21st Century Renewable Fuels, Energy, and Materials Initiative

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Project ID # **FC078**

Overview

Overview

Timeline

- Start – July 2010
- Finish - June 2011
- 35% Complete

Budget

- Total project funding
  - DOE - $1,250,000
  - Cost share - $312,500
- Funding received in FY10
  - $1,250,000

Barriers

- Barriers
  - A. Materials and manufacturing costs
  - B. Membrane performance and durability
  - C. Efficient multi-fuel reforming system
  - D. Alternative fuel source without impact on human food chain.
- Targets –Improved membrane conductivity & durability
  - Cost-effective multi-fuel reformer system
  - High power density lithium-air battery with simple control systems and reduced cost.
  - High energy yield agriculture bio-crop

Partners

- **Michigan Molecular Institute (MMI)** – Polymer membranes and lithium-air battery
- **Saginaw Valley State University-** High energy yield agriculture bio-crop (Miscanthus)

Relevance

Overall Objectives **(2010 – 2011)**	• Development of an improved high-temperature fuel cell membrane capable of low-temperature starts (<100^{o}C) with enhanced performance. • Development of a 5kWe novel catalytic flat plate steam reforming process for extracting hydrogen from multi-fuels and integrate with high-temperature fuel cell systems. • Development of an improved oxygen permeable membrane for high power density lithium-air batteries with simple control systems and reduced cost. • Development of novel high energy yield agriculture bio-crop (Miscanthus) for alternative fuels with minimum impact on human food chain. • Extend math and science alternative energy educator program to include bio-energy and power.

Plan and Approach

Plan & Approach

40% Completed

➢ Task 1: **High temperature fuel cell membrane**

- Increased proton conductivity than peer
- Improved durability and thermal stability
- Performance evaluation

35% Completed

➢ Task 2: **5kWe catalytic flat plate fuel reformer**

- CFD study of catalytic flat plate reformer
- Design and build the reformer prototype
- Test and evaluate the performance

45% Completed

➢ Task 3: **High power density Lithium-Air battery at a reduced cost.**

- Optimize the combination of electrolyte that is best suitable for Li-air battery
- Design and build the prototype
- Test of prototype for durability and efficiency

40% Completed

➢ Task 4: **Research on high energy yield agriculture bio-crop (Miscanthus)**

- Literature survey
- Develop energy- and economic model
- Identify methods to produce alternative fuels from bio-crop (Miscanthus)

30% Completed

➢ Task 5: **Alternative energy education program to include bio-energy and power.**

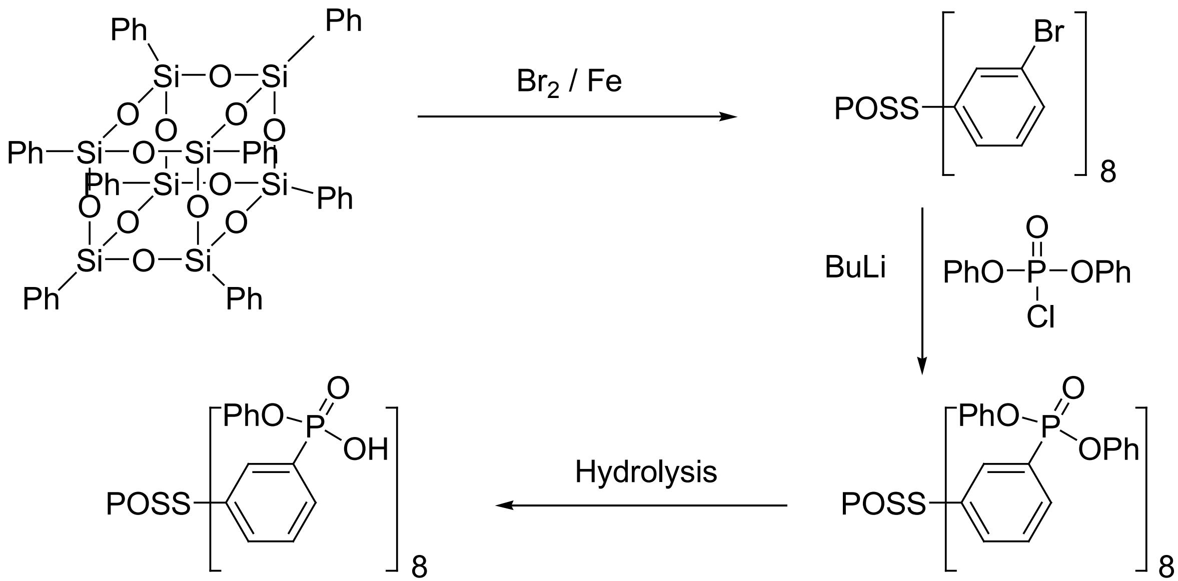
- An educational module preparation incorporating the project results for Bio-Power education

Approach

Approach Overview for High Temperature PEM Membrane

- We used novel patented polymer synthesis technology to prepare robust electrolyte for high temperature PEM fuel cell

- Patented Polymer Synthesis Technology



- New Polymer Membrane

Finished Membrane

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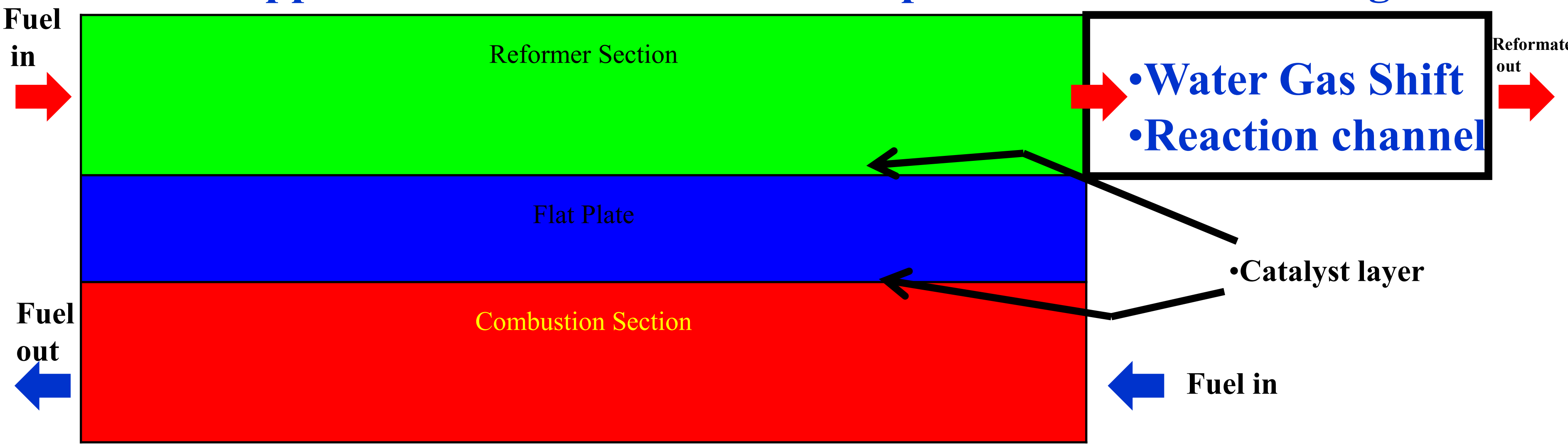
Approach

Approach Overview for CFD flat plate reformer Modeling



- **Length of the channel 30cm**
- **Width of the channel 2mm**
- **Wall (flat plate) thickness 50µm**

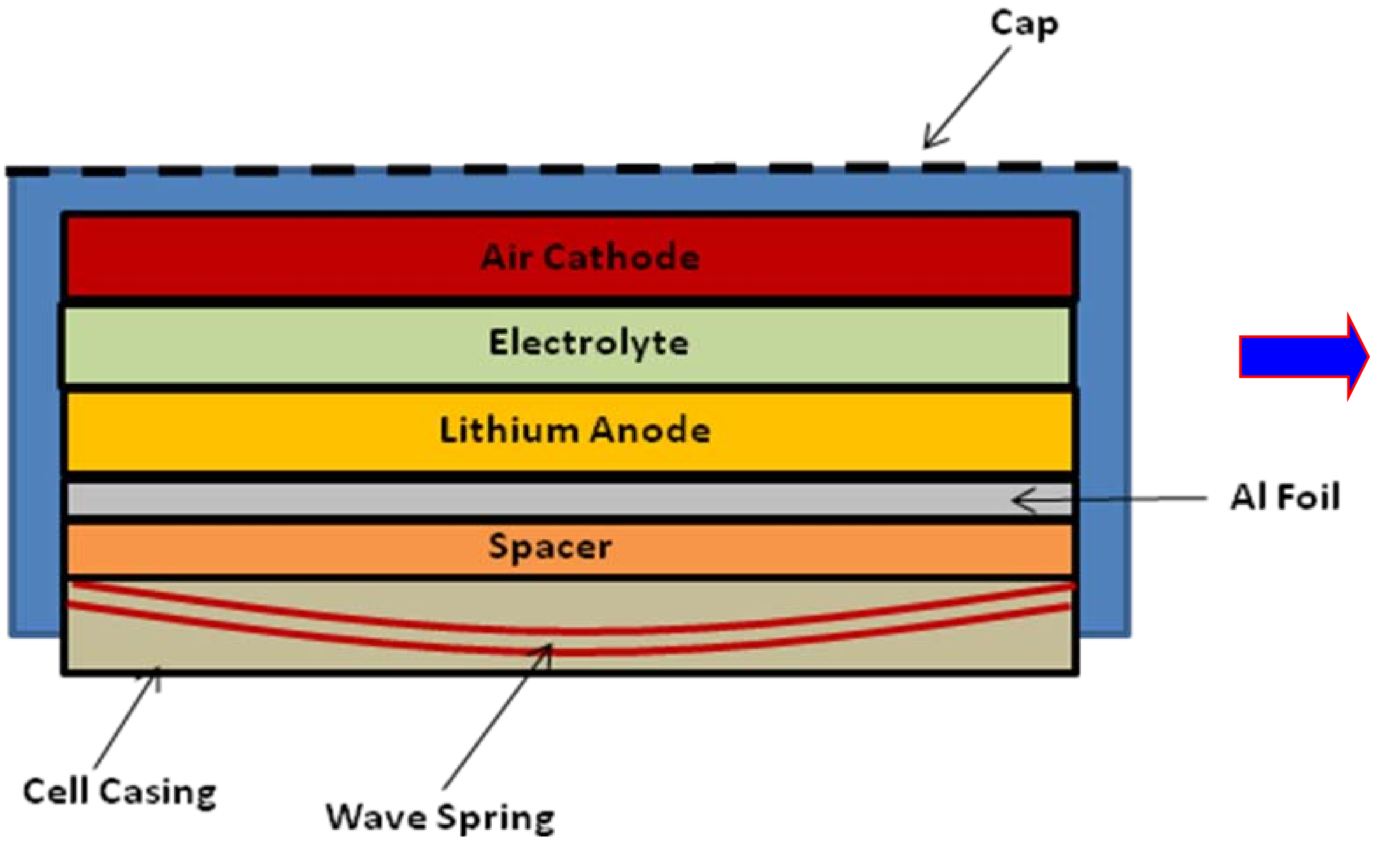
Catalyst layer	
Thickness	$20*10^{-6}$m
Pore radius	$10*10^{-9}$m
Porosity	0.4
Tortuosity	4
Thermal conductivity	0.4 W/m.K
Density	2355 kg/m^3
Solid wall	
Thickness	0.0005m
Thermal conductivity	25 W/m.K

- **Catalyst containing15.2% Ni supported on magnesium spinel.**

Approach

Approach Overview for Lithium-Air Battery

- **Schematic Representation of The Proposed Lithium-Air Battery**



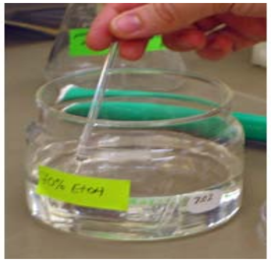
Finished Lithium-Air Battery

Approach

Approach Overview for Biofuel from High Yield Energy Crop

- **Approach for biofuel from high energy yield agriculture crop**

Miscanthus Grass



Ethanol - Biofuel

Torrefied bio-mass

Pyrolyzed bio-char

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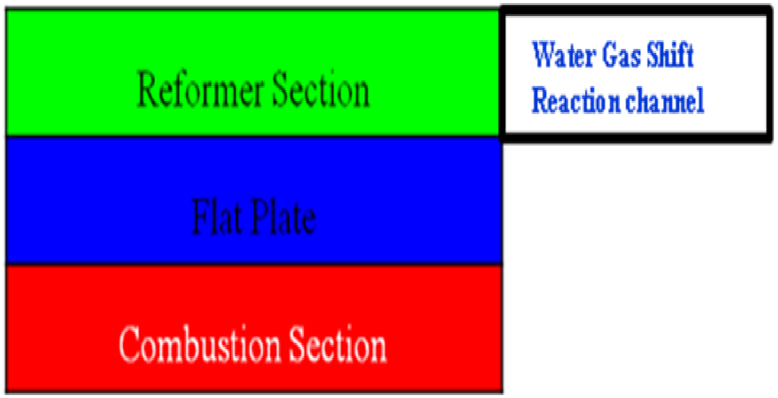
Accomplishments/Progress

- Optimization of high temperature membrane casting protocol

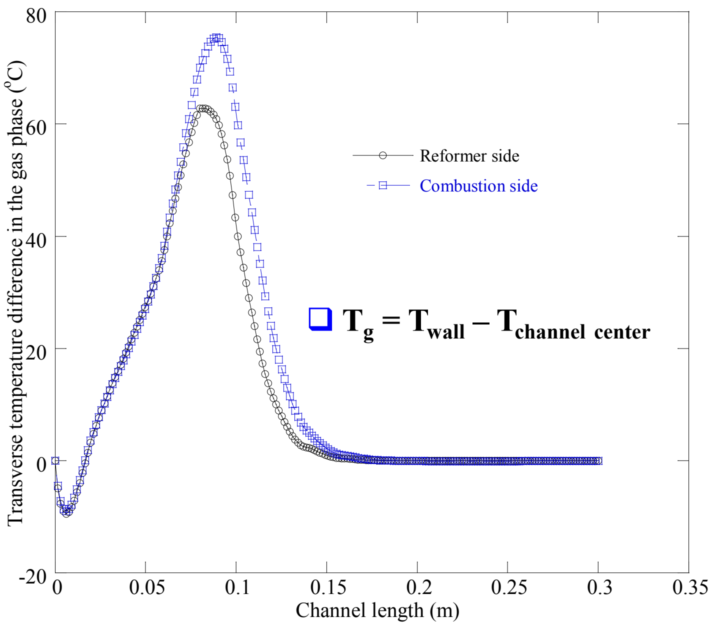
  - **Three control *m*-PBI-PPA membranes have been cast to date**
  - **A nitrogen flow system was found to be preferable to a closed nitrogen system**
    - **Necessary to drive off water to shift the equilibrium toward the desired PBI product**
  - **Storage of PPA under rigorously anhydrous conditions was also found to be key**
  - **The quality of the film was related to the reaction time (mass of PBI)**
    - **Necessary to determine optimum reaction time**

Accomplishments/Progress/Results

• CFD analysis of Catalytic Flat Plate Reformer



- **Schematic of Catalytic Flat Plate fuel reformer**

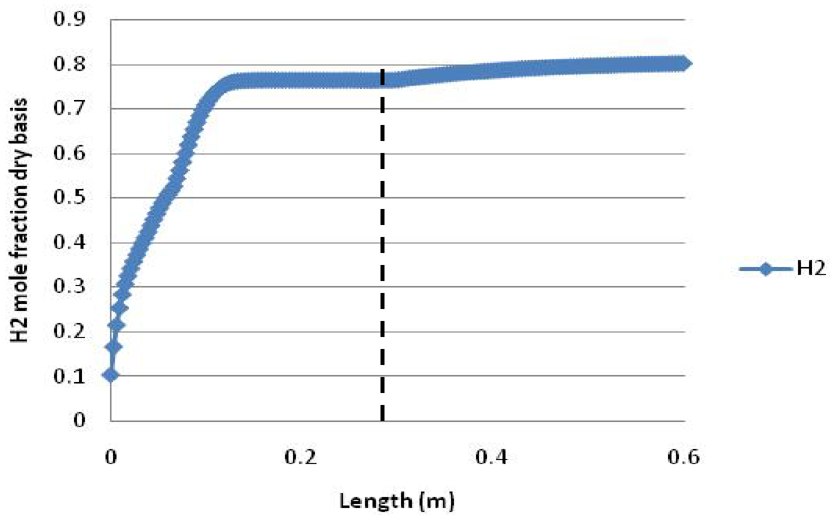


- **Transverse temperature difference in both reformer and combustion side**

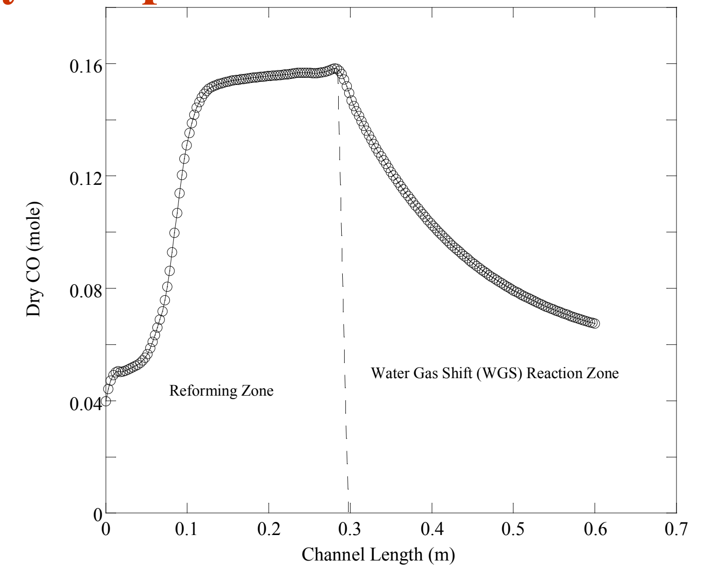
- **In a conventional steam reformer Tg is often greater than 250°K whereas here it is less than 30°K.**
- Virtually no heat loss at the very end section of the reformer.

Accomplishments/Progress/Results

- **CFD analysis of dry hydrogen and dry CO production with WGS**



(a) Production of dry H_2 with water gas shift (WGS) reaction and optimized reformer geometry.



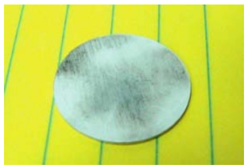
(b) Production of dry CO with water gas shift (WGS) reaction and optimized reformer geometry.

- ❑ **Production of dry hydrogen is increased only 2% with WGS reaction.**
- ❑ **Reduction of dry CO is more than 50% with WGS reaction. CO level has changed from 0.158 to 0.072 on dry basis.**

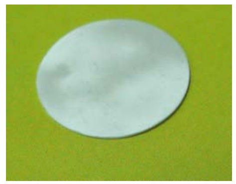
Accomplishments/Progress/Results

- **Comparison of conductivity among ceramic and polymer electrolyte for Lithium-Air Battery**

• **Ceramic electrolyte: Li_2O, Al_2O_3, GeO_2, and P_2O_5**



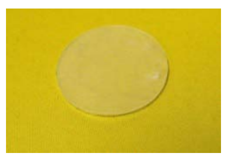
▪ **LAGP disc before sintering**



▪ **LAGP disc after sintering**

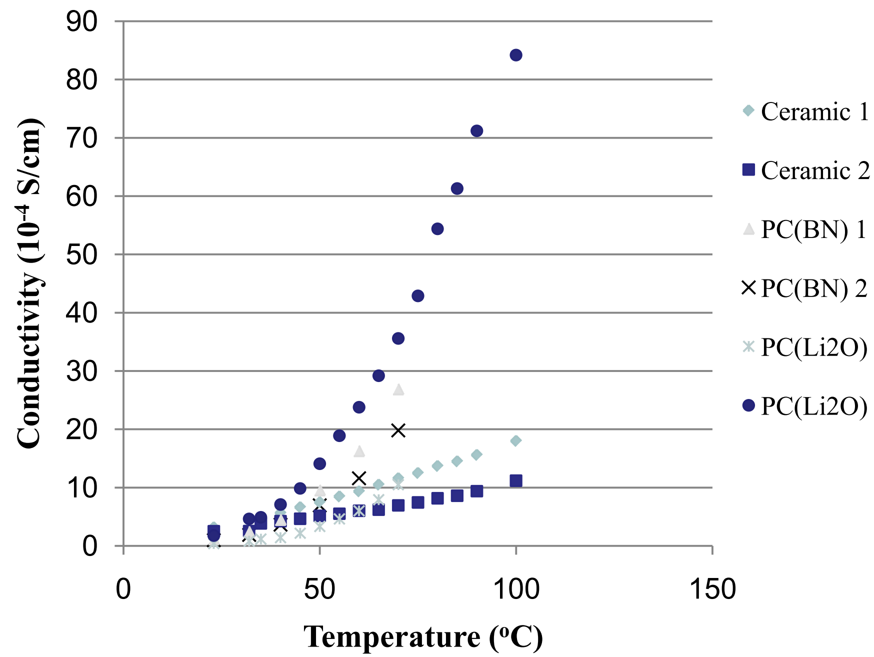
• **Polymer electrolyte: PEO, LiTFSI, BN/Li_2O**

▪ **PC (BN) disc**



▪ **PC(Li_2O) disc**

(a) Ceramic and polymer electrolyte sample preparation.



(b) Conductivity as a function of temperature for ceramic and polymer electrolyte.

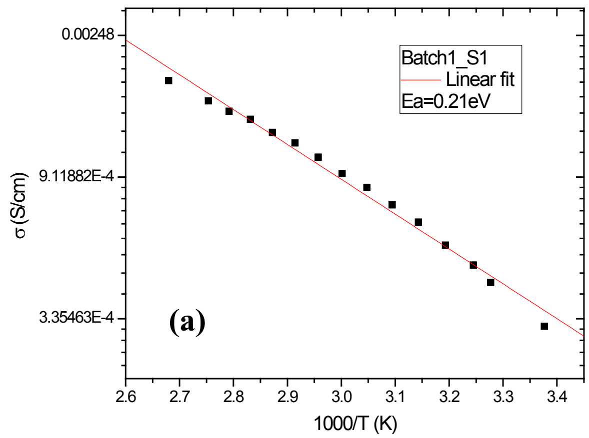
- **The ceramic electrolyte has moderate conductivity at reduced temperature.**
- **The polymer electrolyte shows higher conductivity above 35°C.**
- **The big difference in the conductivity among the polymer samples might be attributed to the poor quality of the Pt coating on the surface of the discs.**

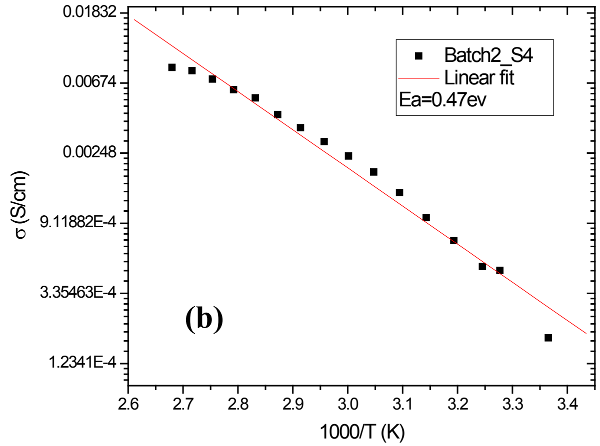
Accomplishments/Progress/Results

- **Activation Energy in Lithium-Air Electrolyte**

Temperature (°C)	Ceramic 1 Conductivity (10^{-4} S/cm)	PC(Li_2O) 2 Conductivity (10^{-4} S/cm)
24	3.18	1.78
35	4.90	4.92
40	5.64	7.11
50	7.49	14.1
60	9.36	23.8
70	11.6	35.6
80	13.7	54.4
90	15.6	71.2
100	18.0	84.2

(i) Temperature dependent conductivity of Ceramic 1 and PC(Li_2O) 2





(ii) Arrhenius plot of the conductivity of (a) Ceramic 1 and (b) PC(Li_2O) 2

- Polymer electrolyte has higher activation energy than ceramic electrolyte

Accomplishments/Progress/Results

• Lithium-Air Battery Fabrication and Characterization

• An all solid cell was fabricated utilizing the Ni/C/LAGP based cathode, the PC(Li_2O)/LAGP/PC(BN) solid electrolyte, and a lithium metal anode

• Testing of Lithium-Air Battery Performance

• Primary test result: The highest OCV observed was 2.74 Volt at room air temperature and the cell lasted 16 days before the voltage dropped to below 2.0 Volt.

Collaboration

PI: Kettering University

- **Task 2: 5kWe catalytic flat plate fuel reformer**
  - CFD study of catalytic flat plate reformer
  - Design and build the reformer prototype
  - Test and evaluate the performance

- **Task 5: Alternative energy education program to include bio-energy and power.**
  - An educational module preparation incorporating the project results for Bio-Power education

Co-PI: Michigan Molecular Institute (MMI)

- **Task 1: High temperature fuel cell membrane**
  - Increased proton conductivity than peer
  - Improved durability and thermal stability
  - Performance evaluation

- **Task 3: High power density Lithium-Air battery at a reduced cost.**
  - Optimize the combination of electrolyte that is best suitable for Li-air battery
  - Design and build the prototype
  - Test of prototype for durability and efficiency

Co-PI: Saginaw Valley State University (SVSU)

- **Task 4: Research on high energy yield agriculture bio-crop (Miscanthus)**
  - Develop energy- and economic model
  - Identify methods to produce alternative fuels from bio-crop (Miscanthus)

Future Work

- **Future Work (FY2011-FY2012)**

- **Performance improvement of High temperature PEM membrane**
  - **Optimize a membrane electrode assembly (MEA) using PBI-phosphoric acid-POSS nanoadditive proton exchange membrane**
  - **Test thermal stability and life-cycle sensitivity based on DOE matrix**
  - **Map membrane conductivity history based on different RH cycles**

- **Design and build 5kWe catalytic flat plate fuel reformer based on CFD study**
  - **Design layout of the reformer has to be developed**
  - **Build the prototype using the optimized layout**
  - **Test prototype performance and benchmark the results**
  - **Develop cost analysis for a optimized reformer system**

Future Work

- **Future Work (FY2011-FY2012)**

- **Explore other avenues for performance enhancement of Lithium-Air Battery**
  - The efforts for the next few quarters will be aimed at the assembly and testing of a working button cell battery utilizing the Ni/C/LAGP based cathode, the PC(Li_2O)/LAGP/PC(BN) solid electrolyte, and a lithium metal anode assembled in a 2032 button cell battery case.
  - Once a working battery is produced, efforts will then be focused on optimizing the processing steps to improve on the battery's performance.
  - Once a reproducible procedure has been identified, batteries with and without the oxygen permeable membrane will be prepared and evaluated under various atmospheric conditions (i.e., different relative humidity values).

- **Cost effective procedure for bio-fuel production from high energy yield agriculture crop**
  - Economic and technical feasibility of procedures to convert the energy crop, *Miscanthus x giganteous (MXG), into either hydrogen or hydrogen carriers suitable for fuel cell use.*
  - Calculation of optimal combination of bio-fuel production procedures for Miscanthus bio-crop

- **Develop a Bio-Energy education module**
  - Math and science alternative energy educator program for bio-energy and power.

Summary

Project Summary

Relevance: Help to develop high temperature PEM fuel cell membrane, Lithium-Air battery and bio-fuel from bio-crop for fuel cell applications

Approach: Using patented polymer synthesis technology for high performance membrane, multi-fuel capable reformer based on CFD study, Lithium-Air battery based on high conductive polymer materials.

Technical Accomplishments and Progress: Advanced roll to roll HTPEM fuel cell membrane manufacturing procedure has been developed. A design layout of multi-fuel reformer is completed. Preliminary test of Lithium-Air battery performance evaluation is completed.

Technology Transfer/Collaborations: Active partnership with MMI, SVSU, presentations, publication and patents

Proposed Future Research: Seek answers by identifying factors limiting HTPEM fuel cell performance and Lithium-Air Battery.

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