Liquid Fuels and Electricity from IT-Fuel Cells

Carl A. Willman

16th Annual SOFC Workshop

Pittsburgh, PA

July 16th, 2015

Objective

Project Objective:

To develop a cell technology capable of direct conversion of methane to liquid product, methanol or formaldehyde, by electrochemical partial oxidation at intermediate temperatures (<500˚C), to provide means for an economic utilization of stranded gas.

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Value Proposition

Western ND

Population
~100,000

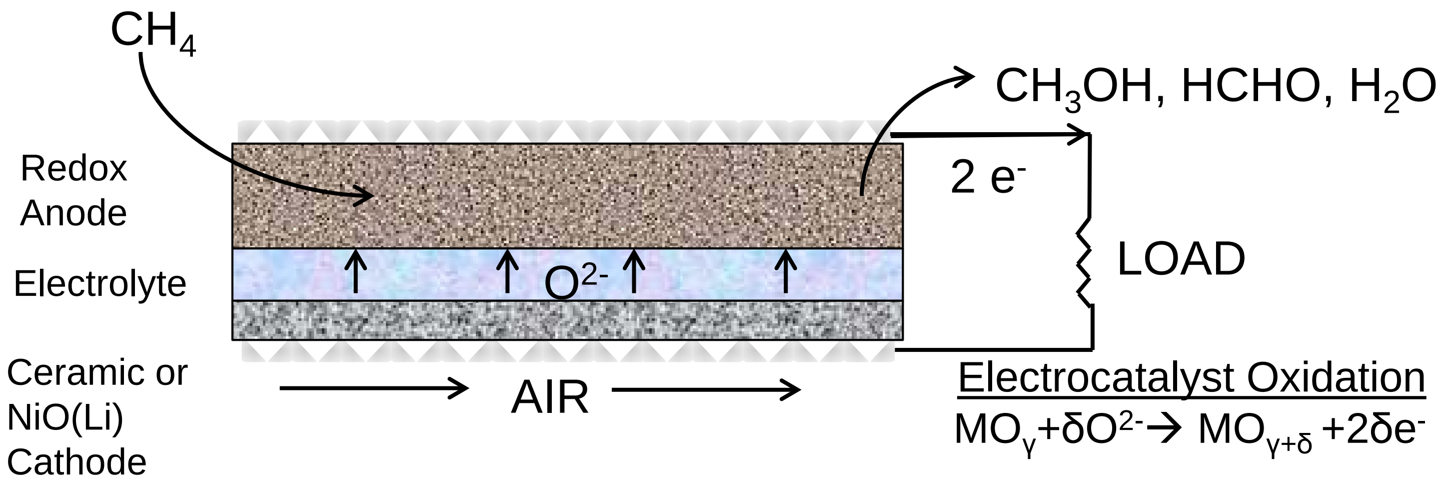
Eastern NY, CT,
MA & RI
Population
~25,000,000

Satellite image of visible light sources in US, demonstrating level of natural gas flaring

Image – NASA Earth Observatory

- Electrochemical Gas-to-Liquid (EC-GTL) offers a cost effective method for reducing emissions impact of stranded gas sources
- Scalability, modular nature, and transportability of electrochemical system also provide the means to economically utilize associated gas at low production wellheads
- The EC-GTL technology will meet ARPA-E's Mission Areas:
  - Enhance the economic and energy security of the United States
  - Ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies

Concept



<u>Electrocatalyst Oxidation</u>

$MO_{\gamma} + \delta O^{2-} \rightarrow MO_{\gamma+\delta} + 2\delta e^{-}$

<u>Fuel Formation</u>

$MO_{\gamma+\delta} + \delta CH_4 \rightarrow \delta CH_3OH + MO_{\gamma}$

$MO_{\gamma+\delta} + \delta CH_4 \rightarrow \delta/2\ HCHO + Mo_{\gamma} + \delta/2\ H_2O$

Electrochemical Gas-to-liquid cell utilizes a metal/metal oxide redox couple, which serves as the anode electrocatalyst, to partially and indirectly oxidize CH_4 to CH_3OH and HCHO.

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Partners

- University of Connecticut – Cell manufacturing technology development
- Pacific Northwest National Laboratory – GTL catalyst development
- Energy and Environmental Research Center at the University of North Dakota – GTL catalyst evaluation and pressurized testing
- Massachusetts Institute of Technology – Electrode interface characterization

Massachusetts Institute of Technology

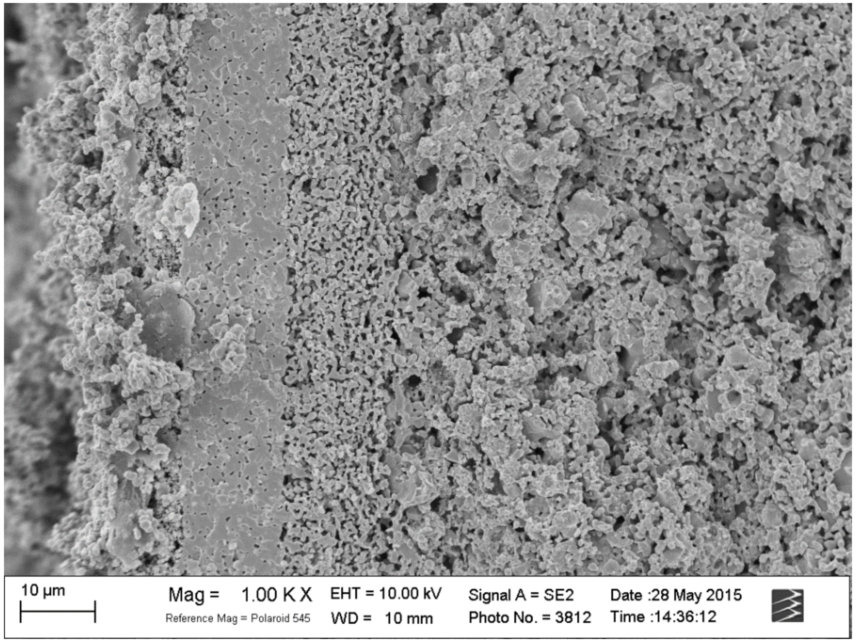
EERC
Energy & Environmental Research Center®
Putting Research into Practice

Pacific Northwest NATIONAL LABORATORY

UCONN UNIVERSITY OF CONNECTICUT

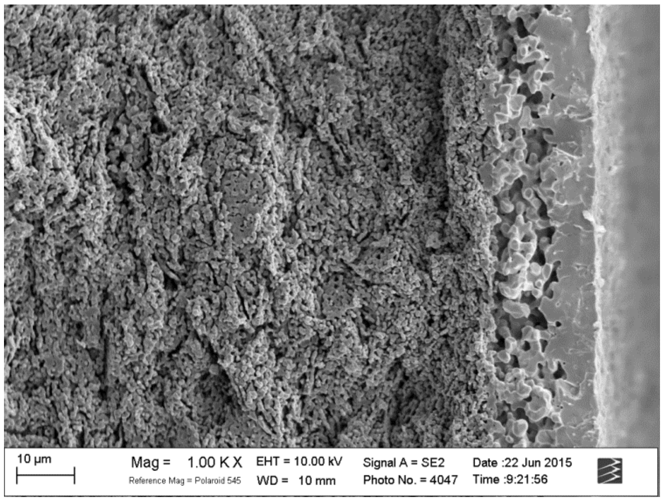
Development Approach

- Development of a novel EC-GTL cell presents an opportunity for top-down approach
- Incorporation of the catalyst within the EC-GTL anode requires ability to withstand constant redox cycling
- Chosen cathode and electrolyte must provide sufficient electrode activity and O^{2-} ionic conductivity to support the Redox reaction with the EC-GTL anode
- Institutional experience with MCFC commercialization can be leveraged to facilitate pathway to commercialization



SEM micrograph of potential EC-GTL cell under development at FCE

Cell Materials - Support

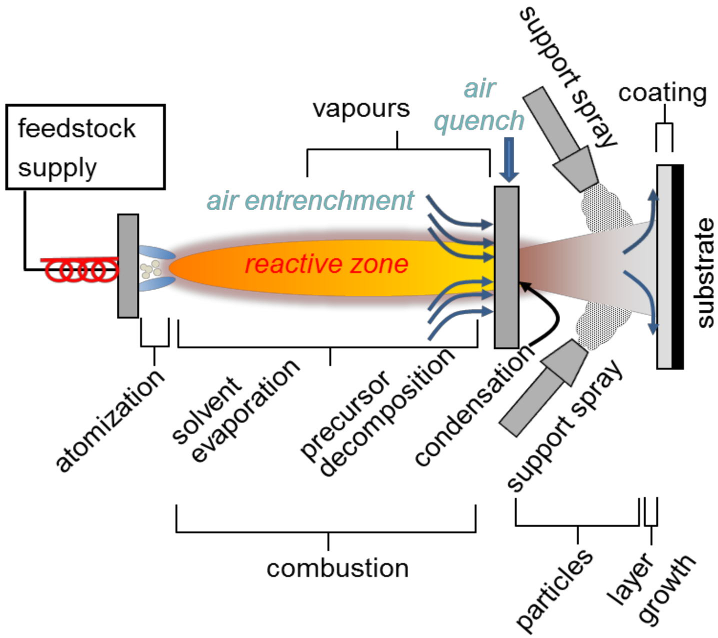


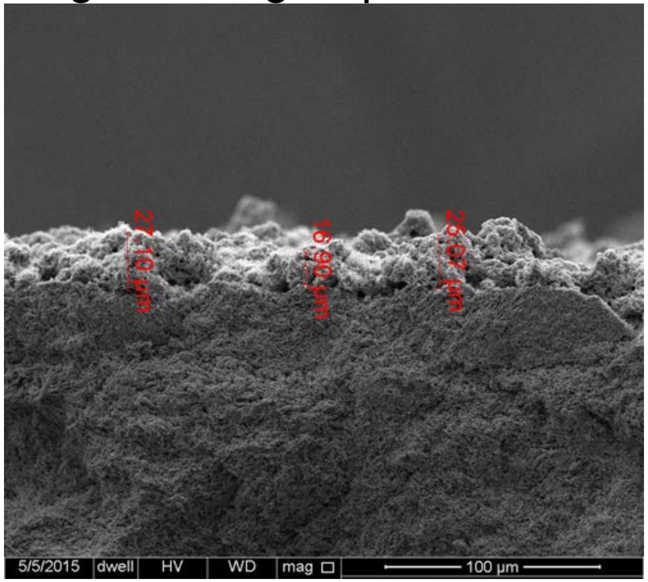
SEM micrograph of ceramic anode support with functional layer and electrolyte

- Initial investigation focused on modified NiO as cathode side support, including production line MCFC cathode, but was found to have insufficient mechanical strength
- Anode side ceramic support was chosen, with desirable conductivity and mechanical properties

Cell Manufacturing

- To reduce future cell cost and streamline commercialization, advanced manufacturing techniques, that can be readily scaled to high volume are being investigated as primary source of laboratory sample testing
- **Reactive Spray Deposition Technology (RSDT)** is employed to produce cell functional layers, in both porous and dense forms, with minimal to no post deposition processing/sintering required





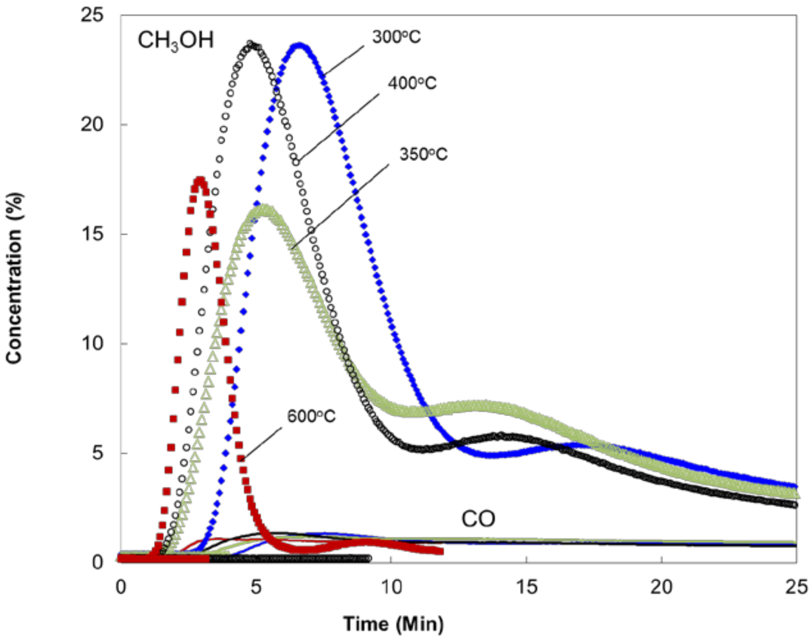
Economically viable RSDT for fabrication of the EC-GTL cell components and thin film layers

GTL Catalyst Development

- Development of GTL catalyst that favors the production of methanol/al with high selectivity as opposed to reformation to hydrogen
- Catalyst selection using candidate materials tested in batch-reactor mode
- Over twenty catalyst compositions have been evaluated, with multiple promising candidates identified
- Promising catalysts, based on selectivity and activity in ideal cell operation range, to be incorporated into button cells, then large area anodes

Batch mode reactor for catalyst evaluation.

GTL Catalyst Development

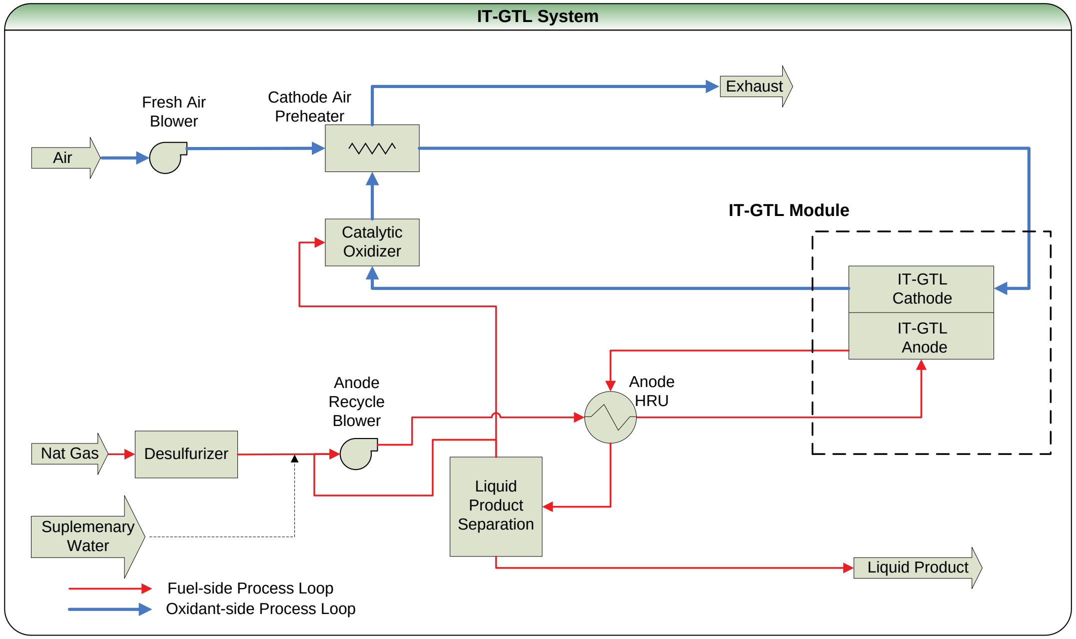


Catalyst screening has identified candidates with promising selectivity over desired range of temperatures

- Less than 1% CO observed, no CO_2
- >90% Selectivity up to 600 °C
- Continued development will focus on increased activity and conversion, while preserving selectivity

EC-GTL System Modeling

- System Process Flow Sheet Identifying the balance-of-plant processing requirements developed
- Performed system simulations based on thermodynamics first principle methods
- Focus on low-volume (~100 MCFD) associated gas systems
- Cost estimate based on prior fuel cell system development



Results of the System Analysis Basis: One Barrel Per Day (BPD) of Methanol Production		
Raw Gas Input	3.0	MCFD
Cell Area	12.5	M^2
Gross DC Power	12.48	kW
Plant Parasitic Loads	0.90	kW
Net AC Power Output	10.9	kW

EC-GTL System Cost

Case Study for 40 BPD Plant

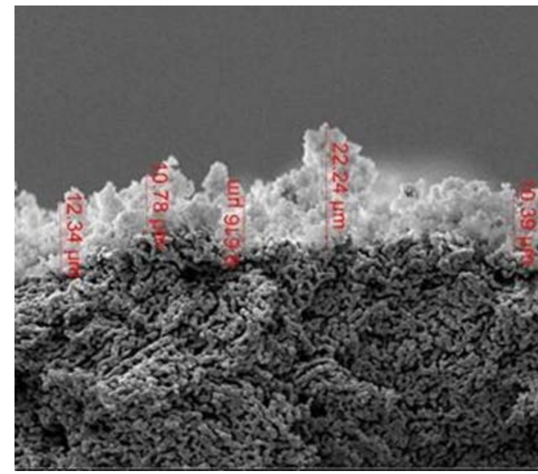
- Cell performance assumptions based on end of project milestones
- Equipment and Stack cost estimated based on SOFC systems of comparable scale
- Gas composition based on Bakken associated gas

PILOT EC-GTL SYSTEM ANNUAL OPERATING COST			
ANNUAL OPERATING COST ITEMS			
	FUEL CELL STACK REPLACEMNT(3 RPLCMNTS)	$	11,459
	FUEL (FLARED GAS)		0
	FUEL DESULFURIZER (10% UNIT COST)	$	29,883
	SYSTEM OPERATION(O&M)		
	2 TECHS ,$50/HR, 2200HR/YR)	$	220,000
	TOTAL	$	261,342
ANNUAL REVENUES			
	POWER SALE (486.4 KW) (6 CENTS/KWHR)	$	229,050
	METHANOL SALES (1.14GPM)($1.33/GAL)	$	716,909
	TOTAL	$	945,959
ANNUAL COST			
	ANNUALIZED CAPITAL COST @ 8%	$	173,000
	ANNUAL OPERATING COST	$	261,342
	ANNUALIZED INSTALLATION COST	$	153,000
	TOTAL	$	587,342
PAYBACK PERIOD, YRS	ANNUAL COST/REVENUES		0.62
RATE OF RETURN,%	ANNUAL REVENUES - ANNUAL COST/INITIAL COST		21%

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Results

- Material selection – parallel path development of multiple cell designs show promise to meet project performance milestones
- Fabrication – RSDT parameters have been refined to new material sets to deposit layers with desired characteristics
- Catalyst development – Multiple catalysts have shown very high selectivity to desired products
- System analysis has shown the EC-GTL has the potential of co-generating 10 kw net electricity while producing one Barrel of methanol per day (BPD), with promising economics



RSDT Fabricated Anode Functional Layer for EC-GTL cell

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Future Plans

- Continued development of GTL catalyst
- Incorporation of GTL catalyst to anode layer for electrochemical evaluation
- Continued fabrication development of RSDT for materials
- Refined Techno-economic analysis with actual cell performance

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Acknowledgements

- DOE/ARPA-E: Ping Liu, John Lemmon, John Tuttle, Mark Pouy
- PNNL: Olga A. Marina
- EERC: Ted Aulich
- UCONN: Radenka Maric, Mark Aindow, Na Li
- MIT: Bilge Yildiz
- FCE: Hossein Ghezel-Ayagh, Alireza Torabi, Mick Barton, Robert Sanderson