

2010 DOE Hydrogen Program

The Effects of Impurities on Fuel Cell Performance and Durability

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Project ID
FC047

Overview

Timeline

- Start March 2007
- End June 2011
- ~75% Complete

Budget

- Total Project Funding \$2,481,917
 - DOE Share \$1,985,533
 - Contractor Share \$496,384
- Funding for FY09 - \$570K
- Funding for FY10 - \$398,580

Barriers

- Establish Tolerance to Fuel and System Derived Impurities

Partners

- United Technologies Hamilton Sundstrand – Historical Impurity Data
- FuelCell Energy, Inc., - Impurity Test Support
- UConn C2E2 – Project Management

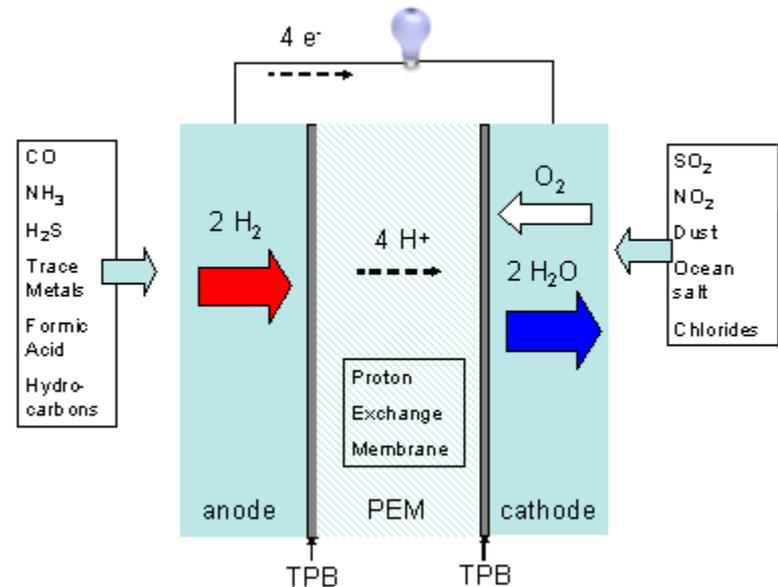
Relevance - Objectives

- Overall Objective – Develop an Understanding of the Effects of Various H₂ Impurities on Fuel Cell Performance and Durability – Critically Important For Automotive Fuel Quality
- Specific Task Objectives Shown Below

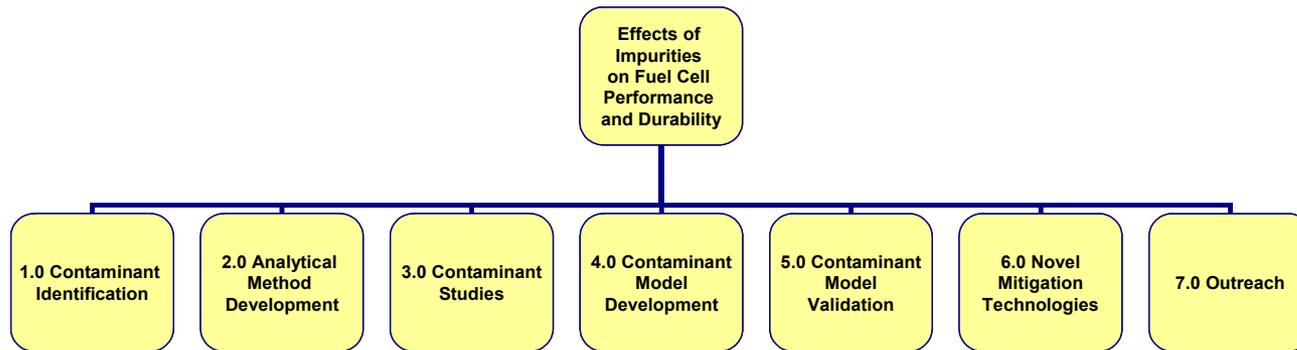
Task	Objectives
1.0 Contaminant Identification	<ul style="list-style-type: none"> • Identify specific contaminants and contaminant families present in both fuel and oxidant streams.
2.0 Analytical Method Development	<ul style="list-style-type: none"> • Development of analytical methods to study contaminants. • Experimental design of analytical studies. • Novel <i>in situ</i> detection methods.
3.0 Contaminant Studies	<ul style="list-style-type: none"> • Develop contaminant analytical models that explain these effects. • Establish an understanding of the major contamination-controlled mechanisms that cause material degradation in PEM cells and stacks under equilibrium and especially dynamic loading conditions
4.0 Contaminant Model Development	<ul style="list-style-type: none"> • Construct material state change models that quantify that material degradation as a foundation for multiphysics modeling • Establish the relationship between those mechanisms and models and the loss of PEM performance, especially voltage decay
5.0 Contaminant Model Validation	<ul style="list-style-type: none"> • Validate contaminant models through single cell experimentation using standardized test protocols.
6.0 Novel Mitigation Technologies	<ul style="list-style-type: none"> • Develop and validate novel technologies for mitigating the effects of contamination on fuel cell performance.
7.0 Outreach	<ul style="list-style-type: none"> • Conduct outreach activities to disseminate critical data, findings, models, and relationships etc. that describe the effects of certain contaminants on PEM fuel cell performance.

Approach

- **Leverage Existing Database From Prior Work**
 - DOE Sponsored Activity
 - USFCC Data
 - Prior Electrolysis Product Experience
- **Focus on Specific Impurities/Concentrations Identified by DOE/Industry/Working Groups**
- **Use Standardized Test Protocols Where Appropriate to Investigate Impurity Effects**
- **Develop Empirical Models Based on Our Findings**

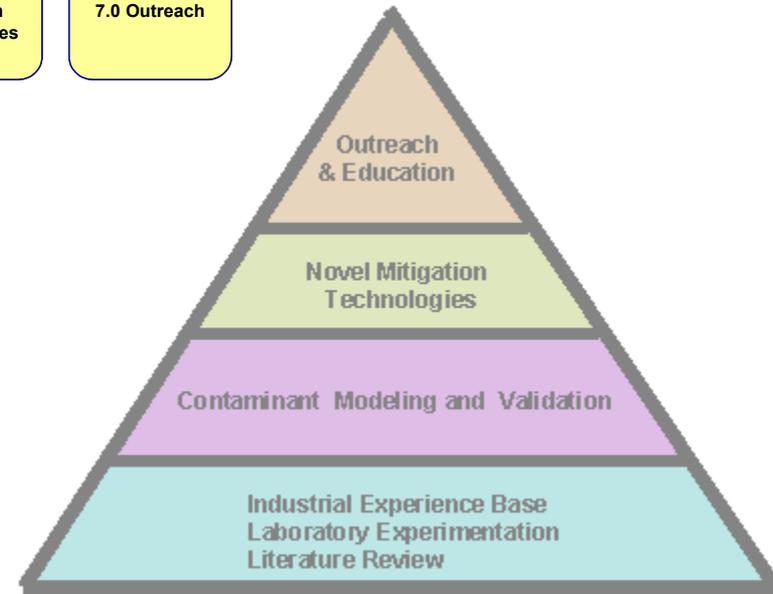


Project Work Plan/Deliverables

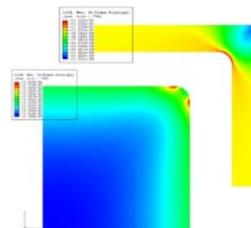
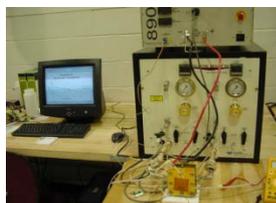
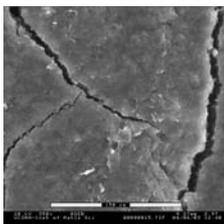
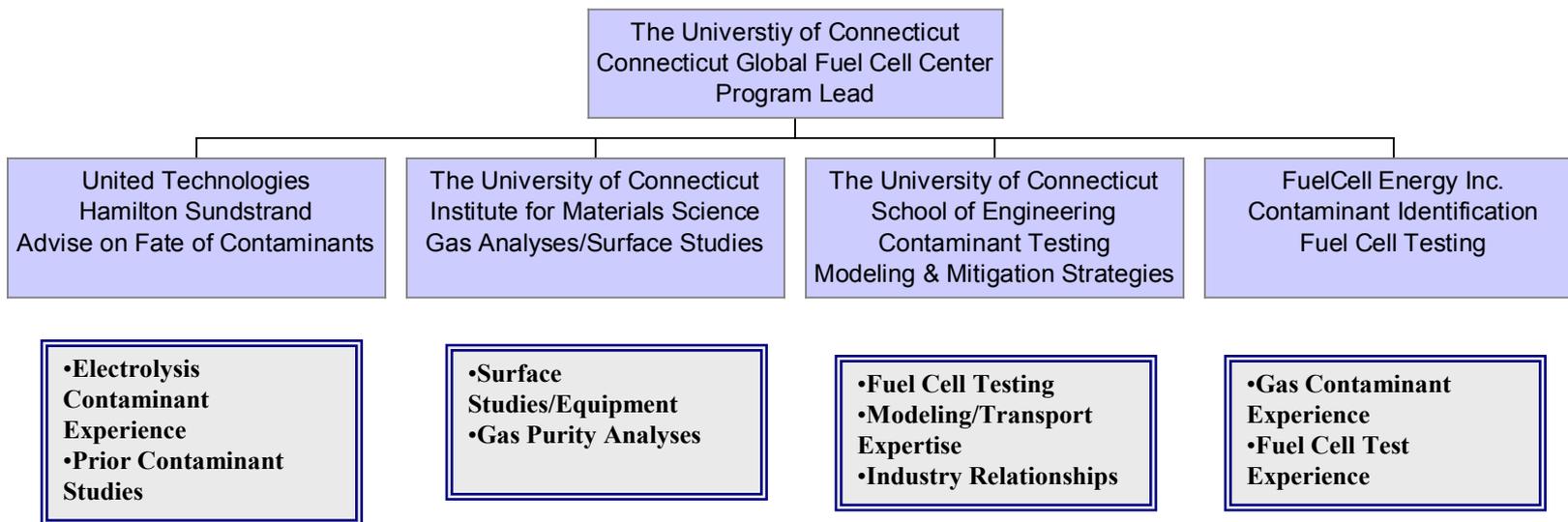


Deliverables

- Validated Impurity Models
 - New Mitigation Technologies
- Outreach: Papers, Workshops, Technical Interchange, Etc.



Roles of Participants



Critical Assumptions and Issues

- **Issues: Impurity Database Not Well Established, More Coordination Between Laboratories Needed, Little Test Standardization**
- **Approach: Significant Coordination Between Labs Being Established Through DOE and Working Groups. Standardized Protocols, Hardware Configurations Being Established.**



Hydrocarbons and Halogenated Compounds



Specification for Draft CD

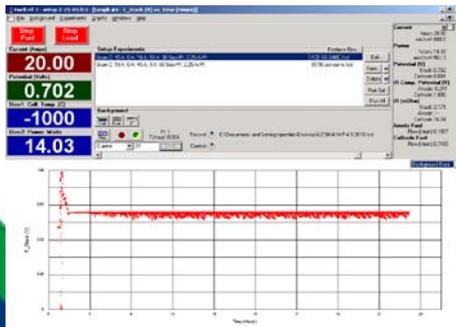
- NMHC/Total HC's – 2 ppm
- Formaldehyde – 10 ppb
- Formic Acid – 0.2 ppm
- Total Halogenates – 50 ppb

- Methane
- Ethane
- Ethylene
- Acetaldehyde

•Formaldehyde

•Formic Acid

- Chloromethane
- Others



Test Strategy

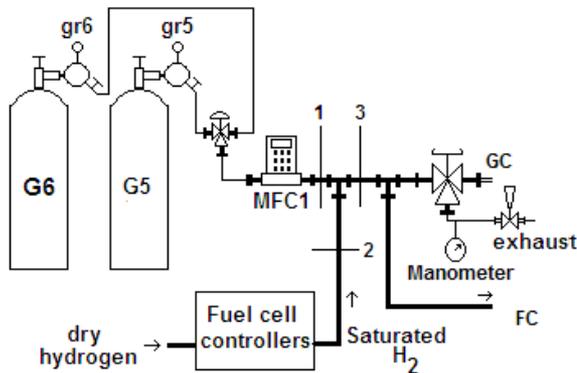
- Focus on Molecules That May Be Present in Fuel Stream
- Impurity Choices Based on Industry Input and Literature Review
- Standardized Hardware
- Standardized Test Protocols
- Begin With High Levels
- If No Effect Move to Different Impurity
- If There is Performance Impact, Reduce Concentration and Test
- Outside Validation of Performance

Mixing and Means of Validating Concentrations

Gases and High Vapor Pressure Oxygenated Compounds
 Eg. Methane, Ethane, Acetaldehyde, Formaldehyde

Mixing of H₂ and high vapor pressure oxygenated contaminants

Certified mixtures H₂ and the contaminant G6 and G5

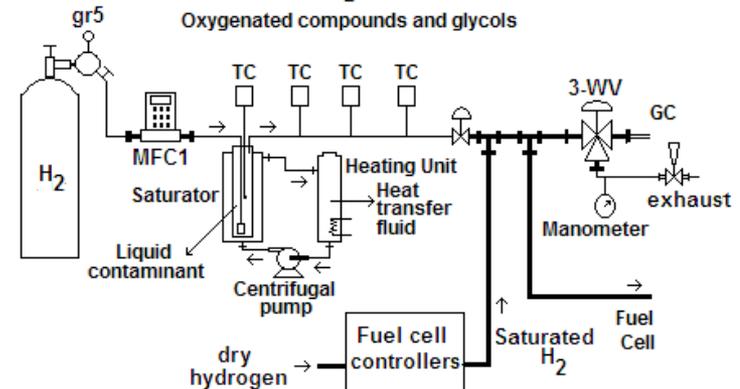


Non-Gaseous Impurities
 Eg. Formic Acid, Acetic Acid, Ethanol, Methanol, Propylene Glycol, Ethylene Glycol

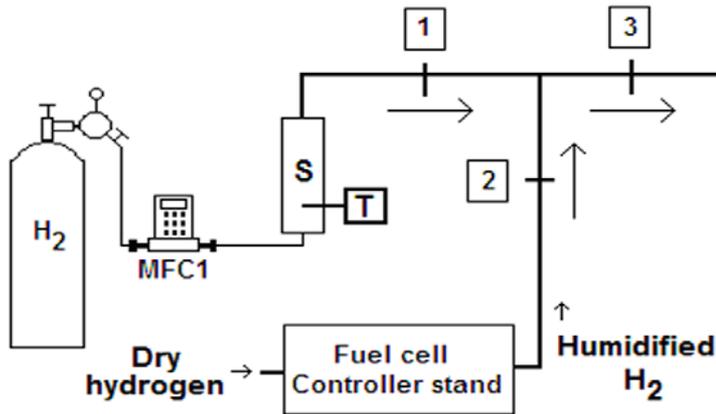
Mixing of H₂ and Non-gaseous contaminant

Saturation of a flow of H₂ with a liquid contaminant

Oxygenated compounds and glycols



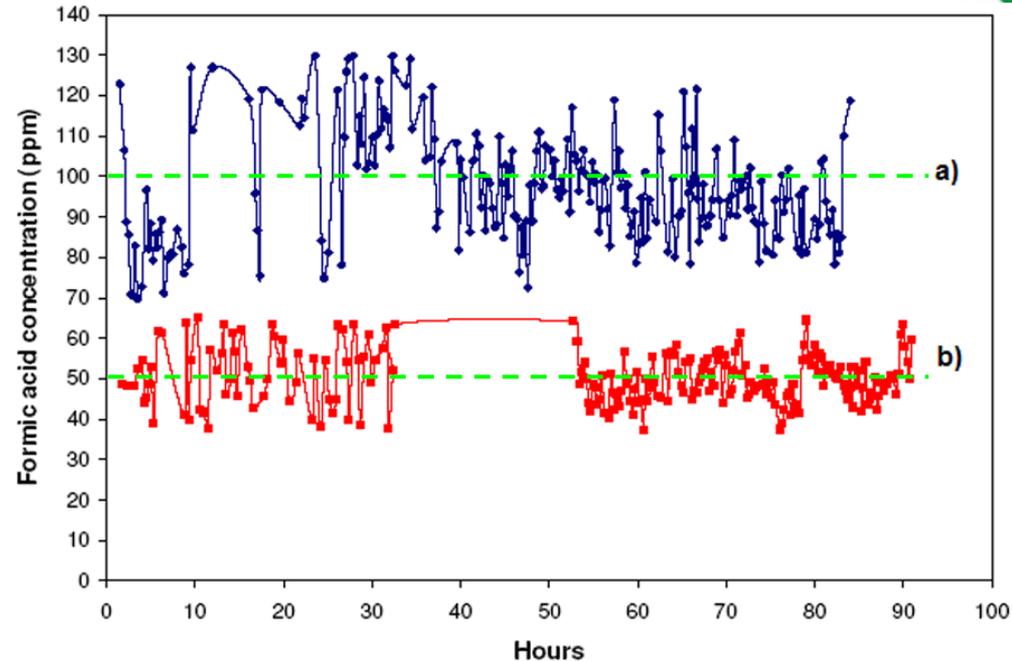
Impurity Mixing and Verification



1. Mixture hydrogen + formic acid (FA) saturated at the temperature T in the saturator
2. Humidified hydrogen from the fuel cell stand
3. Mixture fed to fuel cell

S: Saturator with liquid FA
MFC1: Mass flow controller for H₂ fed to S
T: Saturator temperature controller

General diagram for the setup used to prepare the formic acid in hydrogen mixtures.



HCOOH concentration (ppm) in fuel during the 100 hour experiments.

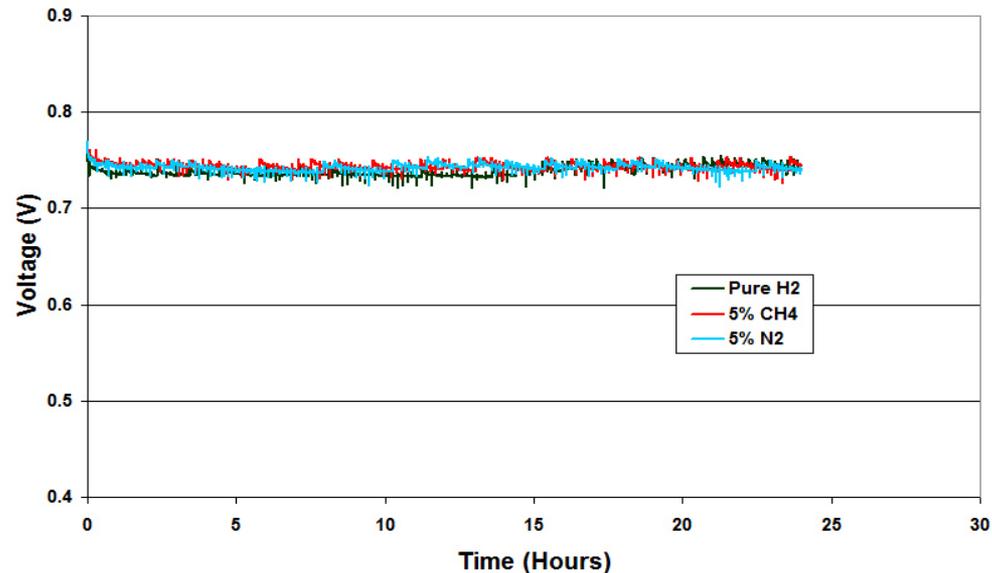
Nominal concentrations of the contaminant 100 ppm and 50 ppm.

Methane (CH₄) – 5% and Nitrogen (N₂) – 5%

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
		3	5% CH ₄ or 5% N ₂	600	100/100	80	25 psig
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Ion-power	Nafion® 212	25	0.4 / 0.2	SGL 10 BB		

Test Procedure

- 1) Fuel Cell conditioning
- 2) Operate the fuel cell for 24 hrs with pure H₂;
- 3) Introduce 5% N₂ and operate for 24 hrs;
- 4) Introduce 5% CH₄ and operate for an additional 24 hrs.

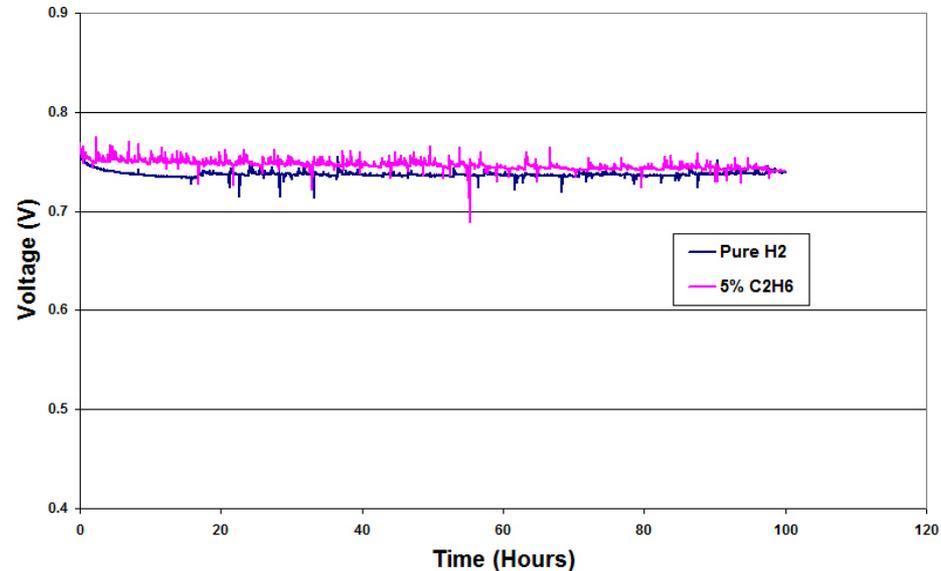


Ethane (C₂H₆) – 5%

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	6	5% C ₂ H ₆	600	100/100	80	25 psig	1.3/2.0
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Ion-power	Nafion® 212	25	0.4 / 0.2	SGL 10 BB		

Test Procedure

- 1) Fuel Cell conditioning;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Recondition the fuel cell when preparing impurity mixture;
- 4) Introduce 5% C₂H₆ and operate for 100 hrs.



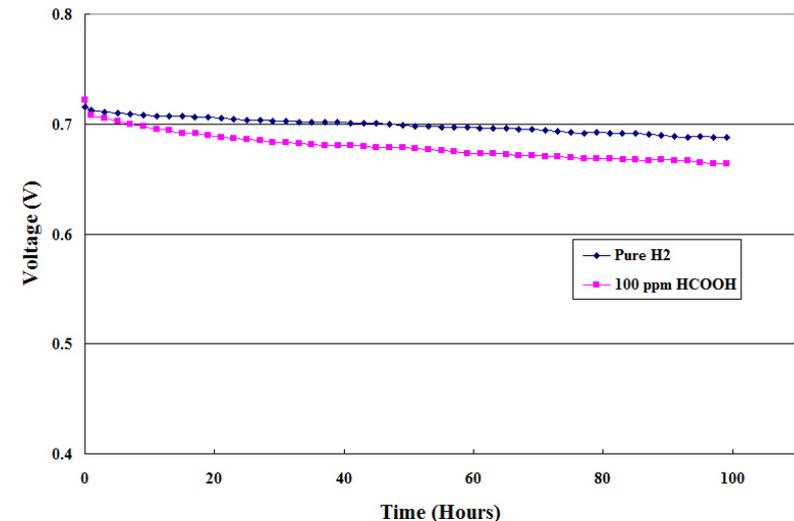
Formic Acid (HCOOH) – 100 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	35	100 ppm HCOOH	800	100/75	80	25 psig	2.0/2.0
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Ion-power	Nafion® 212	25	0.4 / 0.4	SGL 10 BB		

Test Procedure

- 1) Fuel Cell conditioning;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Recondition the fuel cell when preparing the impurity mixture;
- 4) Introduce 100 ppm HCOOH and operate for 100 hrs.

CV and other tests show that HCOOH can cross the membrane and contaminate the cathode. Full recovery of the peaks is not observed; however this may be caused by a combination of coarsening or dissolution of Pt, and more permanent effects of HCOOH contamination.

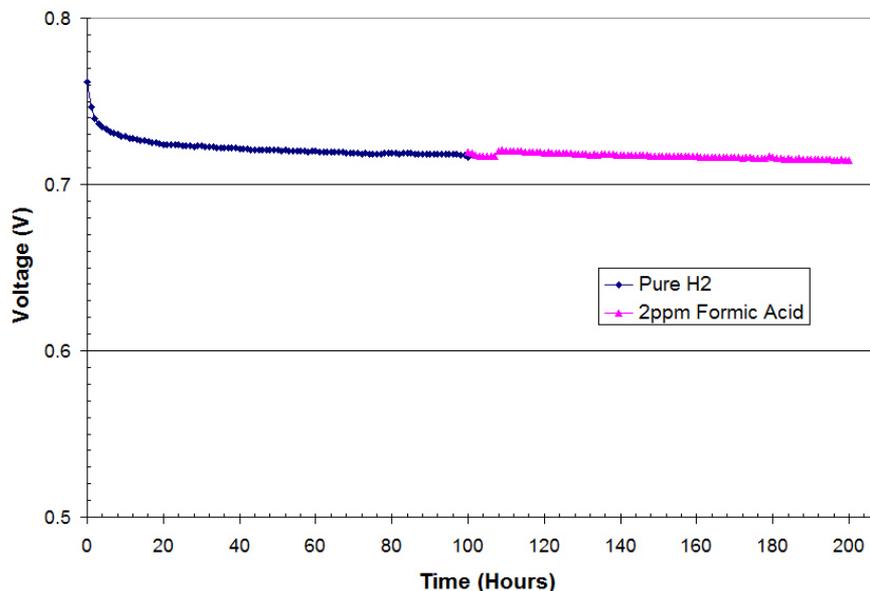


Formic Acid (HCOOH) – 2 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
		48	2 ppm HCOOH	800	100/75	80	25 psig
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Gore	Gore Select	25	0.1/0/4	SGL 25 BC		

Test Procedure

- 1) Fuel Cell conditioning;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Introduce 2 ppm HCOOH and operate for 100 hrs.

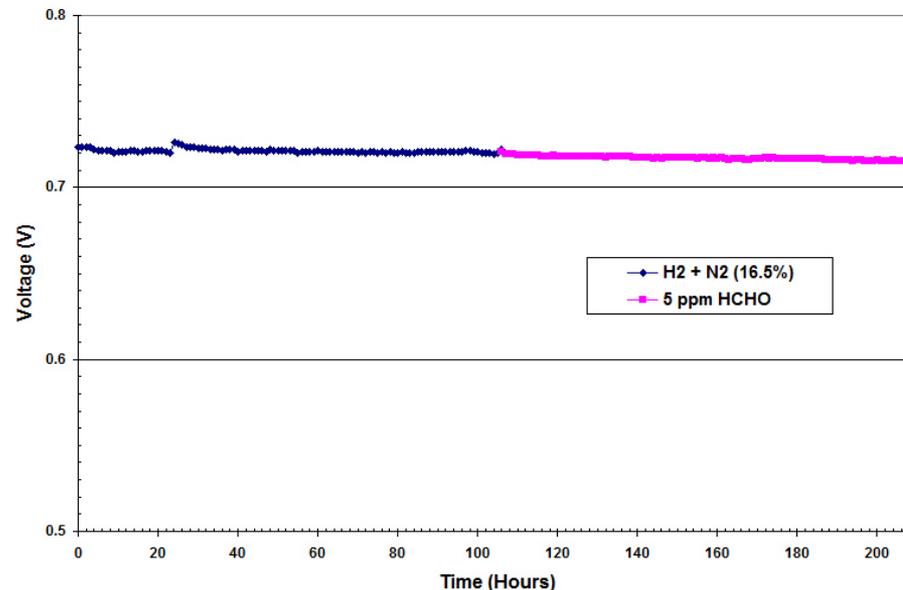


Formaldehyde (HCHO) – 5 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	54	5 ppm HCHO	800	100/75	80	25 psig	2.0/2.0
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Gore	Gore Select	25	0.1 / 0.4	SGL 25 BC		

Test Procedure

- 1) Fuel Cell conditioning;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Introduce 5 ppm HCHO and operate for 100 hrs.

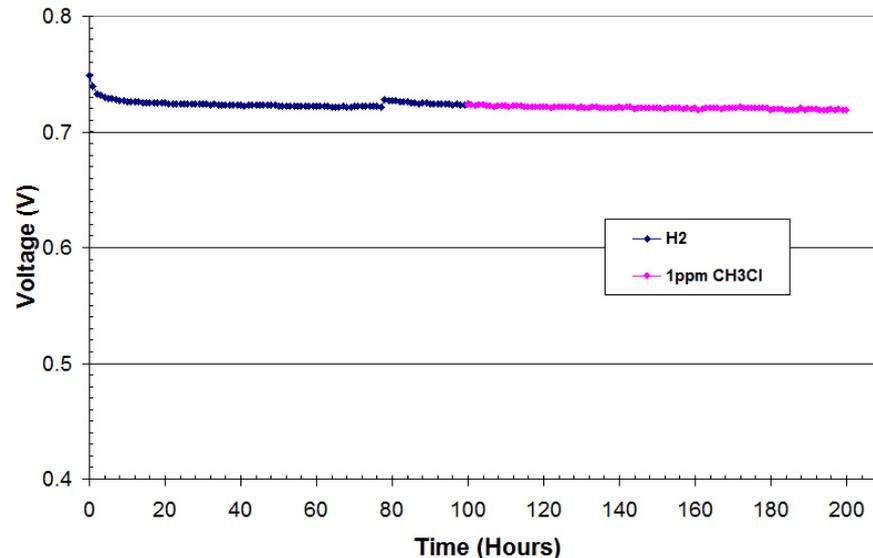


Methyl Chloride (CH₃Cl) – 1 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	49	1 ppm CH ₃ Cl	800	100/75	80	25 psig	2.0/2.0
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Gore	Gore Select	25	0.1 / 0.4	SGL 25 BC		

Test Procedure

- 1) Fuel Cell conditioning;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Introduce 1 ppm CH₃Cl and operate for 100 hrs.

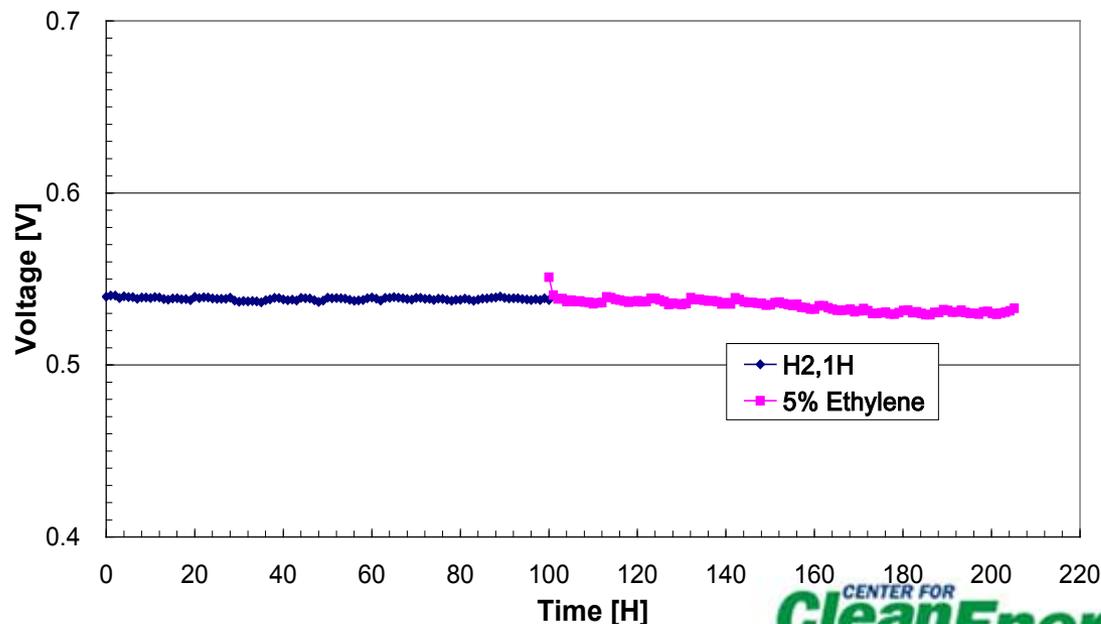


Ethylene - C₂H₄ – 5%

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	57	5% C ₂ H ₄	1000	75/25	80	7PSI	1.2/2.0
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Gore	Gore Select	25	0.1 / 0.4	SGL 25 BC		

Test Procedure

- 1) Condition the fuel cell;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Introduce 5% C₂H₄ and operate for 100 hrs;

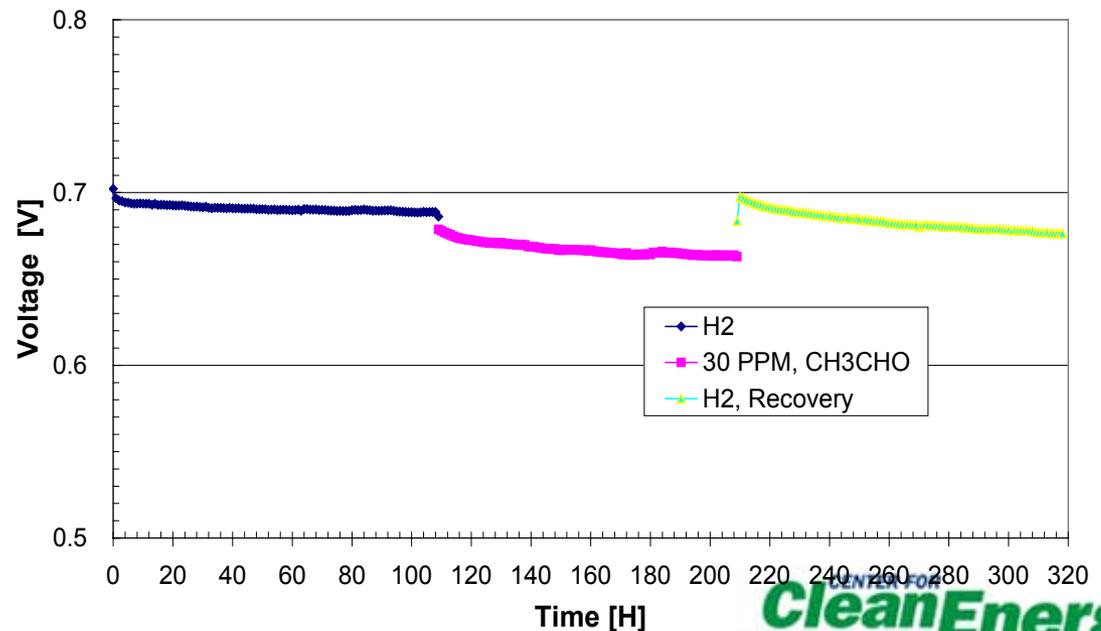


Acetaldehyde - CH₃CHO – 30 PPM

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	57	30 ppm CH ₃ CHO	800	100/75	80	25PSI	2.0/2.0
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Gore	Gore Select	25	0.1 / 0.4	SGL 25 BC		

Test Procedure

- 1) Condition the fuel cell;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Introduce 30ppm CH₃CHO and run for 100 hrs;
- 4) Remove 30ppm CH₃CHO and switch back to H₂ for 100 hrs for recovery test.

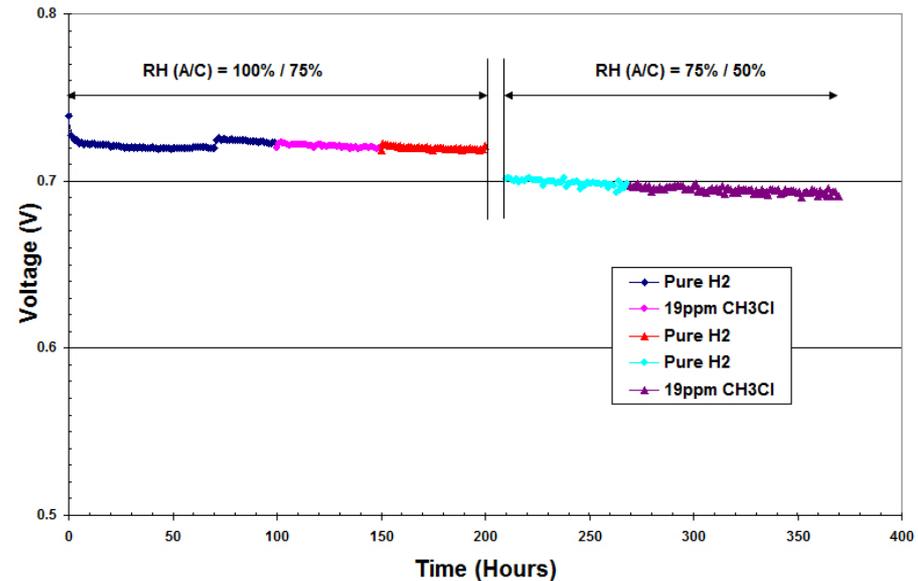


Methyl Chloride - CH₃Cl 19 PPM

Operating Conditions	Cell #	Impurity	Current Density (mA/cm ²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
		52	19 ppm CH ₃ Cl	800	See the figure	80	25 psig
MEA	Vendor	Membrane	Active Area (cm ²)	Pt Loading (mg/cm ²) A/C	GDL		
	Gore	Gore Select	25	0.1 / 0.4	SGL 25 BC		

Test Procedure

- 1) Condition the fuel cell;
- 2) Operate the fuel cell for 100 hrs with pure H₂;
- 3) Introduce 19 ppm CH₃Cl and run for 50 hrs;
- 4) Remove CH₃Cl, switch to pure H₂ and run another 50 hrs;
- 5) Change RH and run for 75 hrs with pure H₂.
- 6) Introduce 19 ppm CH₃Cl again and run for 100 hrs.



Impurity Test Summary

Impurity Class/Target	Tested	Concentration	Source	Result
NMHC/Total Hydrocarbons - 2 ppm	Methane	100 ppm	UCONN	
	Methane	1%	JARI	
	Methane	5%	UCONN/JARI	
	Ethane	100 ppm	JARI	
	Ethane	5%	UCONN/JARI	
	Ethylene	100 ppm	JARI	
	Ethylene	5%	UCONN/JARI	
	Acetaldehyde	30 ppm	UCONN	
	Benzene	500 ppm	JARI	
	Benzene	750 ppm	JARI	
	Benzene	1000 ppm	JARI	
	Toluene	20 ppm	HNEI	
	Methanol	500 ppm	JARI	
	Methanol	1500 ppm	JARI	
	Methanol	2000 ppm	JARI	
Methanol	2500 ppm	JARI		
Acetone	100 ppm	JARI		
Acetone	250 ppm	JARI		
Acetone	400 ppm	JARI		
Acetone	500 ppm	JARI		
Formaldehyde - 10 ppb	Formaldehyde	1 ppm	UCONN	
	Formaldehyde	3 ppm	JARI	
	Formaldehyde	5 ppm	UCONN/JARI	*
	Formaldehyde	10 ppm	JARI	
	Formaldehyde	20 ppm	JARI	
Formic Acid - 0.2 ppm	Formic Acid	2 ppm	UCONN	
	Formic Acid	10 ppm	JARI	
	Formic Acid	20 ppm	JARI	
	Formic Acid	50 ppm	UCONN/JARI	
	Formic Acid	100 ppm	UCONN/JARI	*
	Formic Acid	500 ppm	JARI	
	Formic Acid	5%	UCONN	
Total Halogenates - 50 ppb	Methyl Chloride	1 ppm	UCONN	
	Methyl Chloride	19 ppm	UCONN	
	Perchloroethylene	0.05 ppm	SRNL	
	Perchloroethylene	1 ppm	SRNL	
	Perchloroethylene	30 ppm	SRNL	

Key	
0 mv	
<10 mv	
>10 mv	

* Signifies Disagreement in Data

Impurity Test Summary

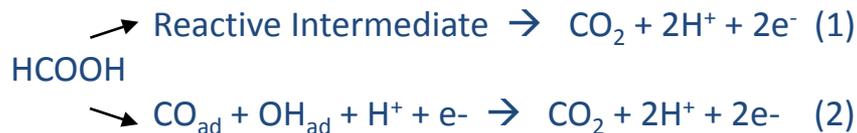
Impurity Class/Target	Category	Examples	Concentration/Result	Supports Target?	Suggestion
NMHC/Total Hydrocarbons - 2 ppm					
	Alkanes	Methane, Ethane	5%	Yes	
	Alkenes	Ethylene	100 ppm	Yes	
	Aldehydes	Acetaldehyde	30 ppm	No	Collect Data at Lower Conc.
	Alcohols	Methanol	500 ppm	Yes	
	Ketones	Acetone	100 ppm	Yes	
	Aromatics	Benzene, Toluene	20 ppm	No	Collect Data at Lower Conc.
Formaldehyde - 10 ppb			1 ppm	Yes	
Formic Acid - 0.2 ppm			2 ppm	Yes	
Total Halogenates - 50 ppb					
		Methyl Chloride	19 ppm	Yes	
		Perchloroethylene	0.05 ppm	No	Separate Limits

- NMHC/THC Target Met for Alkanes, Alkenes, Alcohols and Ketones
- More Data Needed for Aldehydes/Aromatics
- Formaldehyde Does Not Seem to Be a Problem
- Formic Acid Seems OK at 10X Target
- 50 ppb Target Might be a Problem for Halogenates
- General – Limited Data Sets, No Testing on Aged Cells, Recycle?

Difficult to Make a Broad Judgement on NMHC/THC's or Total Halogenates

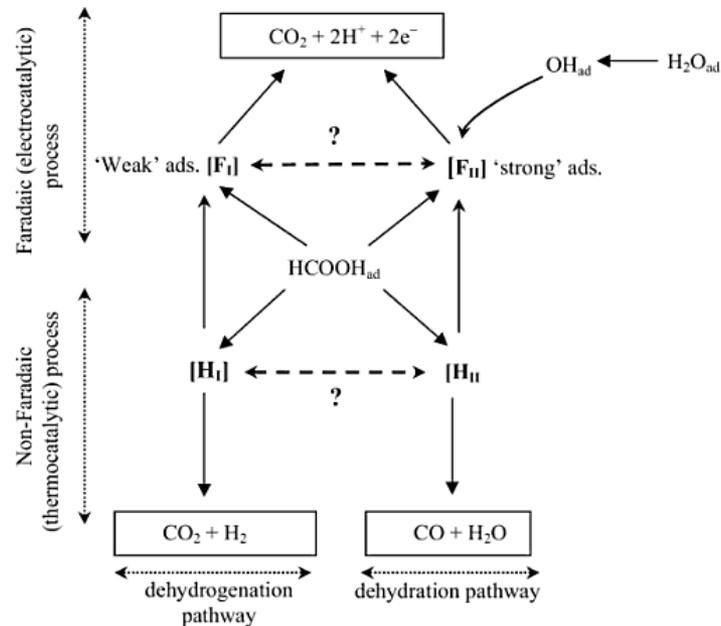
Formic Acid - Potential Contamination Mechanisms

The generally accepted reaction of HCOOH oxidation to CO₂ is so-called “dual path” mechanism. The reaction scheme is:



In pathway (1), adsorbents such as COH/HCO, COOH may be formed on the electrode \rightarrow reduce the electrochemical active area.

In pathway (2), CO is a well known poisoning species to the electrode.

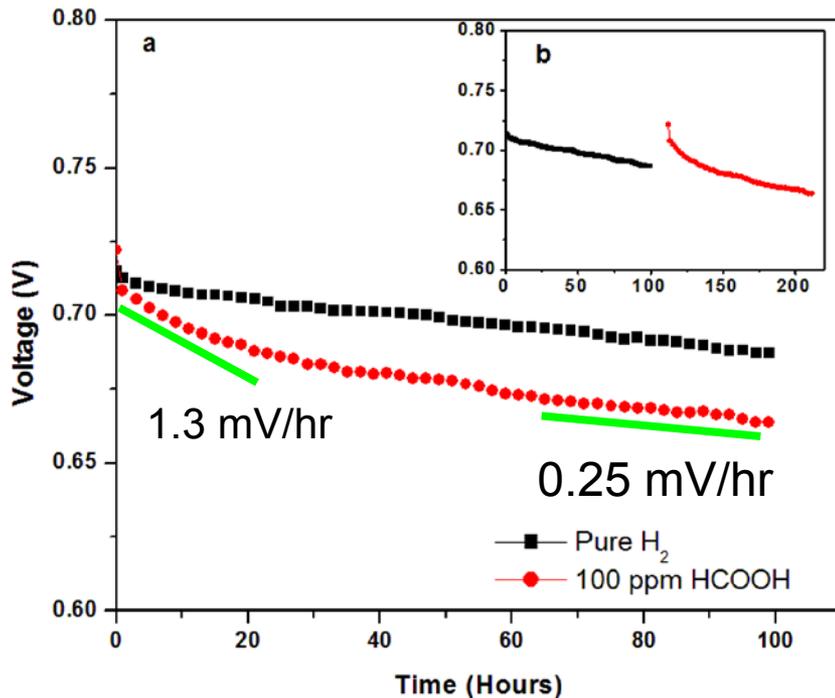


J. Zhang, Ed. *PEM Fuel Cell Electrocatalysts and Catalyst Layers: Fundamentals and Applications*, 2008, Springer.

- A. Capon and R. Parsons, *J. Electroanal. Chem.*, **45**, 205 (1973)
- A. Capon and R. Parsons, *J. Electroanal. Chem.*, **44**, 1 (1973)
- S. Wilhelm, W. Vielstich, H. W. Buschmann, and T. Iwasita, *J. Electroanal. Chem.*, **229**, 377 (1987)
- S. G. Sun, J. Clavilier, and A. Bewick, *J. Electroanal. Chem.*, **240**, 147 (1988)
- C. Lamy and J. M. Leger, *J.Chim.Phys.*, **88**, 1649 (1991)

Rate of Contamination

Formic Acid (HCOOH) 100 ppm



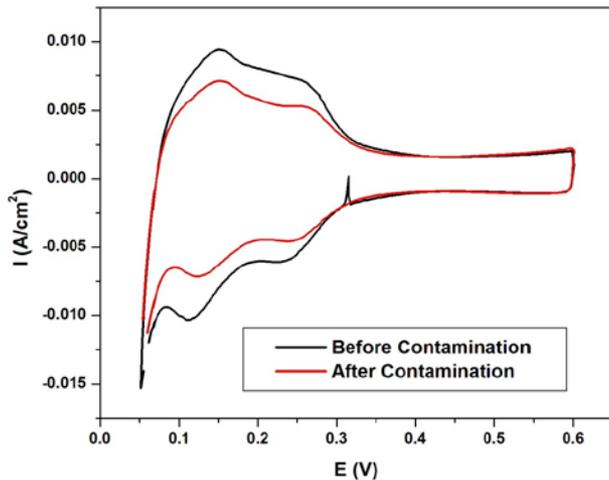
- First 20 hrs
 - Performance degradation rate:
~ **1.3 mV/hr**
- Last 30 hrs
 - Performance degradation rate:
~ **0.25 mV/hr**

- 0.4 mg/cm² anode Pt loading (assuming 50 m²/g):
 - 0.5 m² Pt (25 cm² active area)
- 210 μC/cm² (H₂ charge on Pt (111))
- Monolayer coverage of HCOOH in anode catalyst layer:
 - (assuming all HCOOH immediately absorbed) ~ 5 min.

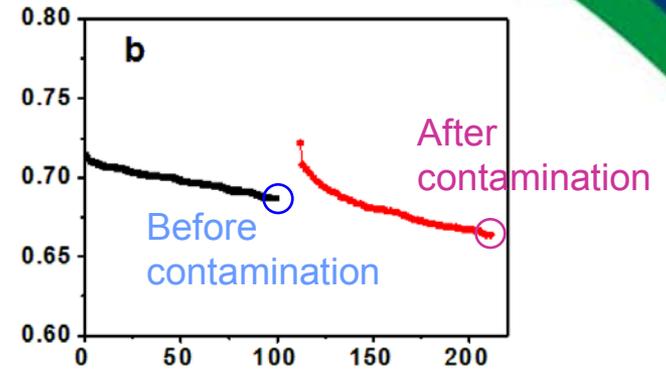
Formic Acid (HCOOH) 100 ppm

Cyclic Voltammetry Before and After Contamination (Cathode)

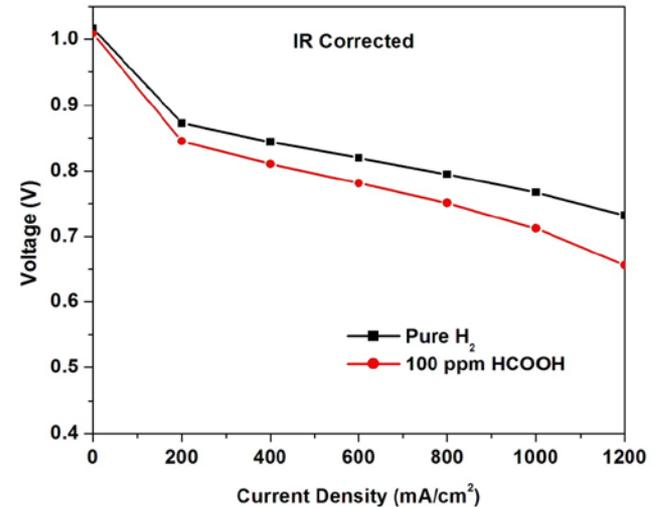
Scan Rate: 20 mV/sec, Scan Range: 0.05 – 0.6 V,
Room Temperature, Ambient Pressure,
Flow Rate (A/C): 250/250 sccm



CV Shows That Hydrogen Oxidation Peak Decreased After 100 Hours Exposure to HCOOH. HCOOH May Cross Over the Membrane and Affect the Cathode.

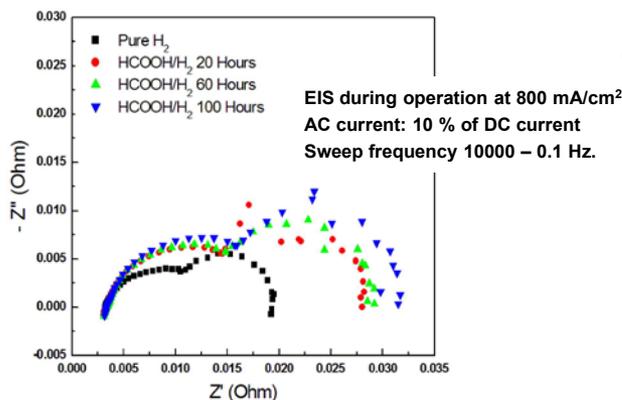
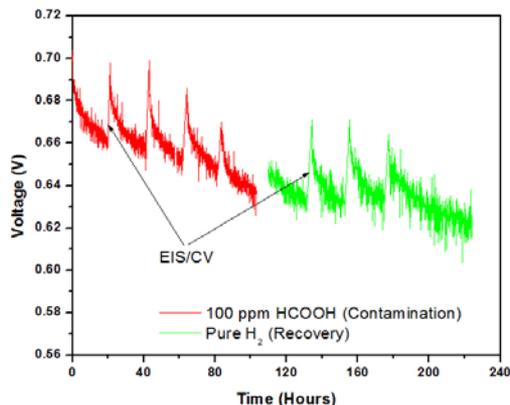


Polarization Scans Before/After Contamination



Electrochemical Characterization

Electrochemical Impedance Spectroscopy



- Same current hold test (100 hrs) with periodic EIS and CV measurements (every 20 hours)

- Contamination
- Recovery

1. 100 hour test with pure H₂;
2. Conditioning at 0.6 V for 12 hours;
3. 100 ppm HCOOH is added into H₂ and another 100 hour test is performed.

Electrochemical Impedance Spectroscopy

As the contamination continues, the diameter of the high frequency arc increases

- Increase in charge transfer resistance
- Effect of HCOOH impurity on electrochemical reaction kinetics

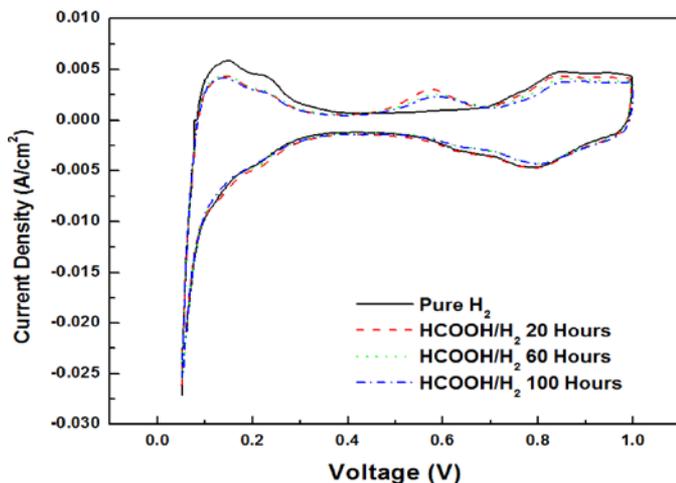
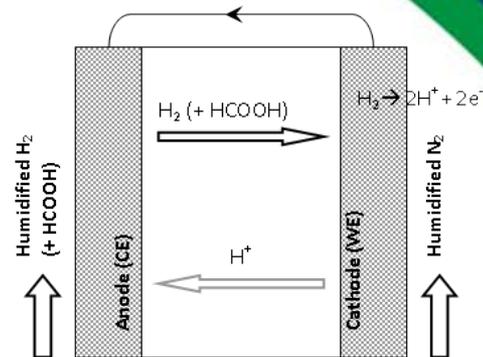
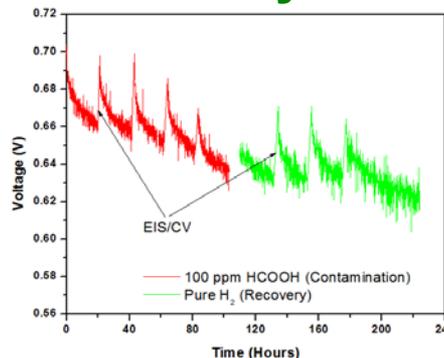
- Diameter of the low frequency arc increases as well
 - Effect of HCOOH impurity on mass transfer

Electrochemical Characterization

Cyclic Voltammetry

“Hot” Cyclic Voltammetry During Exposure

-Record the last CV cycles at each time step
 Scan Rate: 20 mV/sec, Scan Range: 0.05 – 1.0 V,
 Pressure-Anode/Cathode: 25/25 psig
 Temperature-Cell/Anode/Cathode: 80/80/73°C
 Flow Rate-Anode/Cathode: 250/250 sccm



- CVs were performed every 20 hours to characterize the cathode.
 - Last cycle of each scan is shown.
- CVs show a decrease in H₂ desorption peaks
- An oxidation peak at 0.6 V
 - absorbents on Pt surface?

HCOOH can cross the membrane and affect the cathode.

Cyclic Voltammetry (2)

Individual CV cycles at 60 hrs

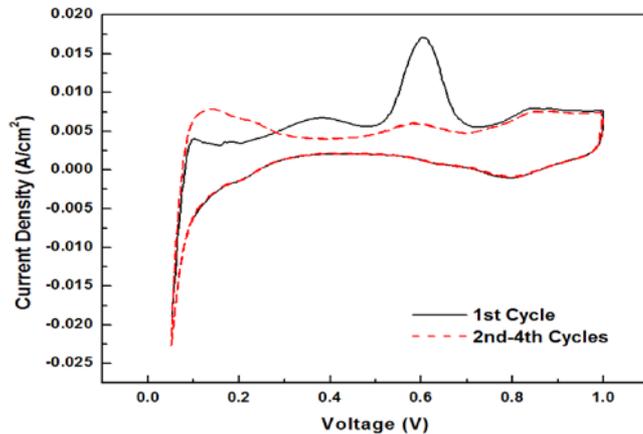
“Hot” Cyclic Voltammetry During Exposure

Scan Rate: 20 mV/sec, Scan Range: 0.05 – 1.0 V,

Pressure-Anode/Cathode: 25/25 psig

Temperature-Cell/Anode/Cathode: 80/80/73°C

Flow Rate-Anode/Cathode: 250/250 sccm

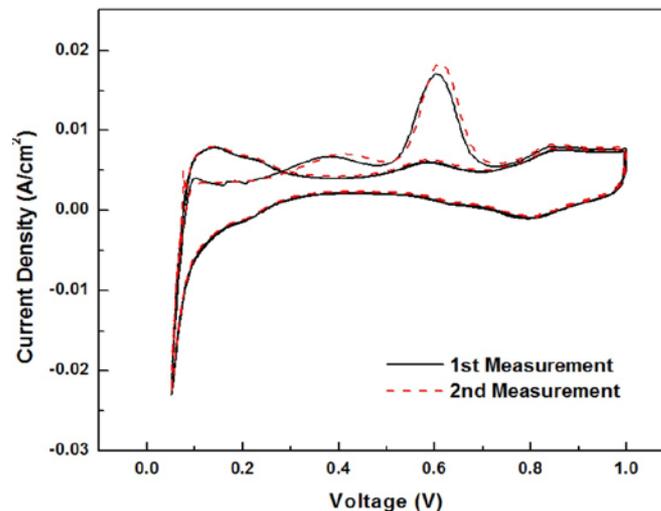


- Four cycles of CV are performed at every 20 hours
 - 1st cycle is different than the 2nd-4th cycles
 - 1st cycle:
 - two oxidation peaks are seen (0.4 V and 0.6 V)
 - Hydrogen desorption peak is not visible
 - 2nd-4th cycles:
 - Oxidation peak at 0.4 V disappeared, the one at 0.6 V is decreased
 - Hydrogen desorption peak is partially recovered.

Cyclic Voltammetry

Repeatable Scans

- Prior to CV, cathode is purged with N_2 , however any residual O_2 may interfere with measured current.
 - A second CV is performed 30 minutes after the first (at 60 hrs)
- CV at 60 hrs and 60 hrs +1/2 hr are identical
 - No involvement of O_2
- During CV measurements, $HCOOH$ crosses over to the cathode.
- In the first cycle of CV measurement, any contaminant ($HCOOH$ +others) is oxidized and removed from the surface, therefore recovery of H_2 oxidation and decrease of oxidation peaks at 0.4 V and 0.6 V are observed.
 - *This may not be what is happening during the cell operation due to relatively high cathode potentials.*



Cyclic Voltammetry

Recovery after Contamination

“Hot” Cyclic Voltammetry During Recovery

-Record last CV cycles at each time step

Scan Rate: 20 mV/sec, Scan Range: 0.05 – 1.0 V,

Pressure-Anode/Cathode: 25/25 psig

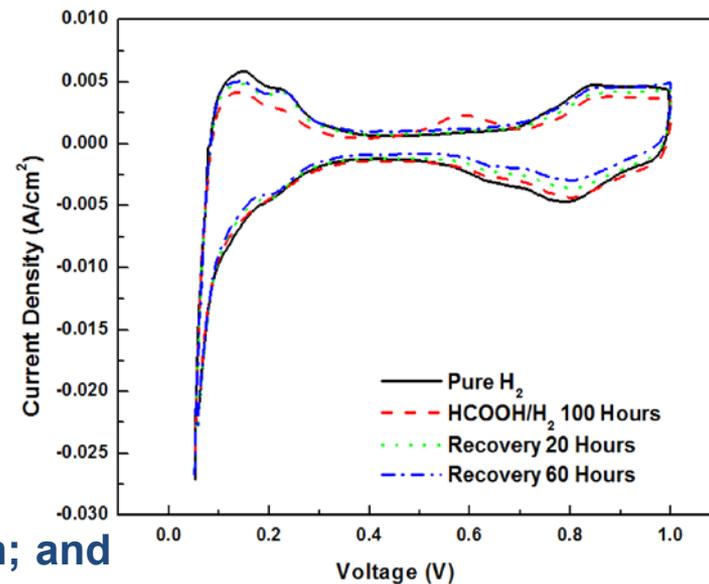
Temperature-Cell/Anode/Cathode: 80/80/73°C

Flow Rate-Anode/Cathode: 250/250 sccm

- After operation with pure H₂ for 20 hours, hydrogen desorption peaks are mostly recovered.
- Further running (>100 hrs) with pure H₂ does not result in further recovery.

Full recovery of the peaks is not seen;
Any permanent effects of HCOOH contamination; and
Coarsening or dissolution of Pt.

CVs were performed every 20 hrs to characterize recovery of the cathode after contamination. Last cycle of each scan is recorded and shown in the figure.



Formic Acid Summary

- Effects of HCOOH contamination on PEFC performance is investigated. Significant effect on cell performance is observed.
- Periodic EIS during contamination shows increased charge transfer and diffusion resistance with contamination time.
- CV scans are performed during non-operating conditions. It is seen that HCOOH can cross-over to the cathode, which results in oxidation peaks at 0.4 V and 0.6 V.
- During the first CV scan, the oxidation peak seen at 0.4 V is completely removed, 0.6 V peak is decreased significantly.
 - During cell operation, HCOOH can be oxidized at the cathode, where O₂ is present and potentials are high enough.
- Recovery with pure H₂ recovers part of the H₂ desorption peak.
 - No further recovery after first 20 hours.
 - *Catalyst degradation (unrelated to HCOOH) + any permanent effect of HCOOH*
- Analysis Showed No Formic Acid on Cathode, Paraformaldehyde Formation on Anode Flow Field
- Separate the contribution of the anode and the cathode is critical to further understand the contamination process.
 - Further characterization is underway

Collaborations

- Collaborated With Hydrogen Quality Working Group on Test Methods, Results, Hardware Configurations, Modeling, Etc.
- Collaboration With ISO Working Group on H2 Quality Standards
- Student Collaboration With Dr. Karren More at ORNL on SEM/TEM Characterization of MEA's
- Continuous Exchange of Data/Personnel/Hardware Amongst our Team

Future Work

Task	Yr 1				Yr 2				Yr 3				Yr 4			
	Q1	Q2	Q3	Q4												
1.0 Contamination Identification	■	■														
2.0 Analytical Method Devt.		■	■	■												
3.0 Contaminant Studies				■	■	■	■	■	■	■	■	■	■	■	■	
4.0 Contaminant Model Devt.							■	■	■	■	■	■	■	■	■	
5.0 Contaminant Model Validation									■	■	■	■	■	■	■	■
6.0 Novel Mitigation Techniques																
7.0 Outreach	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
8.0 Project Mgt. and Rptg.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Activity for FY10

- **Wrap Up Collection of Data on Impurities With Incomplete Data Sets - From Global Test Efforts**
 - Near ISO Goals for Impurities Showing Effects
 - Sparse Data Sets
 - Data Sets Collected With Material Inconsistencies
- **Complete Models/Validation – Share Data/Models With Others**
- **Develop Plan and Implement Mitigation Activity**
- **Continue Outreach/Coordination With Other Labs**

Task	Milestone	Date Year/Quarter
1.0 Contaminant Identification	• Contaminant Identification Review With DOE Sponsor & Industry Focus Group	Y1/Q2
2.0 Analytical Method Development	• Validate Analytical Methods For Studying Contaminants With Ersatz Gases	Y1/Q4
3.0 Contaminant Studies	• Establish an Understanding of the Major Contamination-Controlled Mechanisms that Cause Material Degradation	Y2/Q3
4.0 Contaminant Model Development	• Determine the Relationship Between Contaminant Mechanisms and the Loss of PEM Performance, Especially Voltage Decay.	Y4/Q3
5.0 Contaminant Model Validation	• Validate Contamination Models Through Single Cell Experimentation Using Standardized Test Protocols and a DOE Approved Test Matrix	Y4/Q3
6.0 Novel Mitigation Technologies	• Demonstrate Novel Technologies for Mitigating the Effects of Contamination on Fuel Cell Performance	Y4/Q4
7.0 Outreach	• Dissemination of Results Through Reports (DOE Approved), Papers and Workshops	Continuous
8.0 Project Management and Reporting	• Program Written Reports and Program Reviews	Continuous

Project Summary

- **Relevance** - A Deeper Understanding of the Effects of Specific Contaminants on Fuel Cell Performance is Necessary for Successful Commercialization
- **Approach** - Our Experienced Team Will:
 - Leverage Existing Knowledge and Will Systematically Investigate Certain Fuel Contaminants of Interest
 - Create Empirical and Detailed Analytical Models to Predict the Fate of Specific Contaminants and Their Effect on Fuel Cell Performance
- **Technology Transfer** - Data Will Be Shared Through Papers, Workshops, Working Groups, Etc.
- **Collaboration** – Active Partnership with UTC and FCE, Other Test Labs