Dioxide Materials™

The CO_2 Recycling Company™

SBIR Phase I: Conversion of CO_2, Water and Renewable Energy to Transportation Fuels

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Why Fuels?

CO_2 Utilization for Chemicals

		US Production, Estimated 2015				Global Production, Estimated 2015			
		Mt	Gmol	GWe Coal at 90% Capture	GWe Gas at 90% Capture	Mt	Gmol	GWe Coal at 90% Capture	GWe Gas at 90% Capture
1	Sulfuric Acid	39.3	401.1	2.3	5.6	210.0	2.1	11.0	26.8
2	Nitrogen	31.2	1114.8	6.4	15.5	123.8	4.4	22.7	55.3
3	Ethylene	26.0	813.9	4.6	11.3	150.0	4.7	24.1	58.6
4	Oxygen	24.4	869.4	5.0	12.1	88.7	3.2	16.2	39.5
5	Lime	19.9	355.3	2.0	4.9	367.1	6.5	33.6	81.8
46	Propylene Oxide	2.1	35.5	0.2	0.5	5.5	0.1	0.5	1.2
47	Phenolic Resins	1.5	14.7	0.1	0.2	6.0	0.1	0.3	0.8
48	Calcium Carbonate	3.1	31.5	0.2	0.4	14.7	0.1	0.8	1.8
49	Butadiene (1.3)	2.7	50.5	0.3	0.7	12.9	0.2	1.2	3.0
50	Nylon Resins & Fibers	0.8	3.4	0.0	0.0	2.8	0.0	0.1	0.1
	TOTAL	453	9368	53	130	2620	57	290	708
	2015 Net Generation, GWe-yr			155	152			>1000+	
	CO2e from Electricity	2,000	45,500			10,500	239,000		
	CO2e from All Sources	6,890	156,600			37,000	841,000		

$R + CO_2 \rightarrow RCO_2$
Limited supplies of R & limited sales of RCO_2
CO_2 Emissions >> CO_2 Utilization

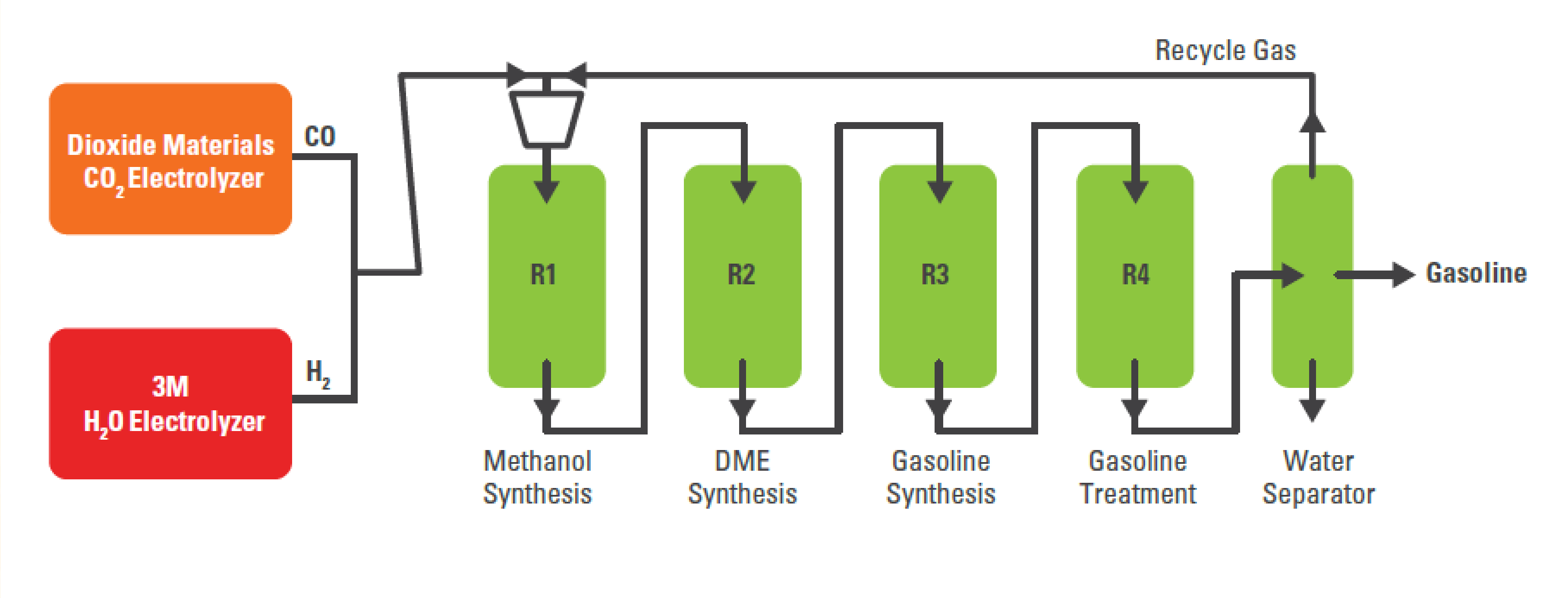
Abhoyjit Brown, NETL Capture Review, Aug 8, 2016

EPRI Electric Power Research Institute

US Production

- Gasoline: 447 million MT of gasoline
  - Need 1.45 Billion MT of CO_2 to make 447 million MT of gasoline
- Diesel: 192 million MT of Diesel
  - Need 0.65 Billion MT of CO_2 to make 192 million MT of Diesel

Objective: Create A System To Convert CO_2 From a Power Plant Into Synthetic Fuels



Dioxide Materials™ PRIMUS GREEN ENERGY™ Your GTL Partner™ 3M

Background

Our Capabilities

Creating a multi-billion dollar CO_2 Recycling Business

Company Founded 2009 – Started Operations 2010 in Champaign IL
Corporate office relocated to Boca Raton June 2015

Now 16 people – Largely grant funded

Present situation:

*Lab Scale CO2 Recycling Unit Largely working; doing long term studies of performance, and expect to start pilot plant studies within 12 months.

5 Issued US patents, 2 allowed many pending in US and abroad

Received ~$14 M – Government funding

Building Energy Efficient Electrolyzers to Convert CO_2 to Industrial Chemicals (*"renewable hydrocarbons"*)

- Based on paper in Science

Science AAAS

Science 4 November 2011:
Vol. 334 no. 6056 pp. 643-644
DOI: 10.1126/science.1209786

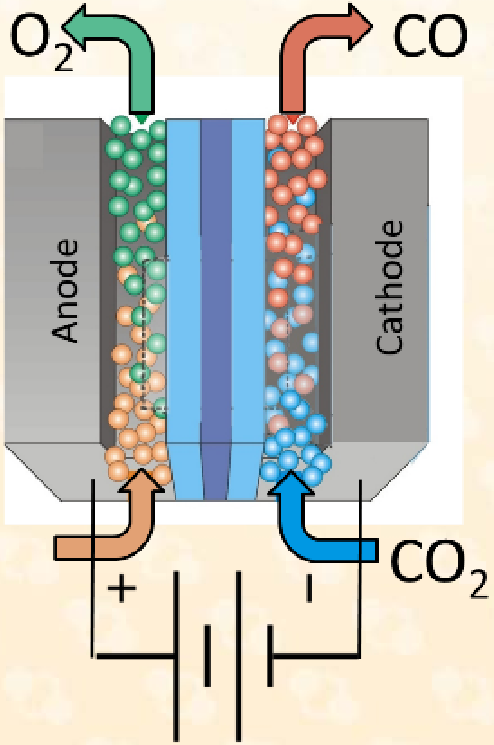
Ionic Liquid Mediated Selective Conversion of CO_2 to CO at Low Overpotentials

Brian A. Rosen, Amin Salehi-Khojin, Michael R. Thorson, W. Zhu, Devin T. Whipple, Paul J. A. Kenis, Richard I. Masel

- How does it work?

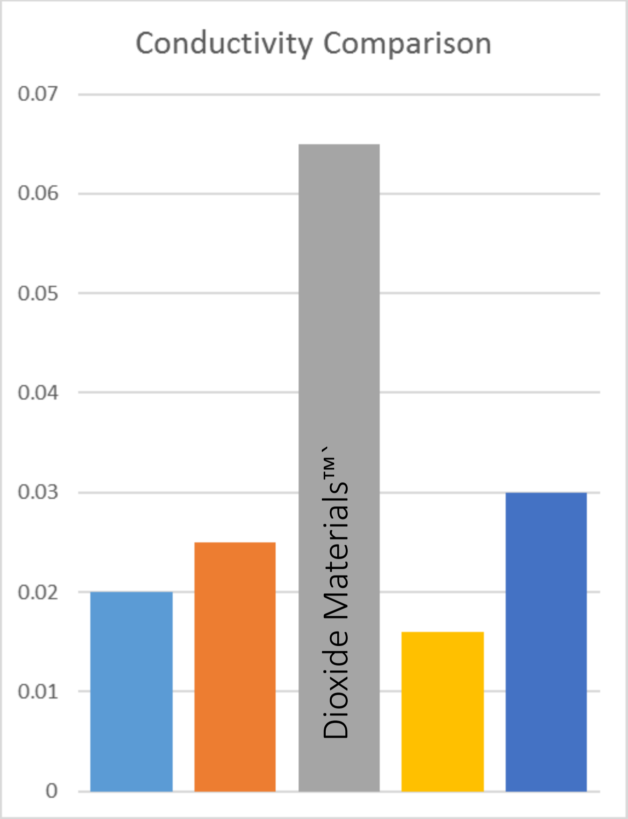
  CO_2 converted to CO + O_2 in an electrolyzer
- What is novel about it?

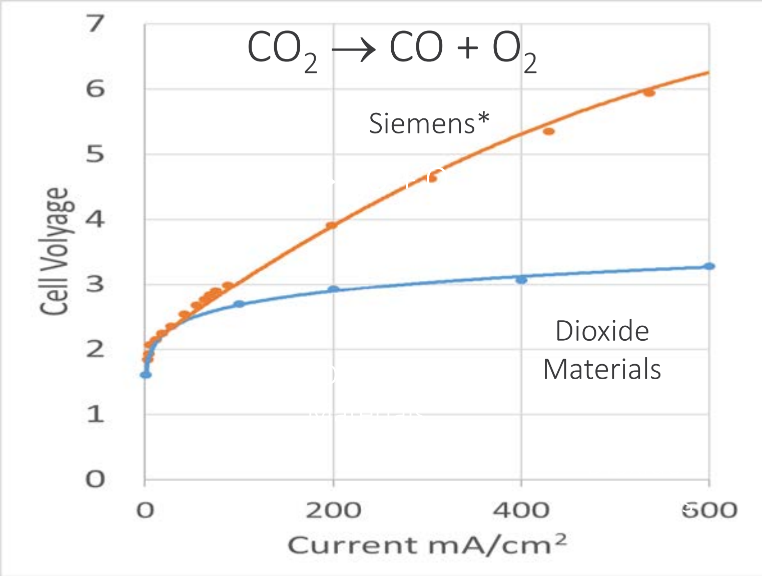
  Use combination of metallic and organic catalysts to lower the overpotential by 0.8 V



Our Advantages

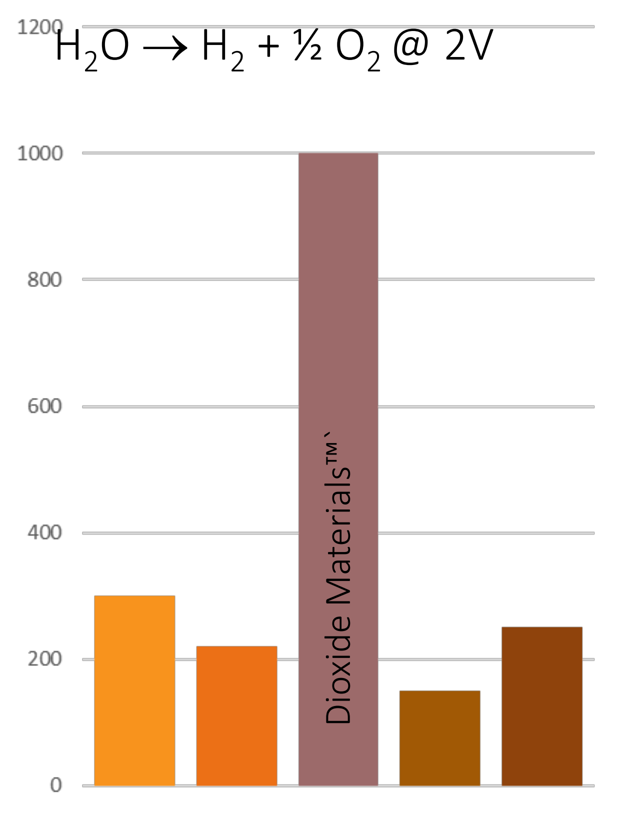
Better Materials



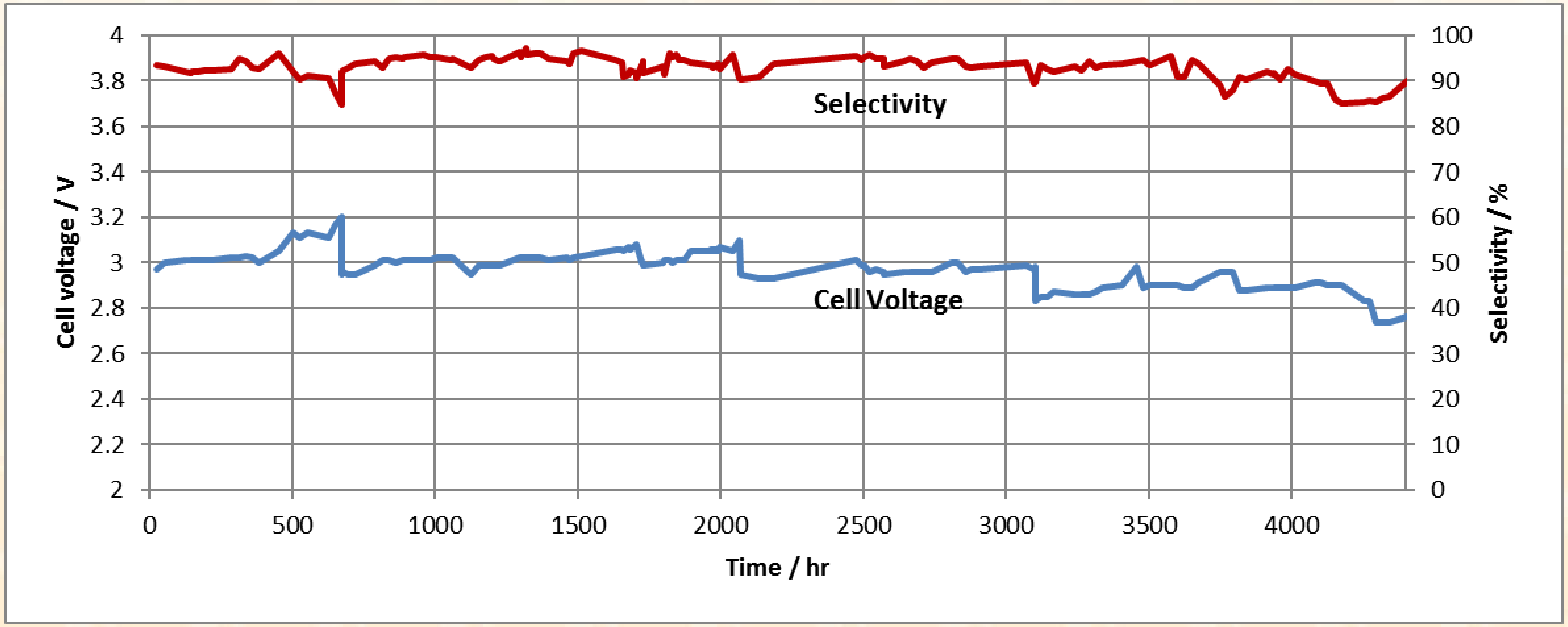


*G. Schmid, M. Fleischer, K. Wiesner, R. Krause, Electrochemical CO_2 Reduction
http://www.sccer-hae.ch/resources/Talks/08_Krause_Power_to_Value.pdf

Better Performance



Stable Long-Term Performance



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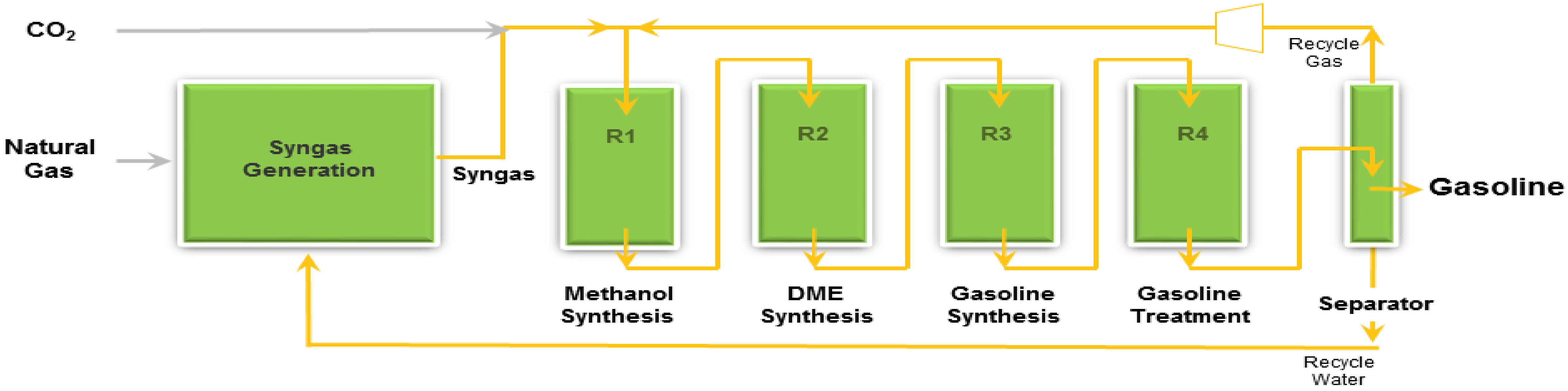
Gasoline Process in Detail



- Continuous gas-phase process, no intermediate condensations
- Standard fixed-bed catalytic reactors
- Standard catalysts with long lifetimes
- Gasoline meets standard RBOB/CBOB specs

Commercial Demonstration Plant

- Start up: Oct 2013
- Commercial testing for variable gas composition and process optimization
- Scaled-down commercial plant
- >8500 hrs operation
- >99.5% availability

"Primus has constructed a first class demonstration facility that has substantially demonstrated the efficacy of its STG+ technology"

-E3 Consulting, Independent Eng. Report

Standard Commercial Plants

Feed Gas Type	Liquid Product	Feed Gas Flow MMSCF/D*	Feed Gas Flow NM^3/D*	Production Capacity
Natural Gas	Gasoline	4-5	110,000-130,000	500 bpd
Natural Gas	Gasoline	17-20	450,000-540,000	2000 bpd
Syngas	Gasoline	17-20	450,000-540,000	500 bpd
Syngas	Gasoline	68-80	1.8-2.1 million	2000 bpd

Convert 300,000 MT/yr of CO_2

Prin Abbott power plant produces ~320,000 MT CO_2/yr

Next: The SBIR Phase I Program

Objectives Of The Phase I Program

- Preliminary design of interface between 3M/Dioxide electrolyzers and Primus Green Energy's Syngas to fuels unit (80% done)
- Explore novel flow field designs for large electrolyzers (30%)
- Identify issues with using CO_2 from a power plant in the system (20%).

Initial Thoughts About Interface To Power Plant

Dilute CO_2 before CO_2 capture unit

- Electrolyzer runs fine
  - Cap cost higher
  - OP cost the same
- Primus system costs go up
  - Cap cost much higher
    - Higher pressures
    - More expensive reactors
  - Op cost higher
    - Higher compression costs
    - Catalyst poisoning

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Other Activities

- Masel met with Linde on 8/29/2016
  - Interested in adding unit to Abbott Power Plant
- Linde visiting 3M 8/31/2016

Summary: Phase I Going well

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Questions