DOE Hydrogen Program

2010 DOE Hydrogen Program

The Effects of Impurities on Fuel Cell Performance and Durability

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Project ID FC047

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FuelCell Energy

Hamilton Sundstrand A United Technologies Company

Center for Clean Energy Engineering University of Connecticut

Overview

Timeline

- Start March 2007
- End August 2011
- ~90% Complete

Barriers

- Establish Tolerance to Fuel and System Derived Impurities

Budget

- Total Project Funding $2,481,917
  - DOE Share $1,985,533
  - Contractor Share $496,384
- Funding for FY10 - $399K
- Funding for FY11 - $117K

Partners

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

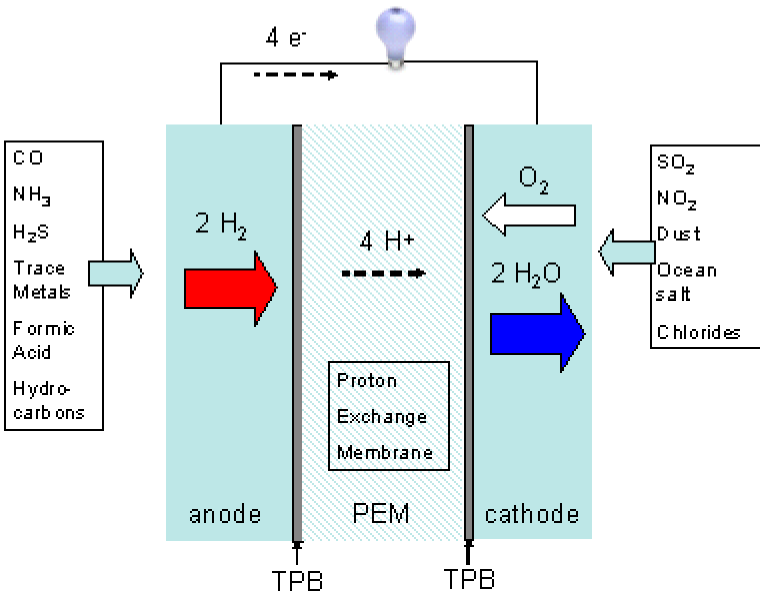
Relevance - Objectives

- **Overall Objective – Develop an Understanding of the Effects of Various H_2 Impurities on Fuel Cell Performance and Durability – Critically Important For Automotive Fuel Quality**
- **Specific Task Objectives Shown Below**

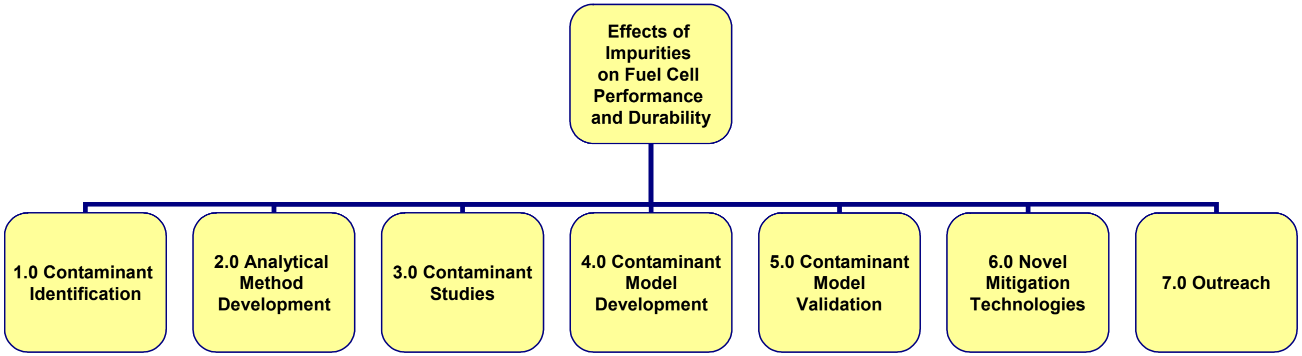
Task	Objectives
1.0 Contaminant Identification	• Identify specific contaminants and contaminant families present in both fuel and oxidant streams.
2.0 Analytical Method Development	• Development of analytical methods to study contaminants. • Experimental design of analytical studies. • Novel *in situ* detection methods.
3.0 Contaminant Studies	• 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	• 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	• Validate contaminant models through single cell experimentation using standardized test protocols.
6.0 Novel Mitigation Technologies	• Develop and validate novel technologies for mitigating the effects of contamination on fuel cell performance.
7.0 Outreach	• 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**



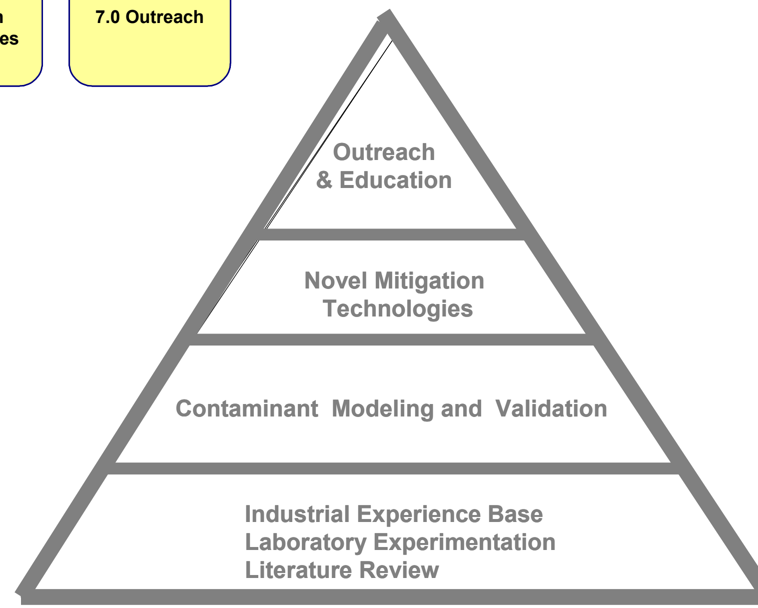
Project Work Plan/Deliverables



<u>Deliverables</u>

- •Validated Impurity Models
- •New Mitigation Technologies

Outreach: Papers, Workshops, Technical Interchange, Etc.

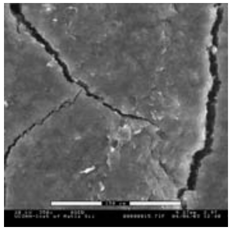


Roles of Participants

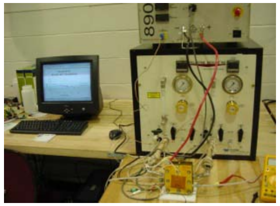
The Universtiy of Connecticut
Connecticut Global Fuel Cell Center
Program Lead

United Technologies Hamilton Sundstrand	The University of Connecticut Institute for Materials Science	The University of Connecticut School of Engineering	FuelCell Energy Inc.
Advise on Fate of Contaminants	Gas Analyses/Surface Studies	Contaminant Testing Modeling & Mitigation Strategies	Contaminant Identification Fuel Cell Testing

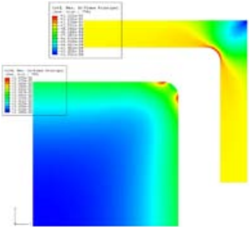
United Technologies Hamilton Sundstrand
- **Electrolysis Contaminant Experience**
- **Prior Contaminant Studies**



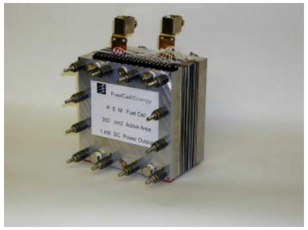
The University of Connecticut Institute for Materials Science
- **Surface Studies/Equipment**
- **Gas Purity Analyses**



The University of Connecticut School of Engineering
- **Fuel Cell Testing**
- **Modeling/Transport Expertise**
- **Industry Relationships**



FuelCell Energy Inc.
- **Gas Contaminant Experience**
- **Fuel Cell Test Experience**



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

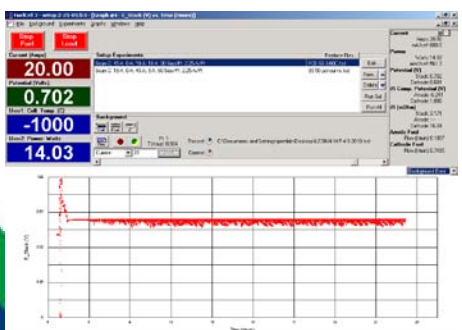
Specification for Draft CD
- •NMHC/Total HC's – 2 ppm
- •Formaldehyde – 10 ppb
- •Formic Acid – 0.2 ppm
- •Total Halogenates – 50 ppb

- •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

Hardware and Test Definition

Cell Hardware Definition

Parameter	Early	Intermediate	Recent
Membrane	Nafion® 212	Nafion® 212	PRIMEA®
Loading (mg/cm^2) (A/C)	0.4 / 0.2	0.4 / 0.4	0.1 / 0.4
MEA OEM	Ion Power	Ion Power	Gore
GDL	SGL 10 BB	SGL 10 BB	SGL 25 BC
Active Area (cm^2)	25	25	25

Test Condition Definition

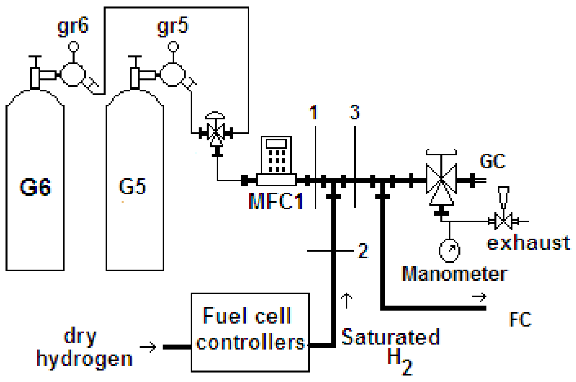
Parameter	Early	Intermediate	Recent
Temperature (° C) (A/Cell/C)	80 / 80 / 80	80 / 80 / 73	80 / 73 / 49
Humidity (%) (A/C)	100 / 100	100 / 75	75 / 25
Stoich. (A/C)	1.3 / 2.0	2.0 / 2.0	1.2 / 2.0
Flow Rate (A/C)	Commensurate with current density		
Pressure (psig) (A/C)	25 / 25	25 / 25	7 / 7

Mixing and Means of Validating Concentrations

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

Mixing of H_2 and high vapor pressure oxygenated contaminants

Certified mixtures H_2 and the contaminant G6 and G5

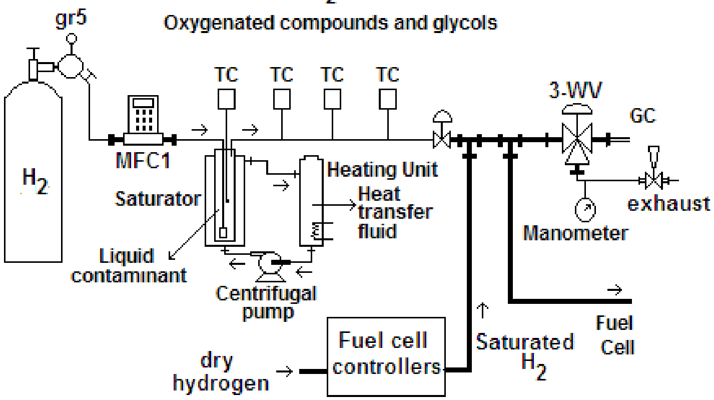


Non-Gaseous Impurities
e.g., Formic Acid, Acetic Acid, Ethanol, Methanol, Propylene Glycol, Ethylene Glycol

Mixing of H_2 and Non-gaseous contaminant

Saturation of a flow of H_2 with a liquid contaminant

Oxygenated compounds and glycols



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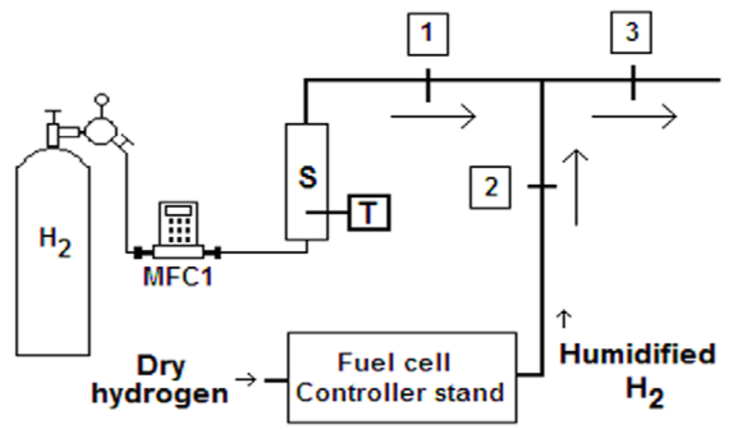
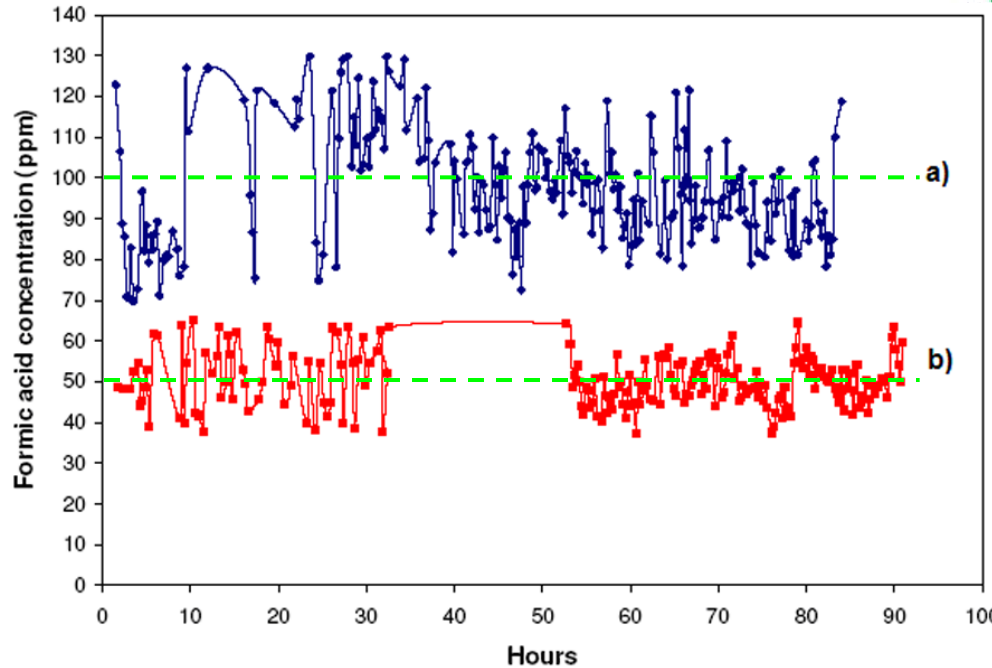
Impurity Mixing and Verification



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 H_2 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*.

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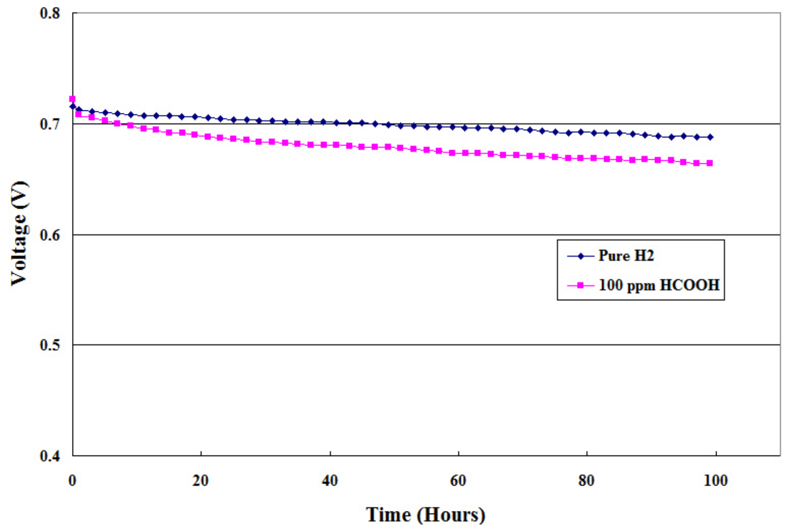
Formic Acid (HCOOH) – 100 ppm

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 H_2;
3) Recondition the fuel cell when preparing the impurity mixture;
4) Introduce 100 ppm HCOOH and operate for 100 hrs.



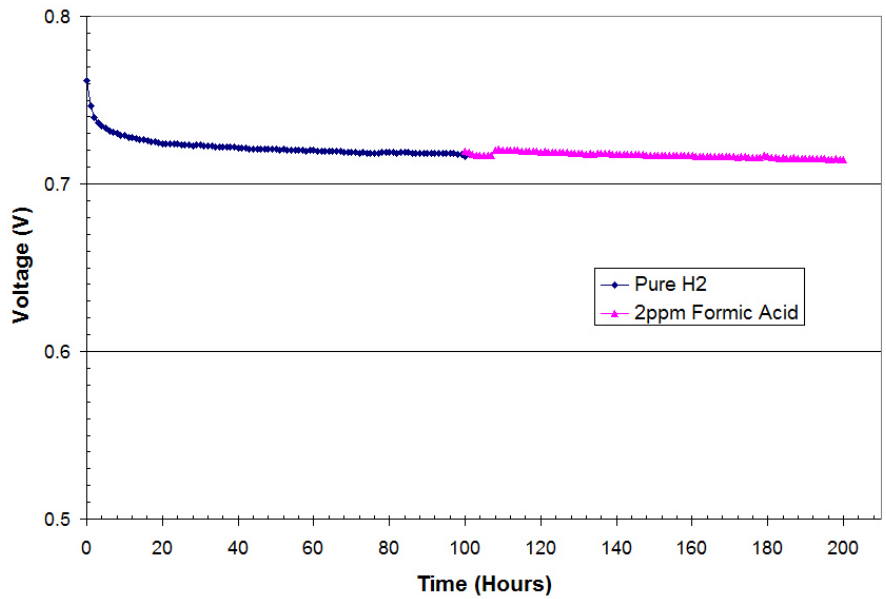
CV and other tests show that HCOOH can cross the membrane and contaminate the cathode. Full recovery of the peaks is not observed; however this may be caused by a combination of coarsening or dissolution of Pt, and more permanent effects of HCOOH contamination.

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	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 H_2;
3) Introduce 2 ppm HCOOH and operate for 100 hrs.

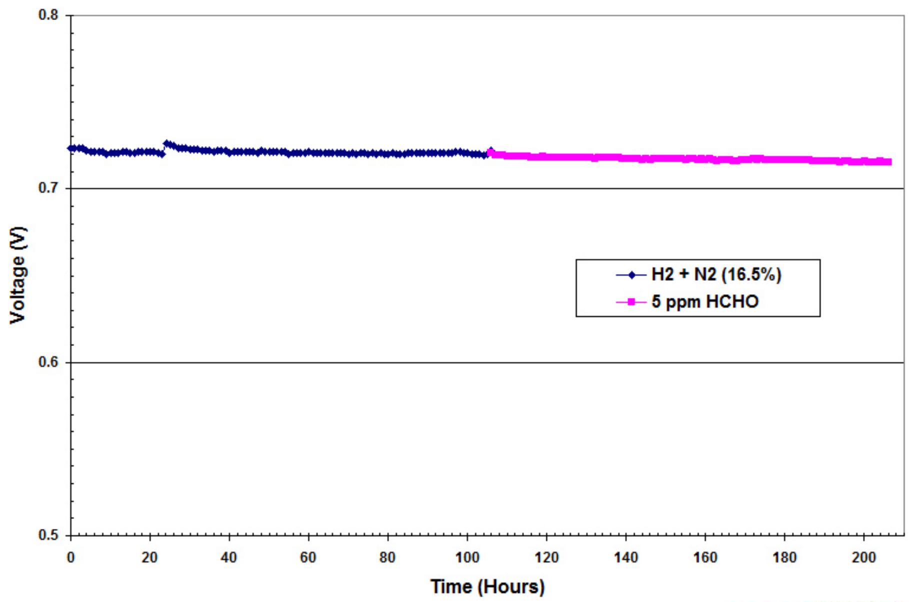


Formaldehyde (HCHO) – 5 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm²)	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 (cm²)**	**Pt Loading (mg/cm²) 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 H_2;
3) Introduce 5 ppm HCHO and operate for 100 hrs.



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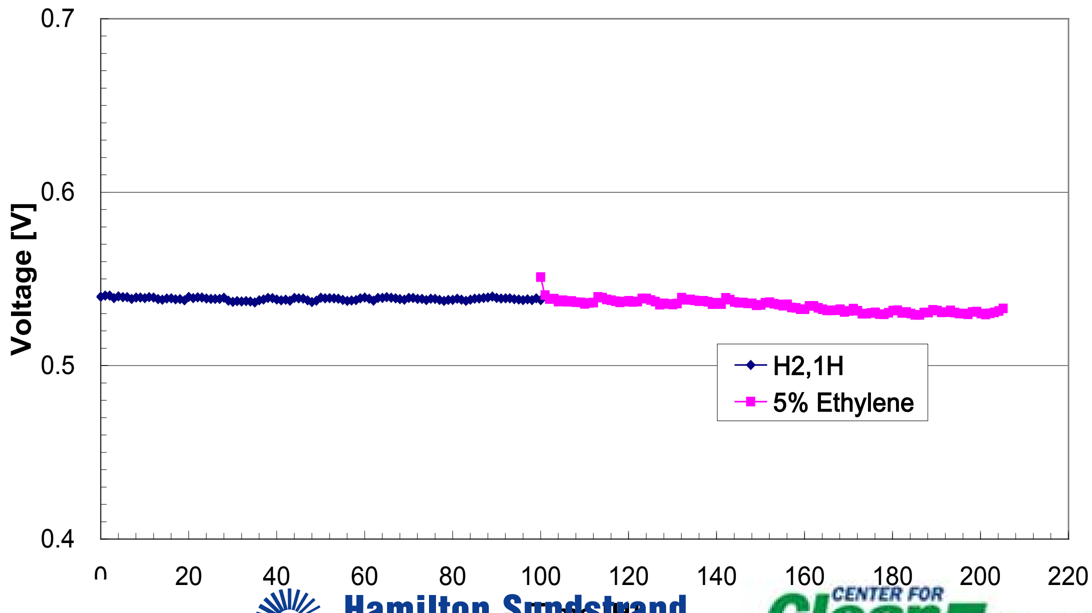
Ethylene (C_2H_4) - 5%

Operating Conditions	Cell #	Impurity	Current Density (mA/cm²)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	57	5% C_2H_4	1000	75/25	80	7PSI	1.2/2.0
MEA	**Vendor**	**Membrane**	**Active Area (cm²)**	**Pt Loading (mg/cm²) 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 H_2;
3) Introduce 5% C_2H_4 and operate for 100 hrs;



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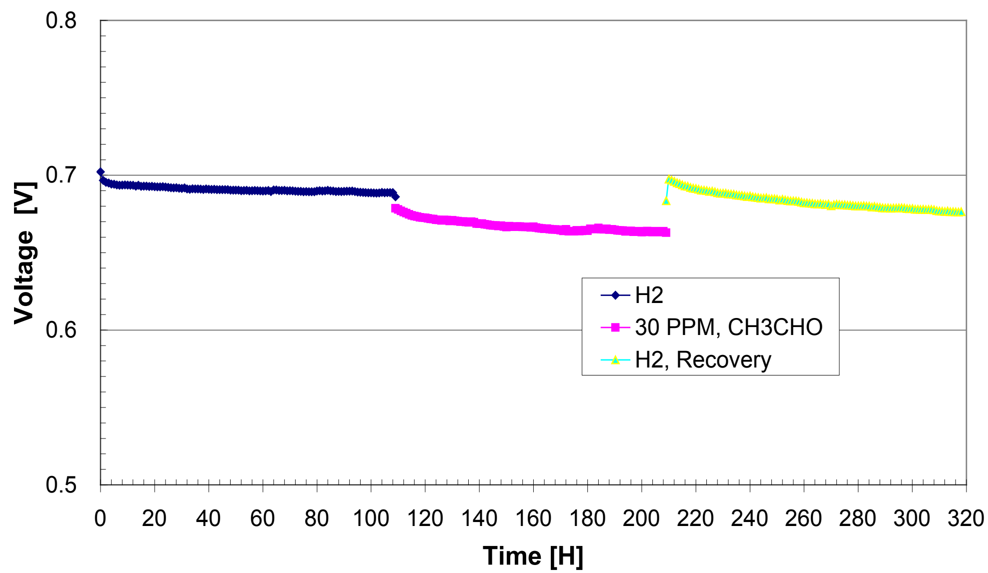
Acetaldehyde (CH_3CHO) – 30 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm^2)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	57	30 ppm CH_3CHO	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 H_2;
3) Introduce 30 ppm CH_3CHO and run for 100 hrs;
4) Remove 30 ppm CH_3CHO and switch back to H2 for 100 hrs for recovery test.



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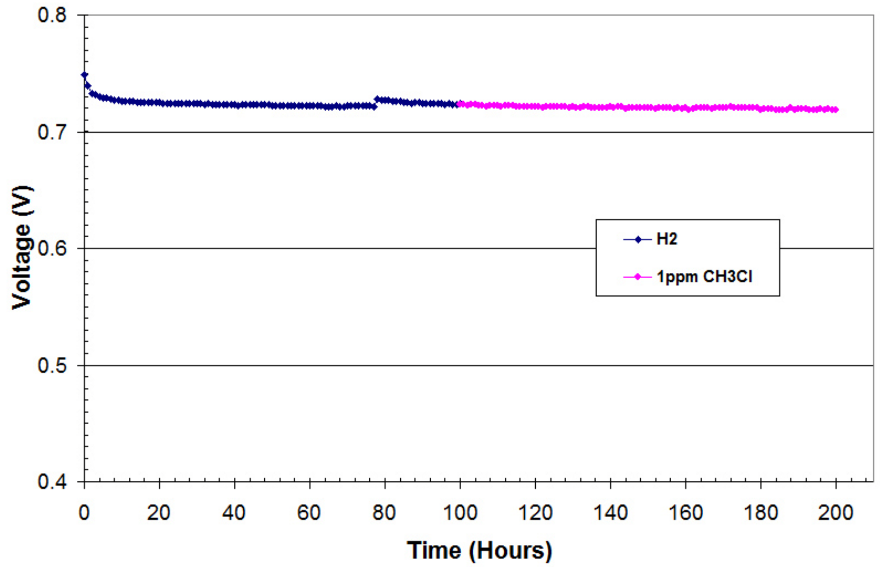
Methyl Chloride (CH_3Cl) – 1 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm^2)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	49	1 ppm CH_3Cl	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 H_2;
3) Introduce 1 ppm CH_3Cl and operate for 100 hrs.



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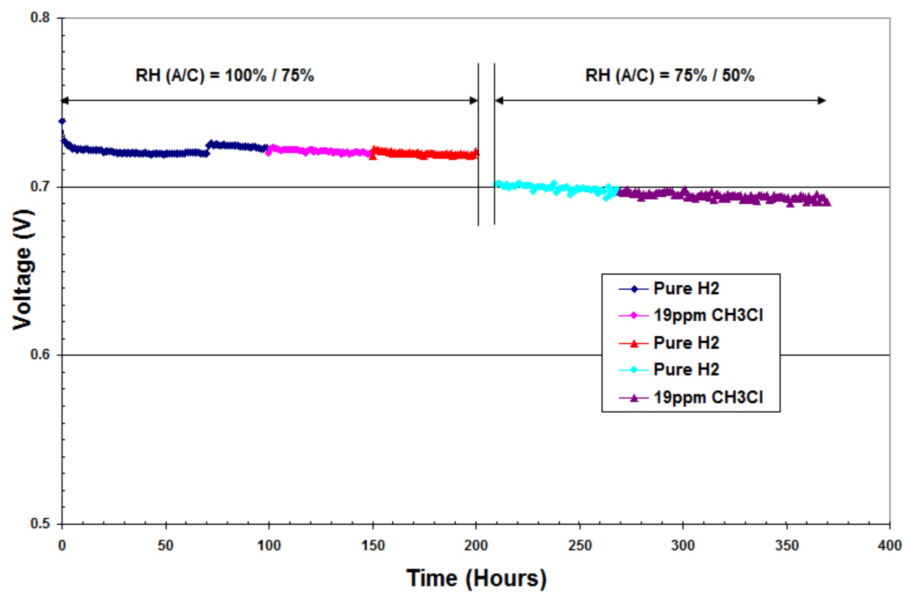
Methyl Chloride (CH_3Cl) – 19 ppm

Operating Conditions	Cell #	Impurity	Current Density (mA/cm^2)	RH (%) A/C	Cell Temp ° C	Back Pressure	Stoich. A/C
	52	19 ppm CH_3Cl	800	See the figure	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) Condition the fuel cell;
2) Operate the fuel cell for 100 hrs with pure H_2;
3) Introduce 19 ppm CH_3Cl and run for 50 hrs;
4) Remove CH_3Cl, switch to pure H_2 and run another 50 hrs;
5) Change RH and run for 75 hrs with pure H_2.
6) Introduce 19 ppm CH_3Cl 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*

Gaps in Testing/Data

- Limited Test Conditions/Data Sets for Many of the Tests
- No Long-Term Tests Conducted – Aged Cells
- No Multi-Contaminant Tests Conducted
- Transients Not Examined (e.g., Automotive Load Cycles/Start-Stop)
- Limited Data Set for Halogenates
- Ethylene Data Collected on Poor Performing Cell
- What Happens With Recycle?

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

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

Formic Acid Summary

- Effects of HCOOH contamination on PEFC performance are 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 O_2 is present and potentials are high enough.
- Exposure to pure H_2 recovers part of the H_2 desorption peak.
  - No further recovery after first 20 hours.
  - *Catalyst degradation (unrelated to HCOOH)* + any permanent effect of HCOOH
- Separate the contribution of the anode and the cathode is critical to further understand the contamination process.
  - Further characterization is underway

Formic Acid Mechanistic Studies

Example: Chemical Analysis

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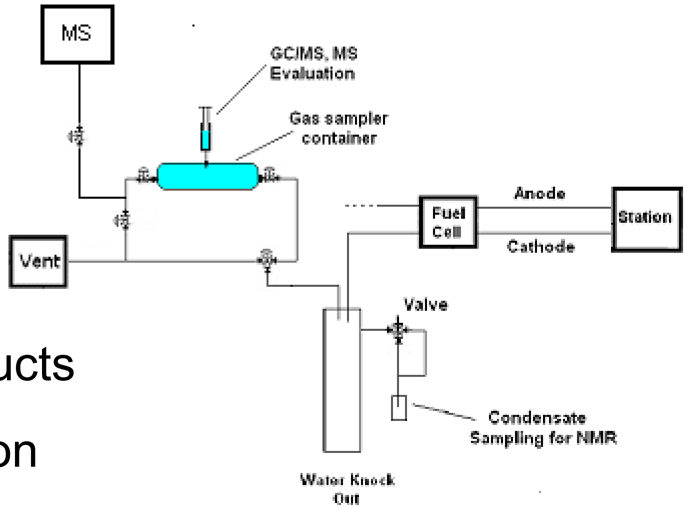
Formic Acid Contamination Pathways



Schematic-Experimental Setup for HCOOH, CO, CO_2 Evaluation (Cathode and/or Anode Side)

GC/MS, FT-IR, NMR, GC, Analysis

GC/MS-MS

- Identification and quantification of possible byproducts
- Monitoring gas evolution during continuous operation

FT-IR

- Identification of functional groups of gaseous streams

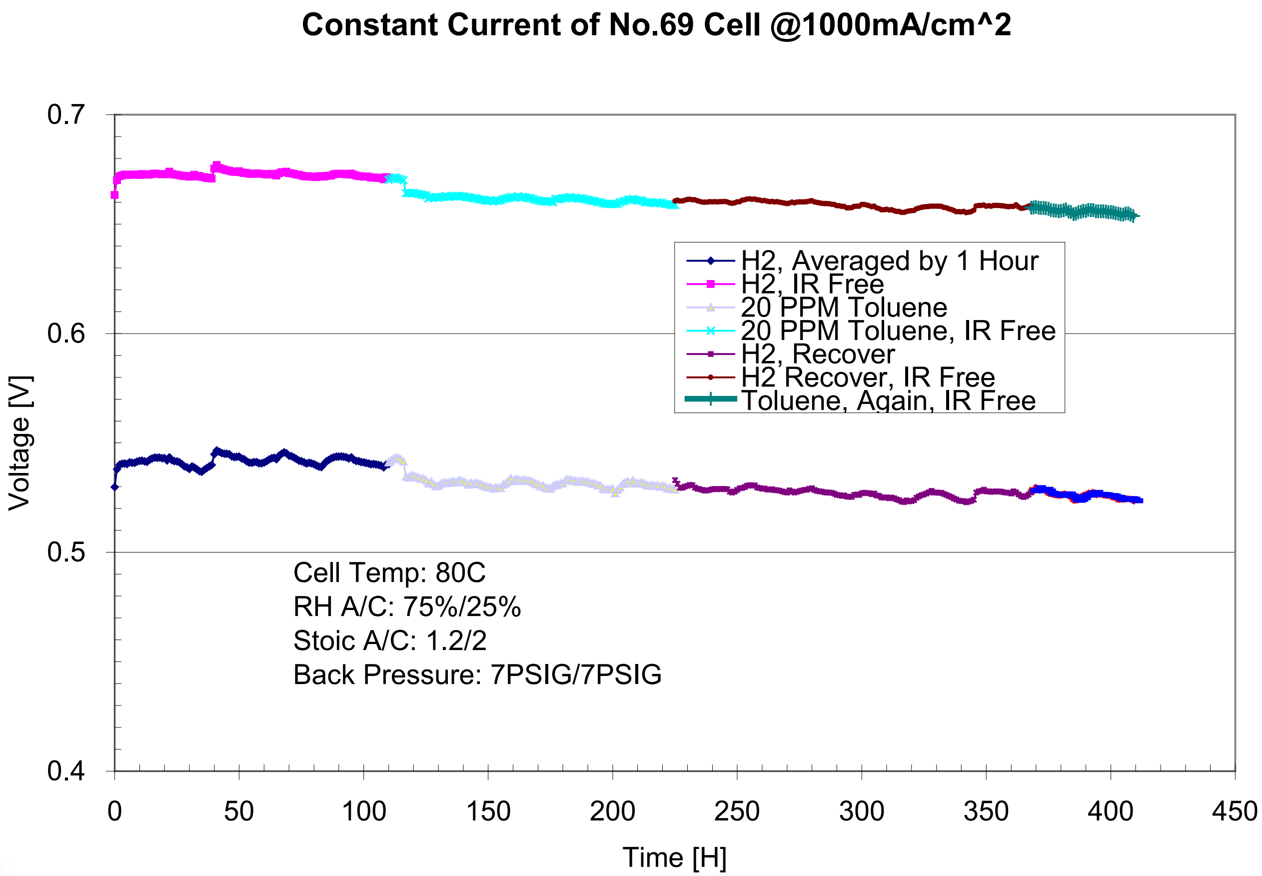
Nuclear Magnetic Resonance, NMR

- Identify different organic compounds in small amounts of liquid samples

Gas Chromatography, GC

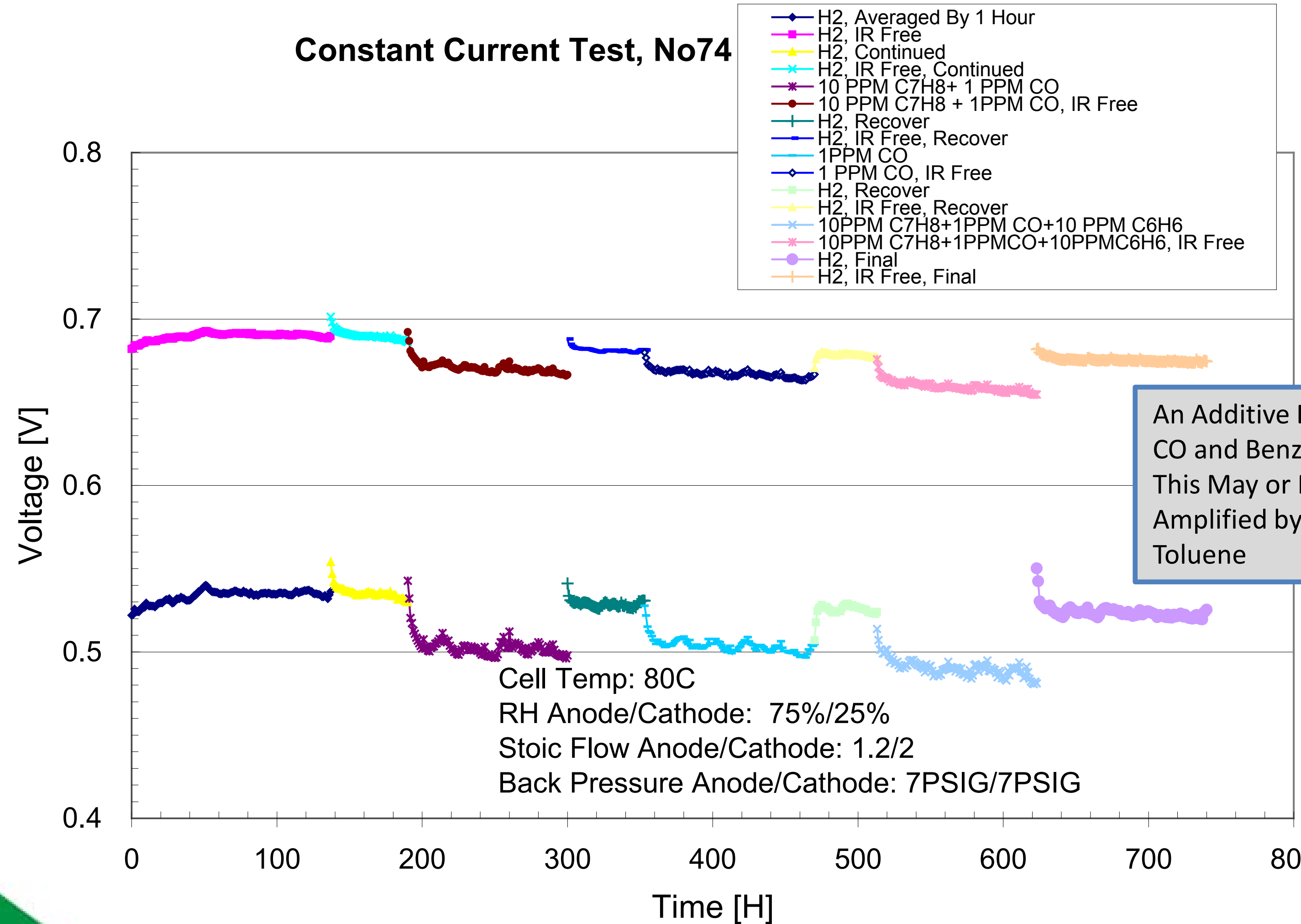
- Identification, quantification liquid compounds

Studies of Aromatics



Perhaps a Very Small Irrecoverable Performance Impact Is Noted

Mixtures - Aromatics + CO



An Additive Effect of CO and Benzene is Noted – This May or May Not Be Amplified by the Presence of Toluene

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FuelCell Energy

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Recent Test Summary

Test ID: C2E2
MEA: GORE, , **Pt Loading A/C**: 0.1/0.4 mgPt/ cm^2
Cell Hardware: Fuel Cell Technologies Inc.
Active Area: 25 cm^2 **Cell Temperature:** 80° C
Test Station: Teledyne MEDUSA®

Cell #	Lot #	Current Density	RH (A/C)	Flow Rates A/C	Back Pressure A/C	Contaminant	Results
51	GORE	800 mA/cm^2	100%/75%	279/664 sccm	25/25 PSIG	100PPM HCOOH	Degradation
52	GORE	1000mA/cm^2	75%/25%	210/883 sccm	7/7 PSIG	19PPM CH_3CL	No Degradation
54	GORE	800 mA/cm^2	75%/25%	210/883 sccm	7/7 PSIG	5PPM HCHO	No Degradation
57	GORE	1000 mA/cm^2	75%/25%	210/883 sccm	7/7 PSIG	5% C_2H_4	No Degradation
64	GORE	1000 mA/cm^2	75%/25%	210/883 sccm	7/7 PSIG	1% C_2H_4	No Degradation
66	GORE	800 mA/cm^2	100%/75%	279/664 sccm	25/25 PSIG	30PPM CH_3CHO	No Degradation
69	GORE	1000 mA/cm^2	75%/25%	210/883 sccm	7/7 PSIG	20PPM C_7H_8	Small Degradation?
71	GORE	1000 mA/cm^2	75%/25%	210/883 sccm	7/7 PSIG	30PPM CH_3CHO	No Degradation
74	GORE	1000 mA/cm^2	75%/25%	210/883 sccm	7/7 PSIG	10PPM C_7H_8, 1 PPM CO, 10 PPM C_6H_6	Degradation Due to CO Amplified By Presence of Benzene

Testing of Fuel Quality Specifications

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- Long term (stability) testing of ISO Draft Fuel Quality Standards
  - Individual impurity concentrations found to be acceptable
  - Investigating compound/additive effects

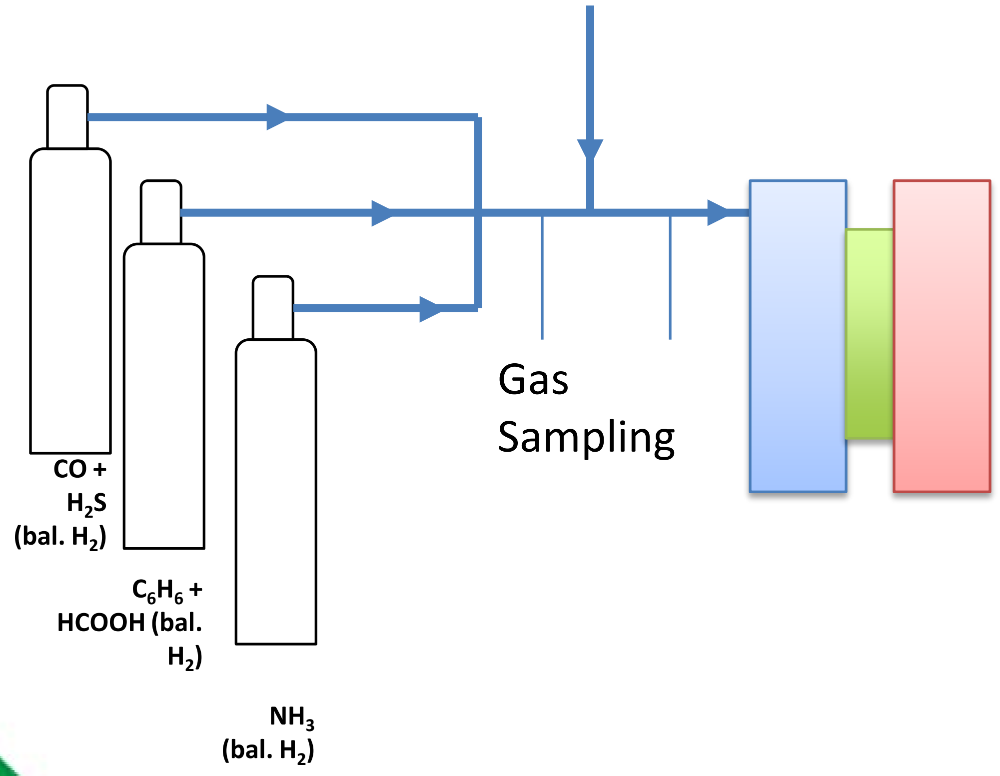
Surrogate H_2 fuel tested:

Component	UConn Fuel
Hydrogen	99.97+
Sulfur (as H_2S)/total S	4 ppb
CO	0.2 ppm
NH_3	0.1 ppm
Total HCs (C_6H_6)	2 ppm
Formic acid	.2 ppm

Specifications for Committee Draft (CD) ISO 14687-2

Component	ISO/SAE Specs
Hydrogen	99.97+
Sulfur (as H_2S)/total S	4 ppb
CO	0.2 ppm
CO_2	2 ppm
NH_3	0.1 ppm
NMHC/Total HCs	2 ppm
Particulates	1 µg/L (10 µm size)
Total non H_2 gases	<.03% (300 ppm)
Water	5 ppm
Oxygen	5 ppm
He	300 ppm
N_2 + Ar	100 ppm
Formaldehyde	10 ppb
Formic acid	0.2 ppm
Total halogenates	50 ppb

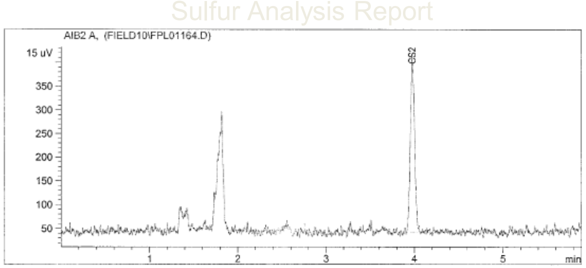
Impurity Cocktail Test Setup



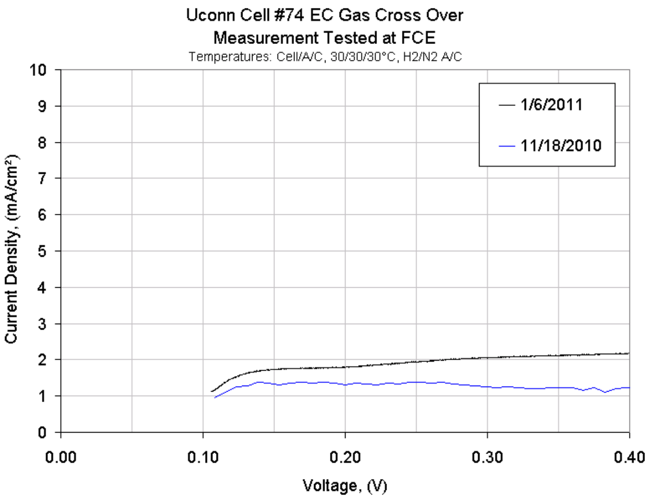
- Gas Composition Used as an Ersatz for Fuel Quality Specification
- Gas Analyses Conducted at FCE Down to 4 ppb of H_2S
  - SulfInert® Canisters
  - SKC 245-28 Sample Bags

Durability Testing

- Impurity Cocktail Test
  - Carbon Monoxide analysis at ppb level
  - Sulfur analysis (H_2S and all other sulfur species) at ppb level
  - Provided special sample cylinders for H_2S analysis (with SulfInert coating)



- Tested three cells at FCE for up to 2,500 hours at accelerated test condi of 1 A/cm^2, to compare performance and evaluate potential long-term effect of contaminants.



Cell characteristics before/after

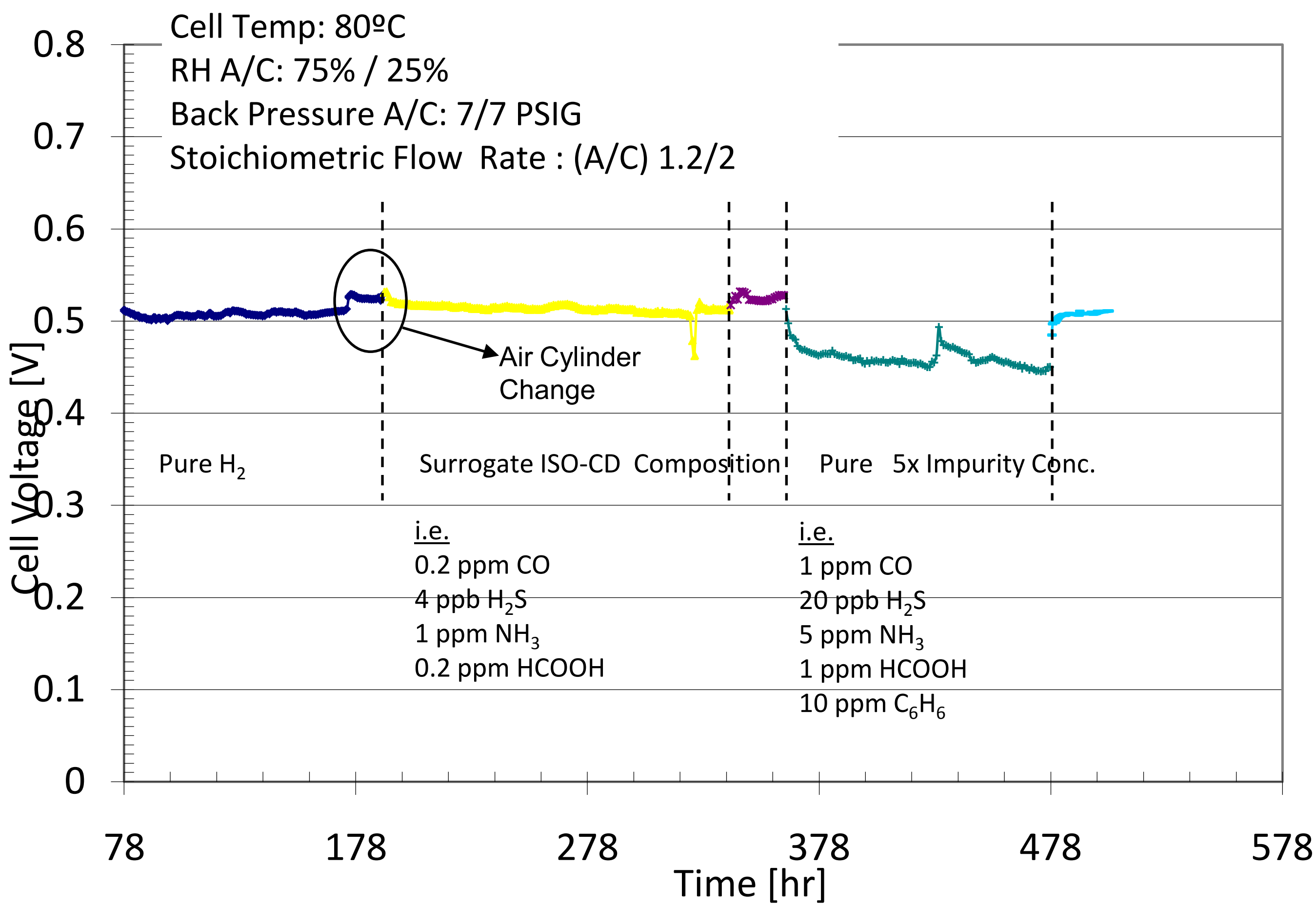
~700 hrs of testing at FCE

DOE74 Single Cell Diagnostic Test Table

	BOL at UConn	EOL at UConn	BOL at FCE	EOL at FCE
H_2 Cross-over (mA/cm^2)	1.1	1.2	1.3	2.1
Anode Surface Area (m^2/g)	56.48	42.57	Jonathan to fill in	Jonathan to fill in
Cathode Surface Area (m^2/g)	65.69	55.85	Jonathan to fill in	Jonathan to fill in

- Outreach: JHQTF, DOE Impurities meetings and program reviews

Impurity Cocktail Testing



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FuelCell Energy

Hamilton Sundstrand A United Technologies Company

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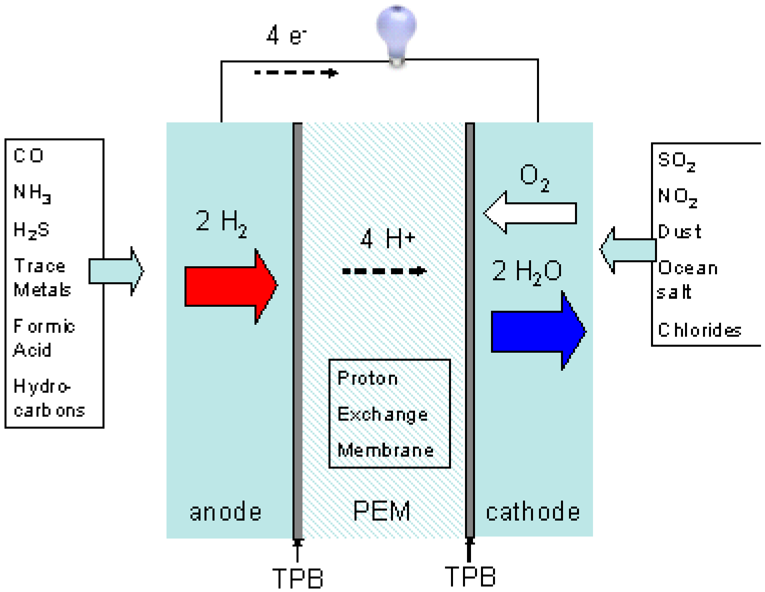
Mitigation Techniques

Three Main Categories

1. Improved Materials
2. Change in Operating Conditions (T, CD, Stoich, Recycle)
3. Processes for Cleaning Up (External or Internal)

Issues/Concerns

- Many Impurities Have Been Studied Individually – Mitigation Strategy for Individual Impurity May Not be as Effective in Presence of Other Impurities
- Cocktail May Change Poisoning Mechanism/Model



Focus to Address
Formic Acid and Relate to Other Organics

Collaborations

- Collaborated With Hydrogen Quality Working Group on Test Methods, Results, Hardware Configurations, Modeling, Etc.
- Collaboration With ISO Working Group on H_2 Quality Standards
- Student Collaboration With Dr. Karren More at ORNL on SEM/TEM Characterization of MEAs
- Continuous Exchange of Data/Personnel/Hardware Amongst our Team

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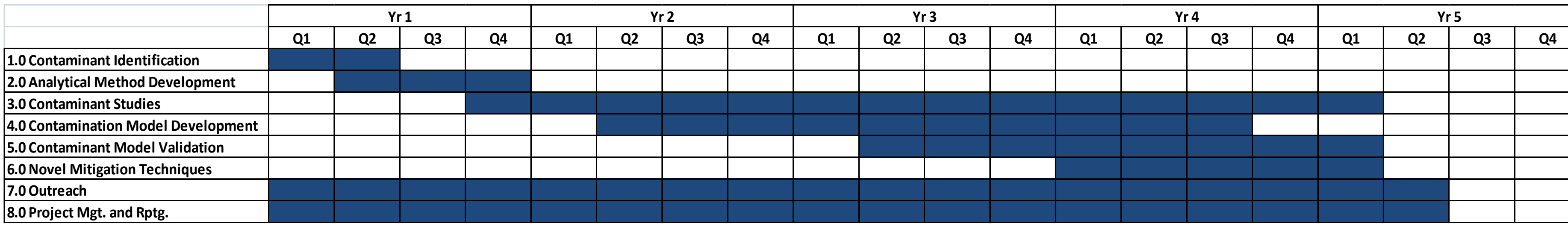
Future Work



Future Activity

- **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	Y24Q3
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

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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