Intermediate Temperature Proton Conducting Fuel Cells

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Project Objectives

- Develop a proton conducting fuel cell that operates at 200 – 250 ° C
  - **Mid-Temp and Low Relative Humidity**
    - **Simplification of Balance of Plant**
    - **Reduction of significant portions of the Balance of Plant cost**
  - **Benefits**
    - **fuel flexibility**
    - **potential use of non-Pt catalyts**
    - **higher quality waste heat**

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Project Team

Team Member	Project Role
Ceramatec, Inc.	Prime
Location: Salt Lake City, UT Focus: Ion conducting ceramics Electrochemistry Advanced Materials	Materials Scale up Stack Testing
Los Alamos National Lab.	National Lab Partner
Location: Los Alamos, NM	Materials Development, Synthesis, & Characterization MEA optimization and Testing
Nissan Technical Center North America	Commercialization Partner
Location: Farmington Hills, MI	Cell validation System Modeling Requirement Definition

Project Target

- Fuel Cell Testing using Tin Pyrophosphate based membrane
  - Demonstration of 25 – 50 cm^2 fuel cell
  - Initial target: 0.5 W/cm^2 at 200° – 250° C ,
  - relative humidity < 5%
  - Low Pt loading
  - **Target revised to 0.8 W/cm^2**

FCEV System-Level Modeling

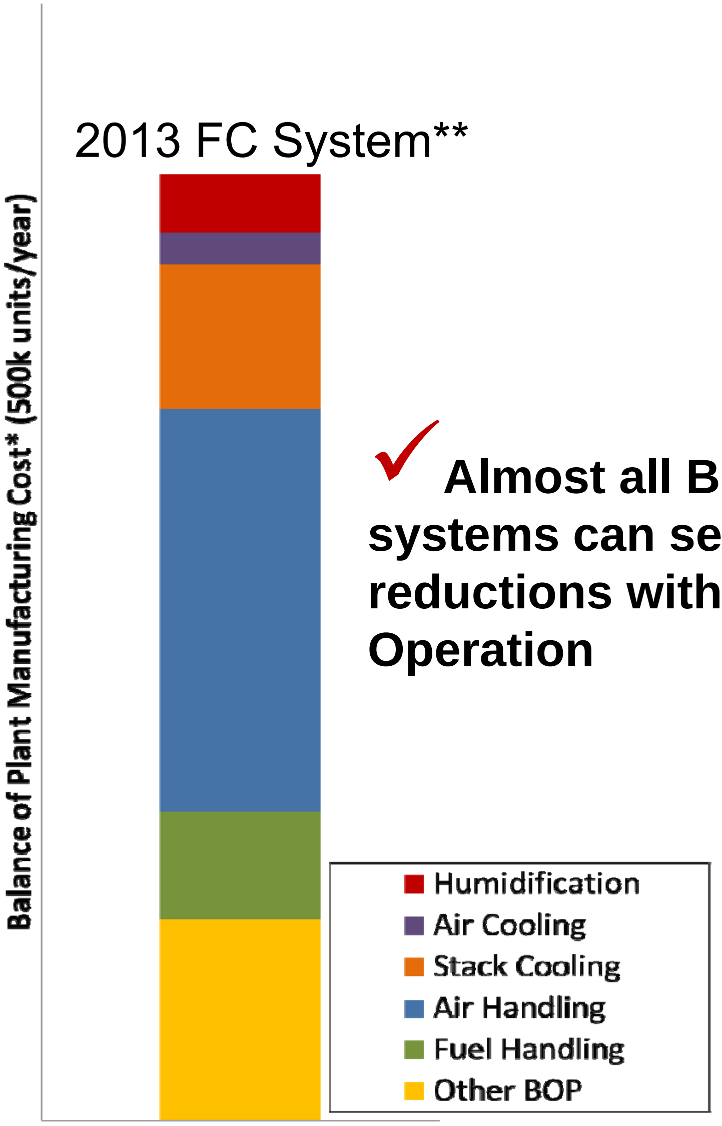
Mid-Temp FCEV System Cost Estimation

Major Cost Saving component/system *

1. Air Handling
   - ✓ Compressor
   - ✓ Expander

2. Water/ Heat Recovery
   - ✓ Humidifier
   - ✓ Radiator
   - ✓ Coolant Loop

* Compared to conventional FC system



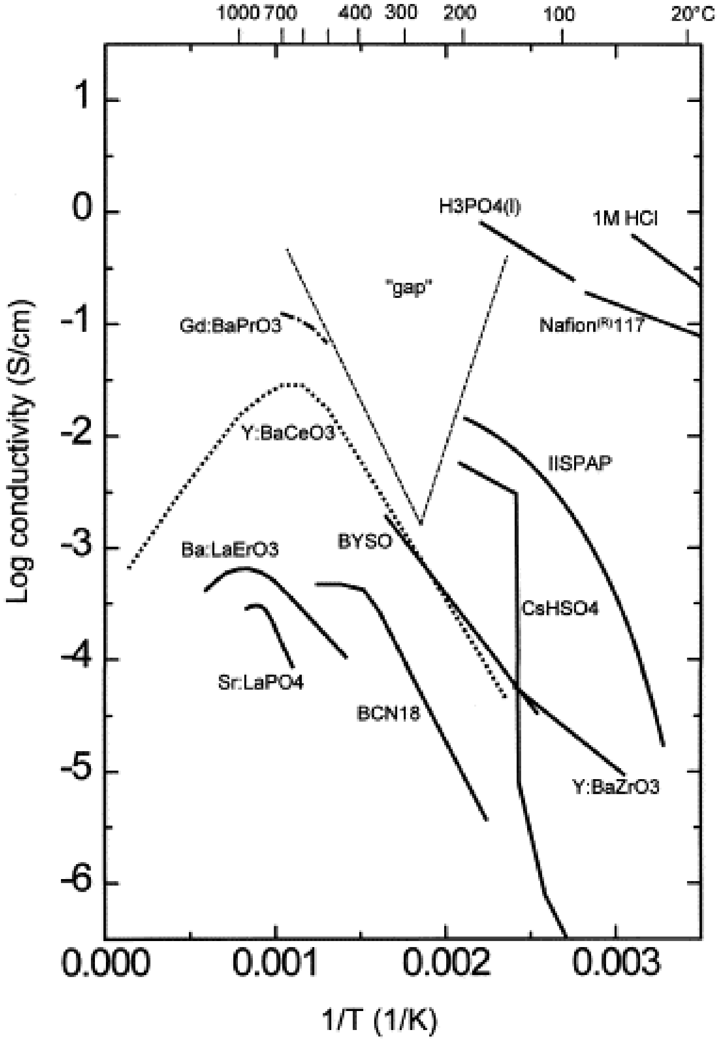
✓ **Almost all BOP sub-systems can see cost reductions with Mid-Temp Operation**

** James Brian D, " Fuel Cell Transportation Cost analysis Prelim Results" DOE Annual Review, May 2013

PROTON CONDUCTOR SELECTION

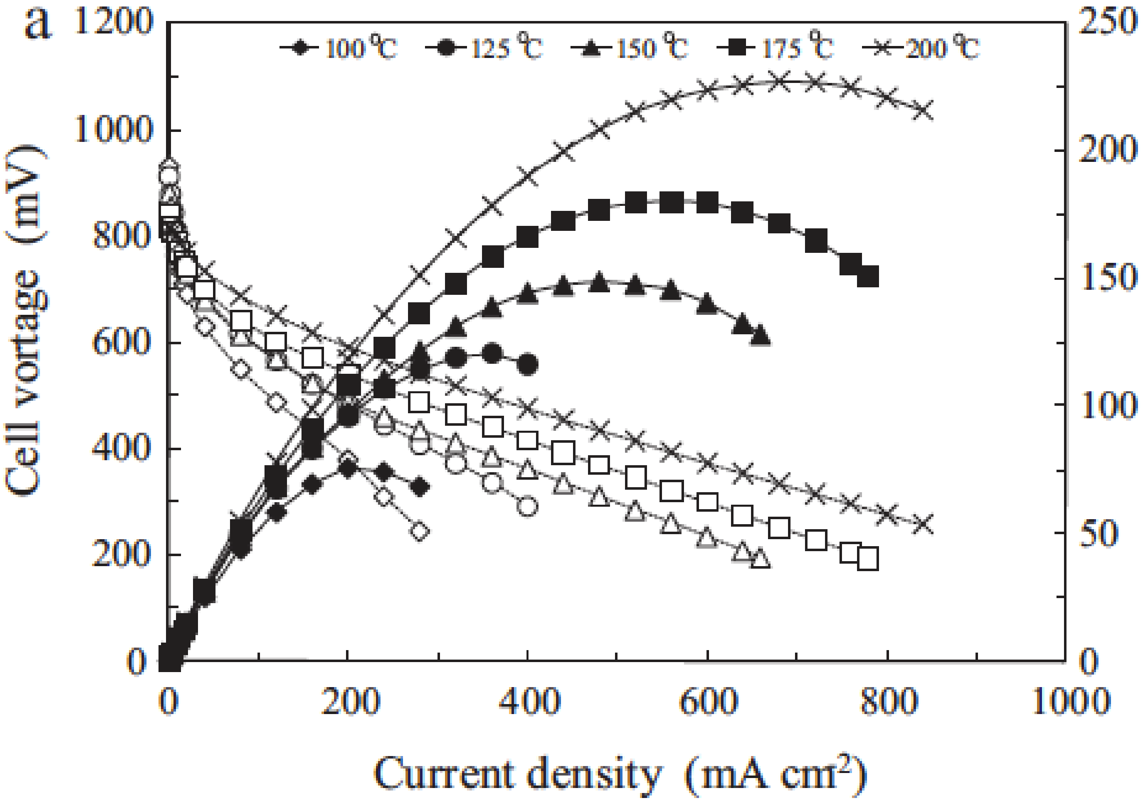
Intermediate temperature proton conducting electrolytes

- Each type of Fuel Cell has an operating temperature regime limited by the employed electrolyte
  - SOFC (700-1000˚C)
  - DMFC (50-120˚)
  - PAFC (150-200˚C)
  - PEMFC (50-100˚C)
- High temperature operation favors kinetics and alleviates water management difficulties
- Low temperature operation favors reduced assembly cost and improved durability
- Limited electrolyte materials available to bridge technologies in intermediate temperature range (100-400˚C)



Norby *SSI*, **124**, 1999.

Prior Publication – Indium Tin Pyrophosphate (ITPP Fuel Cells and Composite Membranes)



Y.C. Jin et al. / Journal of Power Sources 196 (2011) 4905–4910

<u>Project Goals</u>

- ✓ 800 mW/cm^2
- ✓ Fuel Cell durability test up to 1,000 hrs

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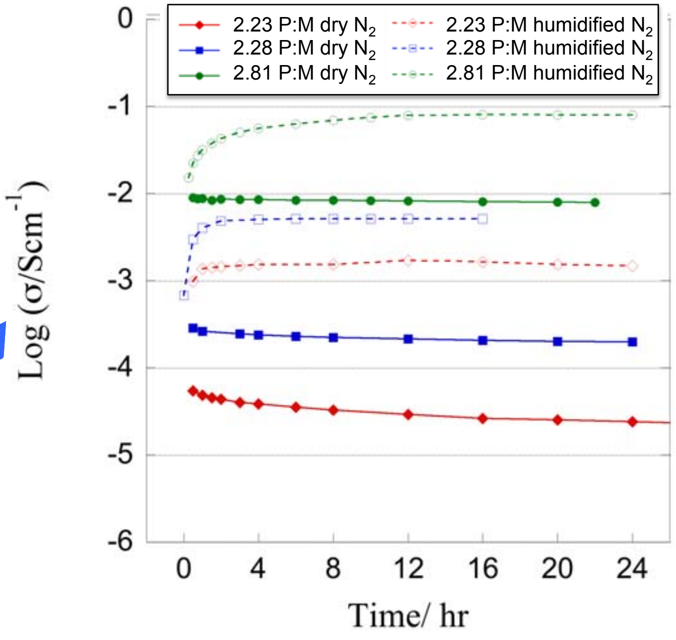
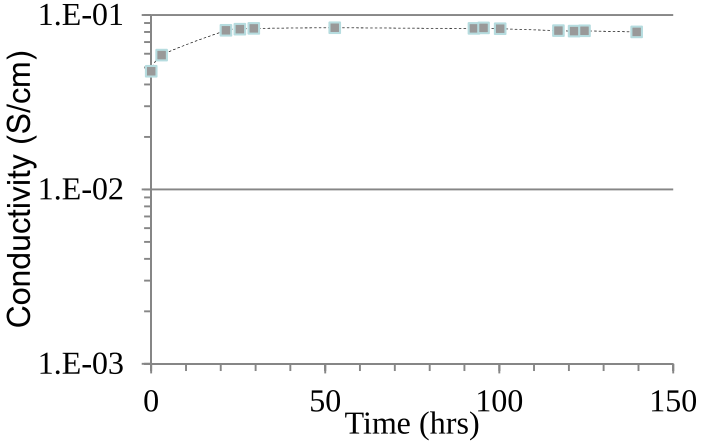
Conductivity of $In_{0.1}Sn_{0.9}P_2O_7$ with varying P:M

- High proton conductivity at Intermediate temp. in anhydrous condition reported for In-doped Sn pyrophosphates
- Inconsistent reproducibility in conductivity reported

Composition optimization for reproducible, high conductivity - LANL



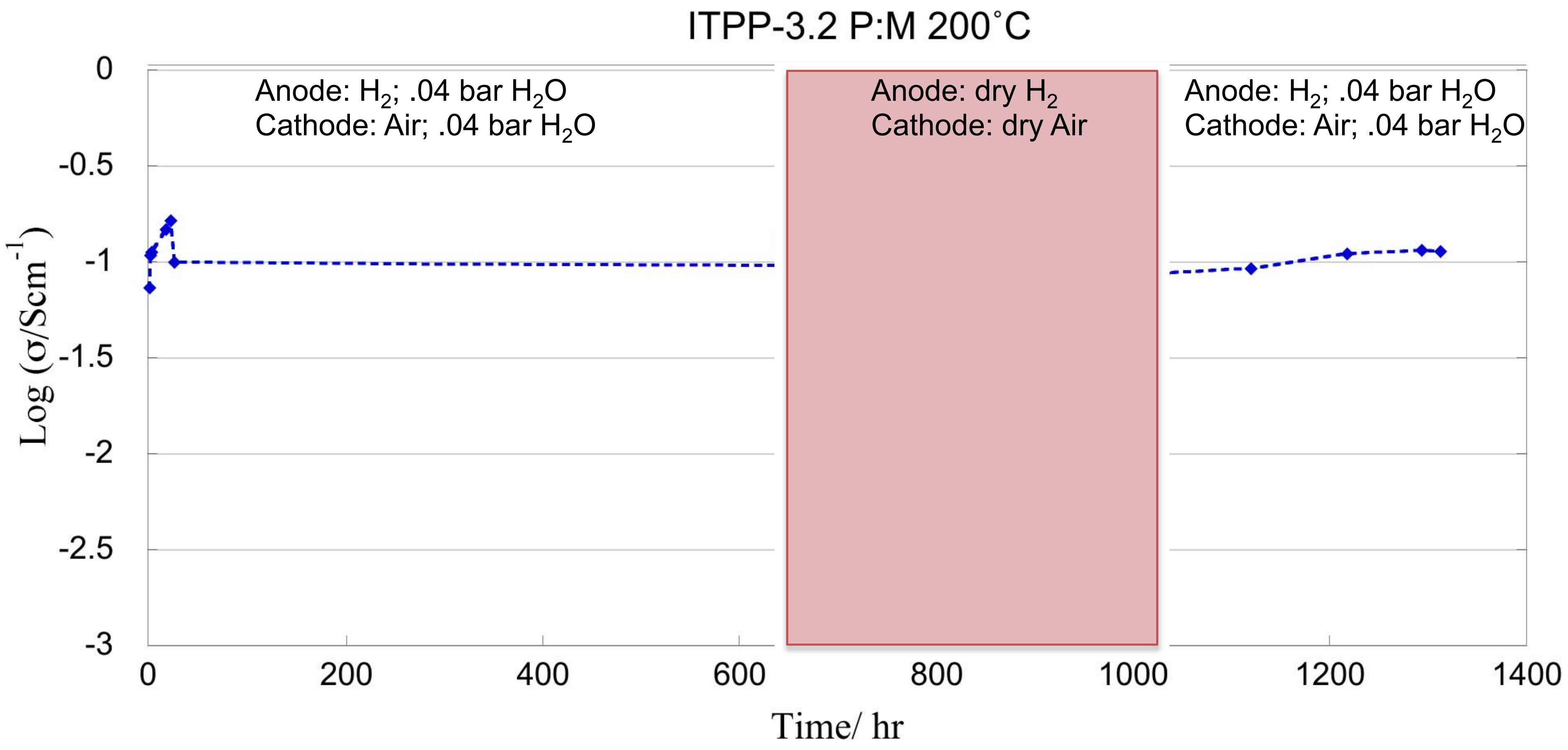
Batch scale up and high conductivity - Ceramatec



- ✓ Conductivity of nominal material (2.02 P:M) is *negligible* at 250˚C.
- ✓ P/M > 3; $\sigma \approx 10^{-1}$ Scm^{-1}

Kreller, C.R.; Wilson, M.S.; Mukundan, R.; Brosha, E.L.; Garzon, F.H. *ECS Electrochemistry Letters* 2013; 2(9): F61-F63.

Stability of Conductivity



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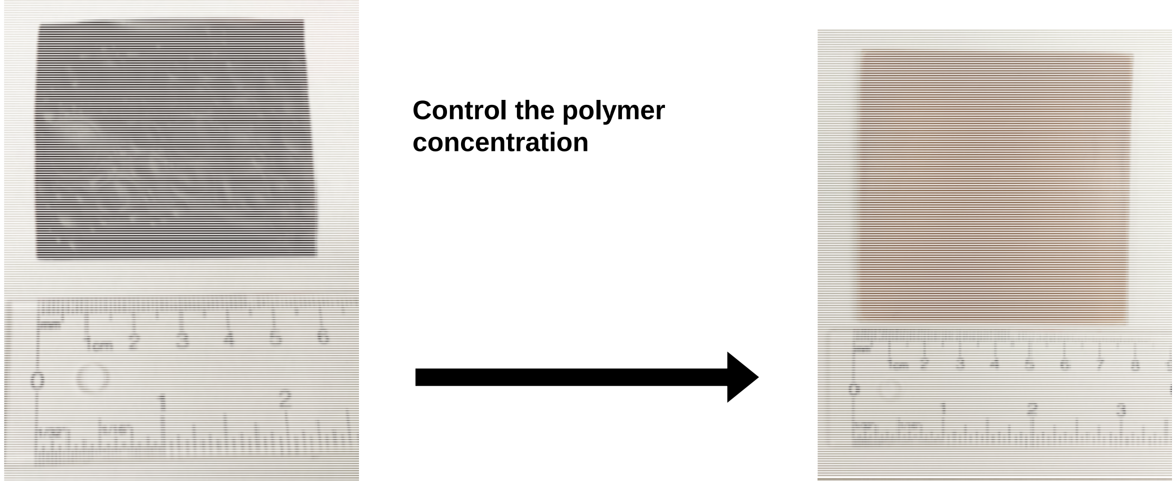
MEMBRANE FABRICATION

Large Area Membrane Fabrication (LANL)

Material difficult to sinter and retain high P/M

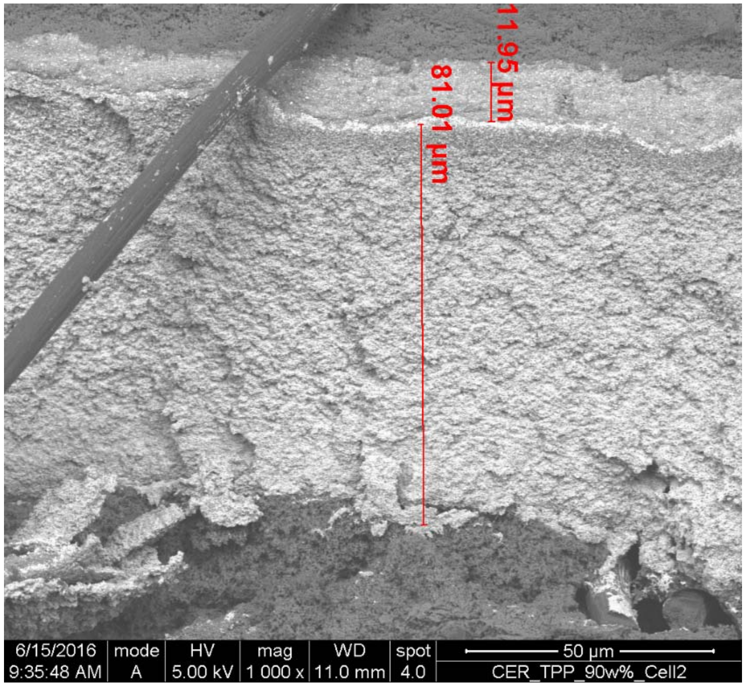
Made a polymer-phosphate composite



Control the polymer concentration

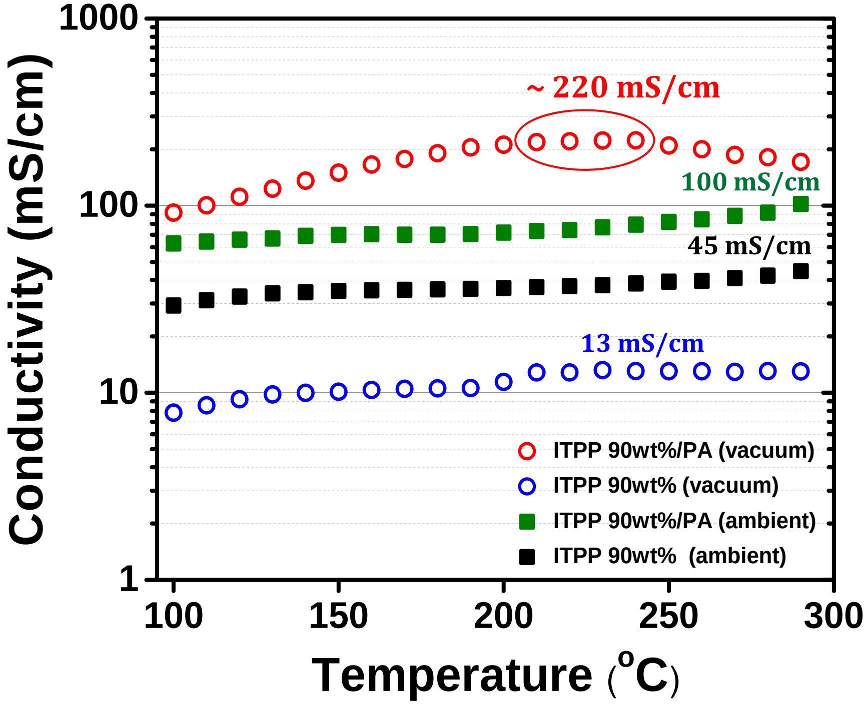
3 X 3 in^2 membranes
ITPP content: 75 %
Thickness: 50 μm ± 2

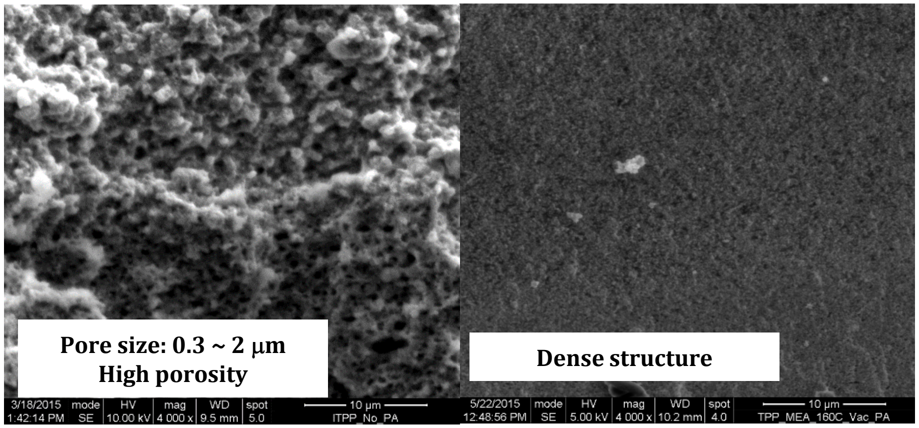
Ceramatec Membrane and MEA



- Dense 80 µm membrane
- High OCV ~ 0.96 V

Enhanced Proton Conductivity of Dense Composite Membrane




(1) Higher Porosity

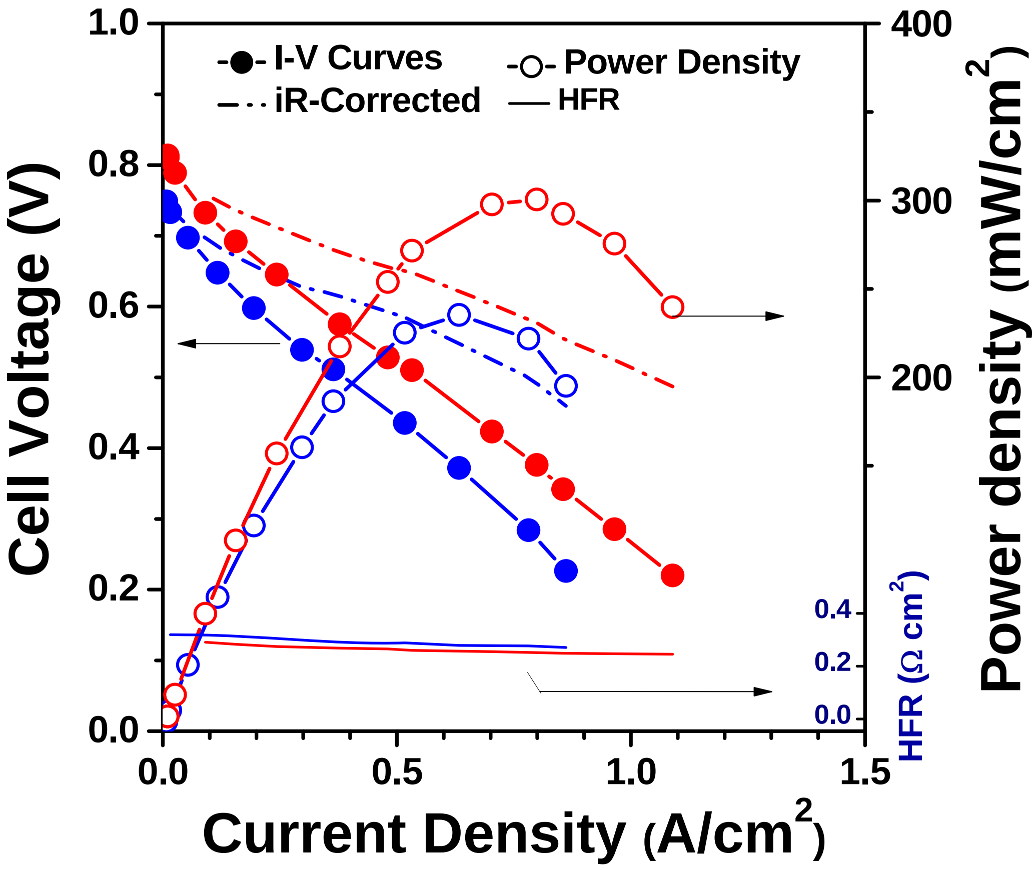
(2) Higher Density

- ➢ Composite membranes cast process improvement for dense structure and to maintain the desired ductility.

- ➢ Membrane with higher density improved the proton conductivity of TPP/PF composite membrane.
  - ➢ Max. proton conductivity; ~220 mS/cm in the range of 210 – 240 °C

MEA TESTING

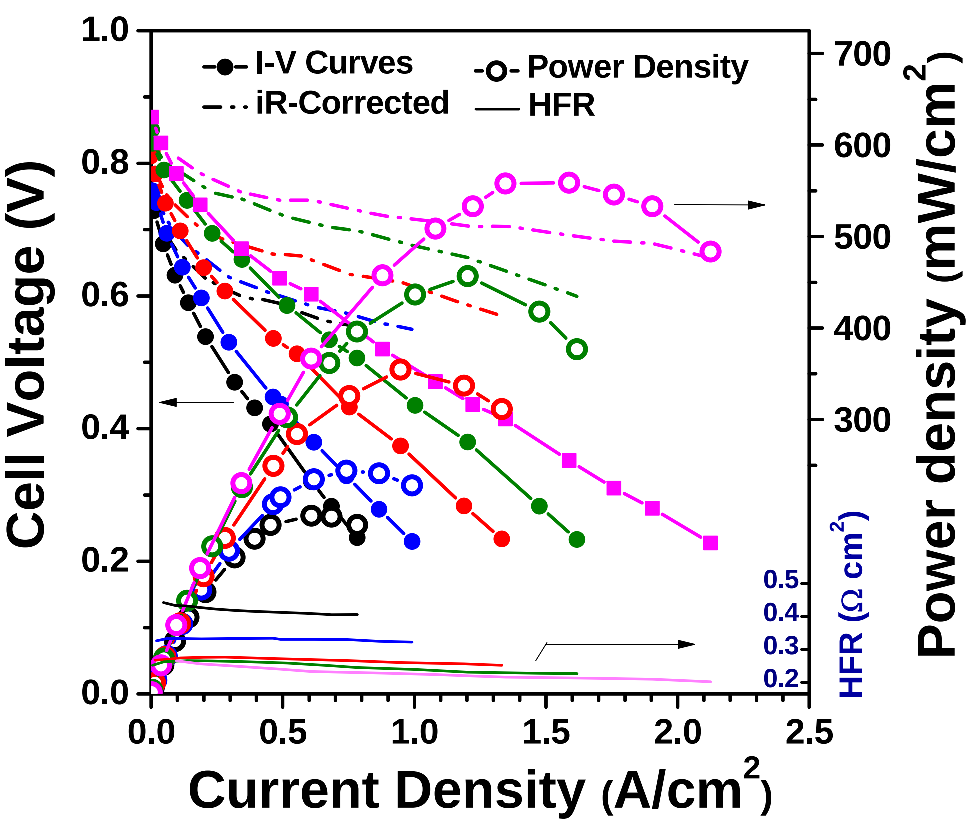
Low Pt Loading (0.2 mg_{Pt}/cm^2) Under No Humidification (H_2/Air)



Fuel cell testing & MEA condition	
Membrane	- TPP : 90 wt% - Thickness: 80 μm - Prepared from vacuum casting
Electrode	- 60 wt% Pt/C - 0.2 mg_{Pt}/cm^2 loading
GDE	- Paint on GDL - Single side GDL
Cell Temp. (°C)	220
Humidification (%)	0
Backpressure (psig)	**30 (red)** **10 (blue)**
H_2/Air flow (sccm)	300/300

Power densities 235 & 310 mW/cm² at 10 & 30 psig back-pressure

Low Temperature Fuel Cell Performance Under No humidification.



Fuel cell testing & MEA condition	
Membrane	- TPP : 90 wt% - Thickness: 80 μm
Electrode	- 60 wt% Pt/C - 0.2 mg_{Pt}/cm^2 loading
GDE	- Paint on GDL - Single side GDL
Cell Temp. (°C)	80 (black) 120 (blue) 160 (red) 200 (green) 220 (pink)
Humidification (%)	0
Backpressure (psig)	10
H_2/O_2 flow (sccm)	300/300

- This type of cell operates efficiently in the temperature range 80 – 220 °C without humidification.

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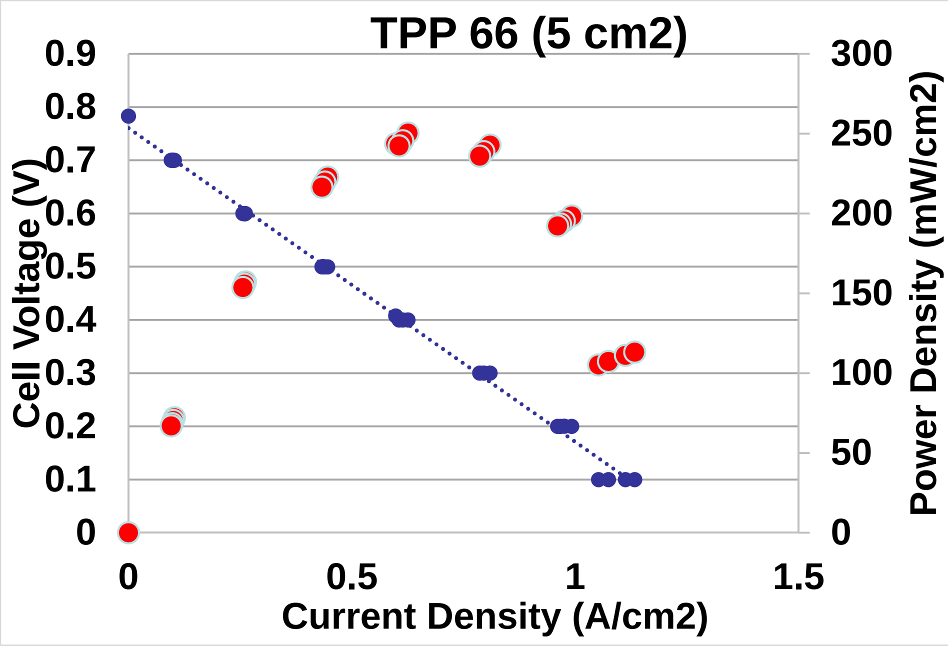
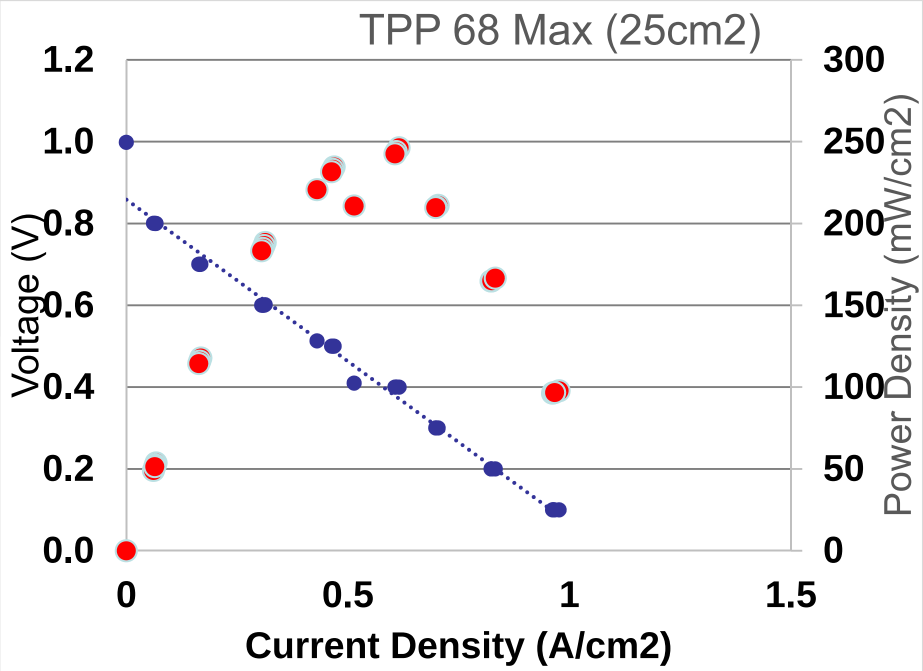
Performance of 5cm^2 and 25cm^2 cells

Temperature: 220 ° C
Dry H_2 vs O_2

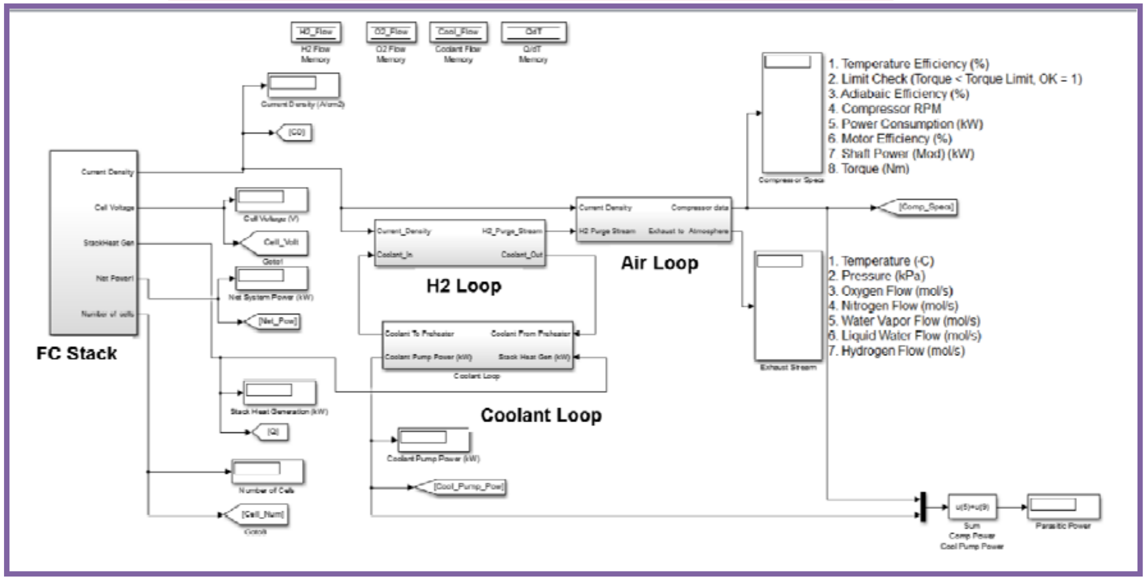




SYSTEM MODELING

FCEV system modeling in Matlab for intermediate temp operation

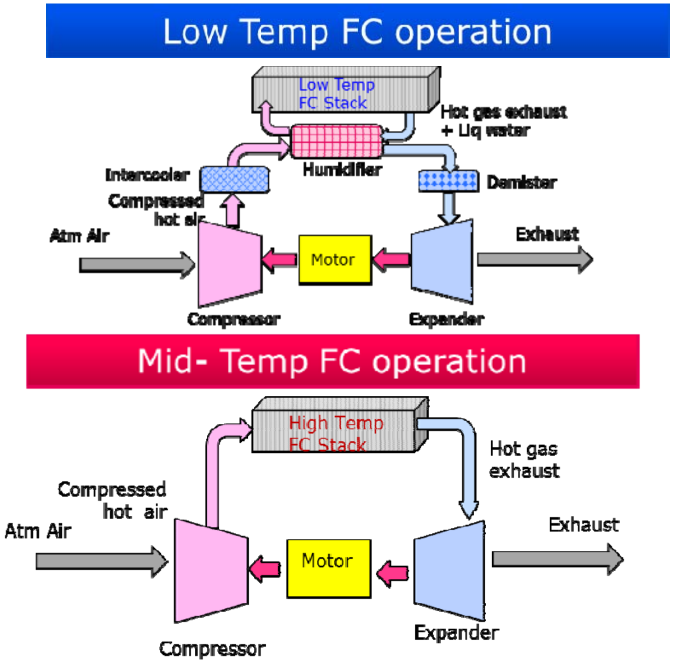
Overall FCEV system model in Matlab-Simulink developed by NTCNA



1. Temperature Efficiency (%)
2. Limit Check (Torque < Torque Limit, OK = 1)
3. Adiabaic Efficiency (%)
4. Compressor RPM
5. Power Consumption (kW)
6. Motor Efficiency (%)
7. Shaft Power (Mod) (kW)
8. Torque (Nm)

1. Temperature (-C)
2. Pressure (kPa)
3. Oxygen Flow (mol/s)
4. Nitrogen Flow (mol/s)
5. Water Vapor Flow (mol/s)
6. Liquid Water Flow (mol/s)
7. Hydrogen Flow (mol/s)

Example of system simplification



System simplification by eliminating the components

<u>Model Features:</u>

❑Three main loops: Air loop, coolant loop and H_2 loop.

❑Typical inputs: Net power (80kW), Peak current density, anode and cathode stoichiometry, active area (400 cm^2), coolant max temperature (120 ^oC), Stack pressure (200 kPa)

❑Typical outputs: Stack heat generation, Q/dT (radiator parameter), Number of cells in stack, Coolant pump power, Compressor power, expander power

➢ Cost benefit analysis for intermediate temperature operation performed using this system model and fuel cell data

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FCEV system Cost savings for intermediate temp operation

Main Cost saving Components:

1. **Radiator: Reduced number of radiators**

2. **Humidifier: Eliminated.**

3. **Cathode Intercooler: No need. Eliminated**

4. **Demister: No need.**

5. **Expander: Less parasitic losses; indirect impact on cost**

- In general, compressor and humidifier cost is major part of the BOP system.

- Operating stack at peak current density, lower pressures (with better catalyst technology), lower/no humidity, higher temperature and reducing parasitic losses can reduce the BOP cost significantly.

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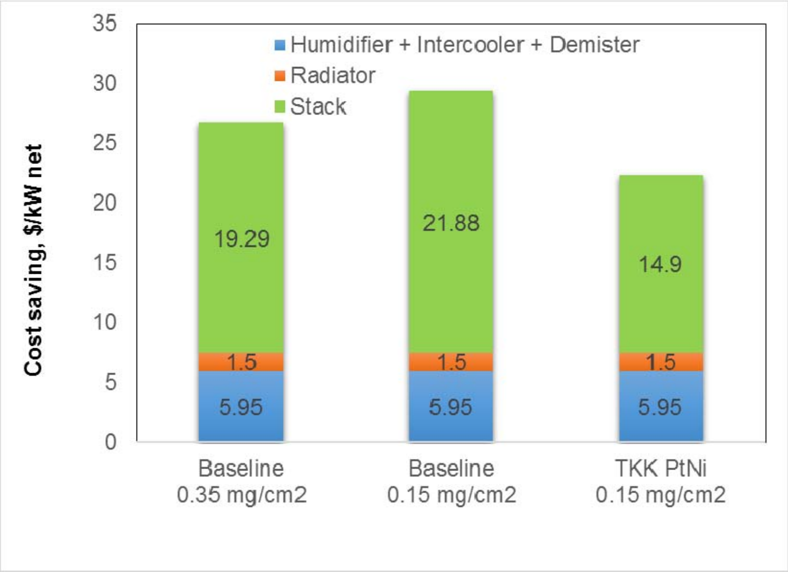
FCEV system cost benefit analysis for intermediate temp operation

❑ **Preliminary cost estimation is based on 10,000 vehicles/yr**

Fixed cost saving due to Mid-temp and no/low RH operation

Component	Cost saving $/system	Cost Saving $/kW$_{net}$	Cost saving path
Radiator*	~$120	~$1.5	By eliminating one radiator
Humidifier	~$420	~$5.25	By eliminating the humidifier
Intercooler	~35	~$0.43	By eliminating the intercooler
Demister	~22	~$0.27	By eliminating Demister
Total	~$597	~7.45	



Main cost saving comes from Stack cost reduction due to increase in power density (reduction in number of cells)

- ➢ **For use as an automotive application, stack performance (power density) need significant improvement**
- ➢ **Intermediate temp operation and improved stack performance can result in maximum cost saving**

Summary

- Demonstrated Performance:
  - ✓Low humidity
  - ✓600 mW/cm^2 (with oxygen); 325 mW/cm^2 (with air) compared to prior work using this membrane ~ 200 mW/cm^2
  - ✓Scale up to 25 and 50 cm^2 cell in progress
  - \+ CO tolerance test planned
  - \+ Working towards new target: 800 mW/cm^2
  - ✧Additional power density increase needed to realize maximum cost savings in automobile application

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