (TP & IP)	TP and IP Conductivity	Thermal conductivity (under compression) Thermal diffusivity (TP)	Surafce defects (number/size)
Membrane	**Function**	Transfer protons from anode to cathode	Maintain electrical isolation/physical inertness	Minimize fuel, oxidant and nitrogen crossover	Maintain chemical & electrochemical inertness		
	Property	Proton conductivity (IP & TP)	Thickness	Hydrogen crossover	Chemical durability		
CL	**Function**	Transfer protons from membrane/ CL to CL	Transfer reactant gases to catalyst surface	Transfer and distribute water	Provide electronic current passage between reaction sites and current collectors	Provide reaction sites for ORR and HOR with three-phase boundaries	
	Property	Proton conductivity Thickness	Ionomer coverage O2 diffusion resistance	Water uptake/hydration Hydrophilic vs hydrophobic pore volume	Contact resistance IP & TP electronic conductivity	Pt utilization Pt loading and uniformity Pt (Pt/C) agglomerates size and distribution	
BP	**Function**	Reactant /product distribution and removal	Separation	Chemical stability			
	Property	Dimensional accuracy (Material thickness, plate thickness and channel shaper/landing radium)	Gas and liquid (fluid) impermeability (Pressure drop)	Corrosion resistance (peak active current, passive current density)			
Gasket	**Function**	Electrical insulation & Prevention of gas mixing	Thermal tolerance	Mechanical strength	**CCM**	Transfer and distribute MD/TD forces	Maintain electrical isolation & gas tightness
	Property	Gas peration (visual inspection, thickness, and gas permeability)	Thermal stability (Glass transition temperature)	Compressibility Compression set		Tensile strngth Burst strength CL adhesion on membrane	Thickness CCM integrity
Sub-gasket	**Function**	Electrical insulation & prevention of gas mixing	Mechanical strength	Chemical stability	**Catalyst ink**	Provide ink with uniformity, stability, and processability	
	Property	Gas tightness	Compressibility	Chemical aging stability (long term & short term)		Viscosity Ink composition	

Concluding remarks

- Accomplished through a close collaboration between national labs across the world, QC participants and fuel cell industries.
- Contributed to the component specification and standardization of fuel cells, in particular, to the QC during its manufacturing, processing, and assembling.
- Through review of the book of attributes for different components:
  - Identify critical parameters for components QC and areas that can be further improved and future projects via collaboration
  - Develop QC tools for fuel cell components/sub-components
- Book of attributes for different components will be kept as live documents and updated as the technology advances.

Acknowledgments

- This work is financially supported by the Vehicle Propulsion Technologies (VPT) Program of NRC.
- International collaboration (5 countries,17 organizations,70 participants)
- Internal NRC members:

- *Nima Shaigan*
- *Zhiqing Shi; Nana Zhao*
- *Régis Chenitz; Asmae Mokrini*
- *Zhong Xie; Chaojie Song; Lei Zhang*
- *DaTong Song; Qianpu Wang*

Acknowledgments

- Special thank goes to:
  - *Frauhofer ISE* (**Nada Zamel**, Patrick Schneider, Sebastion Prass, Ulf Groos)
  - *CEA* (**Christine Nayoze**, Jean-François Blachot, Frédéric Fouda-Onana, Laure Guetaz, Marie Heitzmann, Pierre-André Jacques, Arnaud Morin, Joel Pauchet, Jean-PhilippePoirot-Crouvezier, Philippe Clement, Laurent Antoni)
  - *ElringKlinger AG* (**David Fisher**, Michael Götz, Alexander Höflich, Martin Quintus, Michael Paul)
  - *Ballard* (**Monica Dutta**, Shanna Knights, Darcy McGowan, Erin Rogers, Julie Bellerive, Alan Young, Esmaeil Alvar, Mike Lauritzen, Derek Cheng, Madhu Saha)
  - *Unilia Fuel Cells Canada* (**Carmen Chuy**, Sharon Wong)
  - *DLR* (**Pawel Gazdzicki**, Mathias Schulze, Andreas Friedrich, Indro Biswas)
  - *NREL* (**Michael Ulsh,** Peter Rupnowski)
  - *HySA Catalysis* (**Darija Susac**, Sharon Blair)
  - *ZSW* (**Ludwig Jörissen**, Paritosh Mohanta, Florian Wilhelm, Sylvain Brimaud)
  - *MBFC* (**Taryn Biggs**)
  - *Freudenberg PM* (**Achim Bock**, Volker Banhardt)
  - *AVL Fuel Cell Canada* (**Stephen Lee**)
  - *AUDI* (**Robert Schlumberger**, Christian Wachtel)
  - *Toray* (**Kazuyo Shigeta**, Naoki Kobayashi)
  - *BOSCH* (Siegmund Zweigart)

THANK YOU

Riny Yuan • Research Officer •

xiao-zi.yuan@nrc-cnrc.gc.ca