Sustainable Innovations

Electrochemical Conversion of CO_2 to Fuels for Power-to-Gas Energy Storage

Phase I Kickoff Meeting

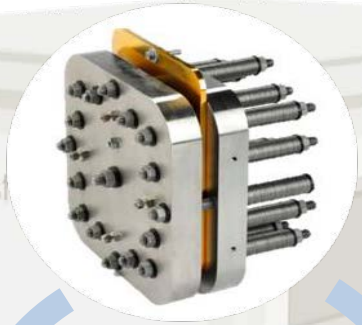
August 30, 2016

Agenda

- Relation to Sustainable Innovations Technology
  - Related Applications
  - Specific Challenges of DOE Application
- Current State of Development
- Work Plan for the Phase I Project
- Discussion of System Requirements

Sustainable Innovations
Common PEM Platform Addresses Multiple Markets

Low Cost
Modular and Scalable



High Pressure
Suitable for Multiple Chemistries

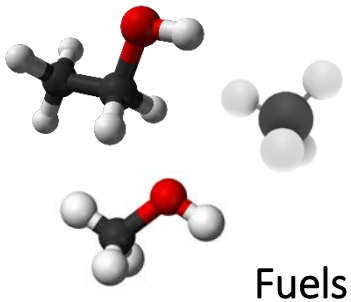
Hydrogen Separation & Compression

Hydrogen Production For Fueling

Grid-Scale Energy Storage

CO_2 Conversion to Fuels and Chemicals

Carbon Neutral Fuel Cycle



Fuels

CO_2 Emissions
- Power Plants
- Industry

CO_2 Capture

Renewable Power
- Solar
- Wind

CO_2 Electroreduction

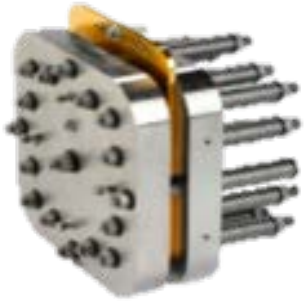
High Value Commodity Chemicals

Related Activity – CO2RENEW™ For Generation of Fuels and Commodity Chemicals

Gas Stream Containing CO_2, H_2O

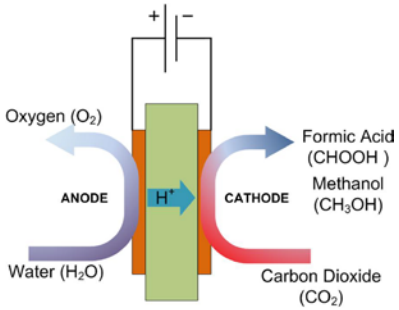
H_2 or H_2O

Power



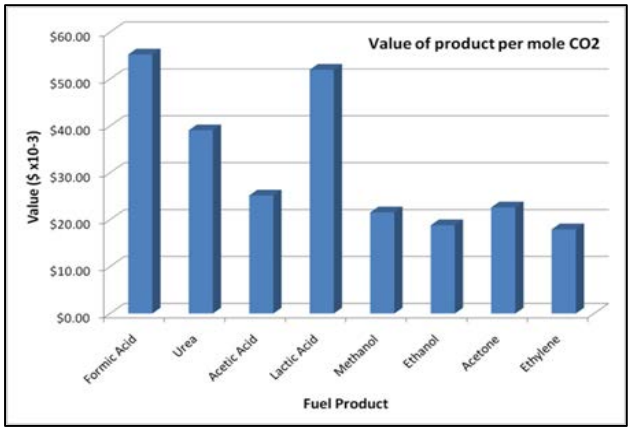
Expandable Modular Architecture

Chemicals and Fuels

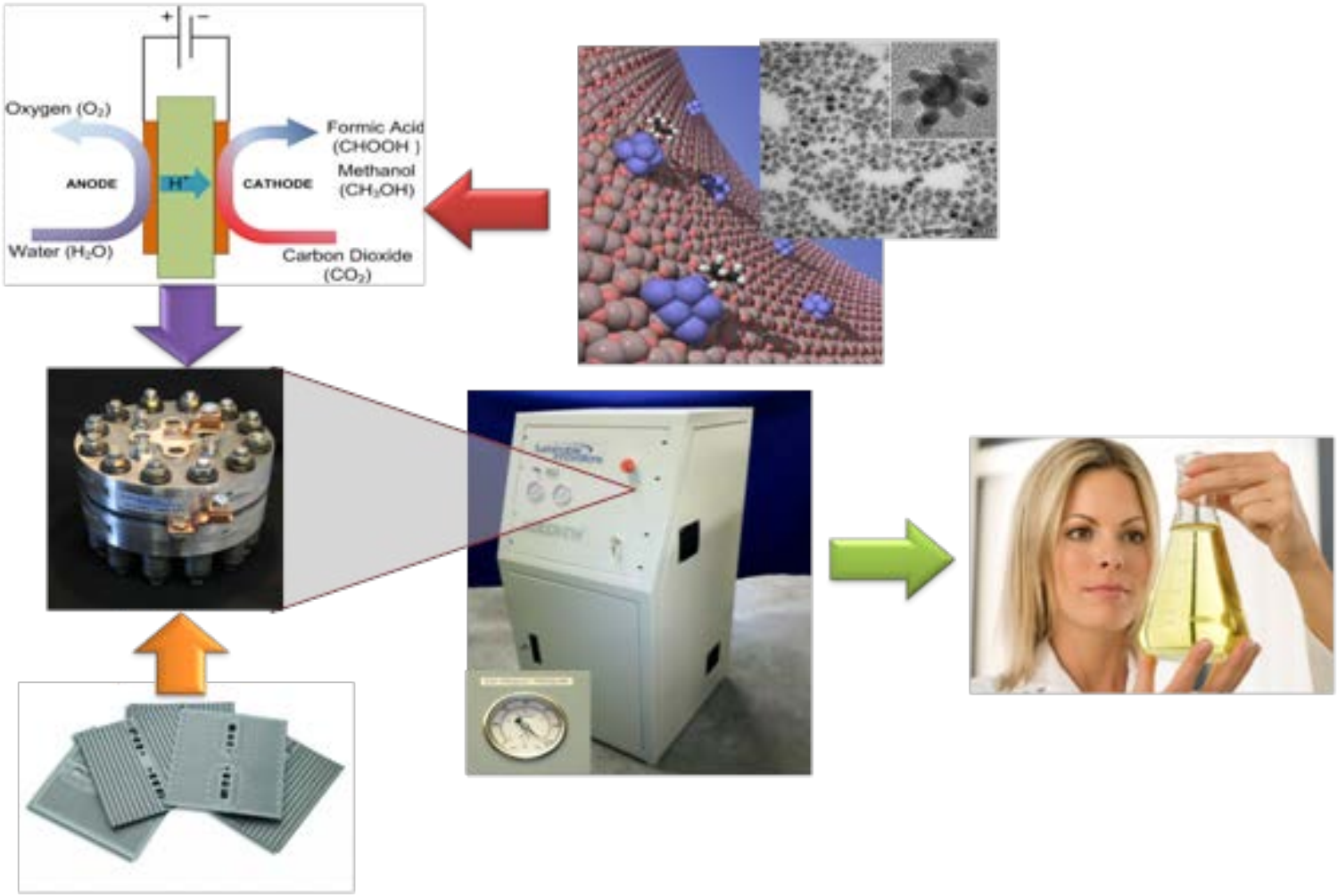


Cathode ½ Reactions and their hydrocarbon products

Formic Acid	$CO_2 + 2H^+ + 2e^- \rightarrow CH_2O_2$
Acetic Acid	$CO_2 + 4H^+ + 4e^- \rightarrow \frac{1}{2}C_2H_4O_2 + H_2O$
Oxalic Acid	$CO_2 + 2H^+ + 2e^- \rightarrow \frac{1}{2}C_2O_2(OH)_2$
Lactic Acid	$CO_2 + 4H^+ + 4e^- \rightarrow \frac{1}{3}C_3H_6O_3 + H_2O$
Methanol	$CO_2 + 6H^+ + 6e^- \rightarrow CH_4O + H_2O$
Ethanol	$CO_2 + 6H^+ + 6e^- \rightarrow \frac{1}{2}C_2H_6O + 1\frac{1}{2}H_2O$
Methane	$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$
Ethane	$CO_2 + 5H^+ + 5e^- \rightarrow \frac{1}{2}C_2H_6 + H_2O$
Ethylene	$CO_2 + 4H^+ + 4e^- \rightarrow \frac{1}{2}C_2H_4 + H_2O$
Urea	$CO_2 + N_2 + 6H^+ + 6e^- \rightarrow (NH_2)_2CO + H_2O$



Related Activity – CO2RENEW™ For Generation of Fuels and Commodity Chemicals

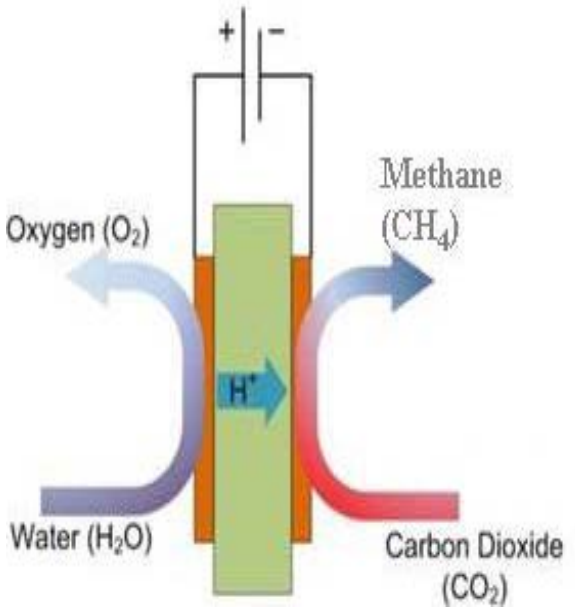


Project Objective

- Electroreduction of CO_2 to Methane

$$\boldsymbol{CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O}$$

- Integration of High-Temperature MEAs
  - PBI, Advent TPS
- Design Methanation Cell Capable of 40 g CH_4/Day
  - Performance Validation with Pure and Dilute CO_2 Streams
- Design 5-Cell Stack Prototype for 0.2 kg CH_4/day
- Ongoing Techno-Economic Modeling



DOE SBIR Phase I Project

Work Plan
Task 1: Advance and Further Develop Integrated Methanation Concept via Laboratory Testing
Task 2: Design 0.2 kg/day Methanation Cell Stack
Task 3: Build and Test Prototype Methanation Cell
Task 4: Design Prototype EMG System with a Capacity of up to 0.2 kg/day
Task 5: Fabricate and Test Prototype EMG at a Capacity up to 0.2 kg/day
Task 6: Program Management and Reporting

Task 1: Advance and Further Develop Integrated Methanation Concept via Laboratory Testing

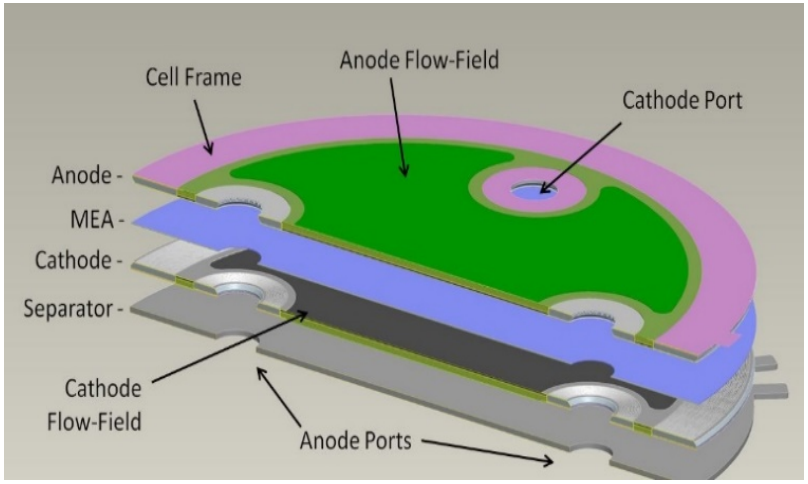
- Characterization of PFSA Membrane at Temperatures up to 80°C
- Integration and Characterization of High Temperature Membrane at Temperatures up to 200°C
- Single Cell Test Article
- 81.6 cm^2 Active Area

Parameter	Anticipated Testing Range	Unit
Current Density	200-1000	mA/cm^2
Cathode Temperature	50-200	°C
Cathode Pressure	0-500	psig
Electrolyte	Nafion, PBI, Advent TPS	

Work Product: Fundamental Understanding of Design Requirements for a 0.2 kg/day Methanation Cell Through Performance Testing and Parametric Mapping With a Goal of Conversion of a 100% CO_2 Stream to CH_4 at a Faradaic Efficiency of >80%

Task 2: Design 0.2 kg/day Methanation Cell Stack

- Optimization of Pre-Prototype Embodiments Incorporated Into Cell Stack
- Stack Size 1 to 5 Cells
- 81.6 cm^2 Active Area



Work Product: Complete Design Package for 0.2 kg/day Methanation Cell Stack

Task 3: Build and Test Prototype Methanation Cell

- Single Cell – 40 g CH_4/Day Parametric Evaluation
  - 200 Hour Durability
- Three Cell Stack Parametric Evaluation
  - Ascertain Issues From Cell Stacking
- Five Cell Stack Parametric Evaluation
  - 0.2 kg CH_4/Day
  - 200 Hour Durability
- Concentrated and Dilute CO_2 Streams

Work Product: Prototype 0.2 kg/day Methanation Cell Stack Evaluated With Concentrated CO_2 and Dilute CO_2 as Found in Flue Gas Chemistries

Task 4: Design Prototype EMG System with a Capacity of up to 0.2 kg/day

- Design 0.2 kg CH_4/Day Prototype Automated System
  - CO_2 Regulation
  - Temperature/Pressure Monitoring and Control
  - Stack Current Monitoring and Control
- Generate System P&ID
- Conduct Design Review and FMEA

Work Product: Prototype Design Package for 0.2 kg/day Electrochemical Methane Generator

Task 5: Fabricate and Test Prototype EMG at a Capacity up to 0.2 kg/day

- Assemble 0.2 kg CH_4/Day Automated Prototype
- Parametric Evaluation Based on Expected Effluent Streams
- 200 Hour Durability Evaluation of System

Work Product: 0.2 kg/day Electrochemical Methane Generator and Associated Parametric, Durability and Techno-Economic Data

Task 6: Program Management and Reporting

- Milestone 1 (End of Month 4): Performance Evaluation and Durability of 5-Cell Stack Complete
- Milestone 2 (End of Month 9): Performance Evaluation and Durability of 0.2 kg CH_4/Day Prototype Complete

	Months								
	1	2	3	4	5	6	7	8	9
Task 1: Advance and Further Develop Integrated Methanation Concept via Laboratory Testing	■								
Task 2: Design 0.2 kg/day Methanation Cell Stack	■	■							
Task 3: Build and Test Prototype Methanation Cell			■	■					
Task 4: Design Prototype EMG System with a Capacity of Up to 0.2 kg/day					■	■			
Task 5: Fabricate and Test Prototype EMG at a Capacity up to 0.2 kg/day							■	■	■
Task 6: Program Management and Reporting	■	■	■	■	■	■	■	■	■

Work Product: Achieve Program Objectives on Time and Within Budget

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