

Integrated Hydrogen Combustion with Energy Efficient Ethylene Production

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EcoCatalytic Inc/Dow Chemical Company

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This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Timing

- AMOERE Award Notification issued February 2018
- Projected End date June 2020
- Project 0% complete

Partners



- Dow Chemical Company
 - Supporting the project through the resources at Dow's Hydrocarbons Research and Development organization

Budget

	Budget Period 1	Budget Period 2	Total Planned Funding (FY 20-Project End Date)
DOE Funded	\$1.33M	\$0.67M	\$2M
Project Cost Share	\$0.99M	\$1.01M	\$2M

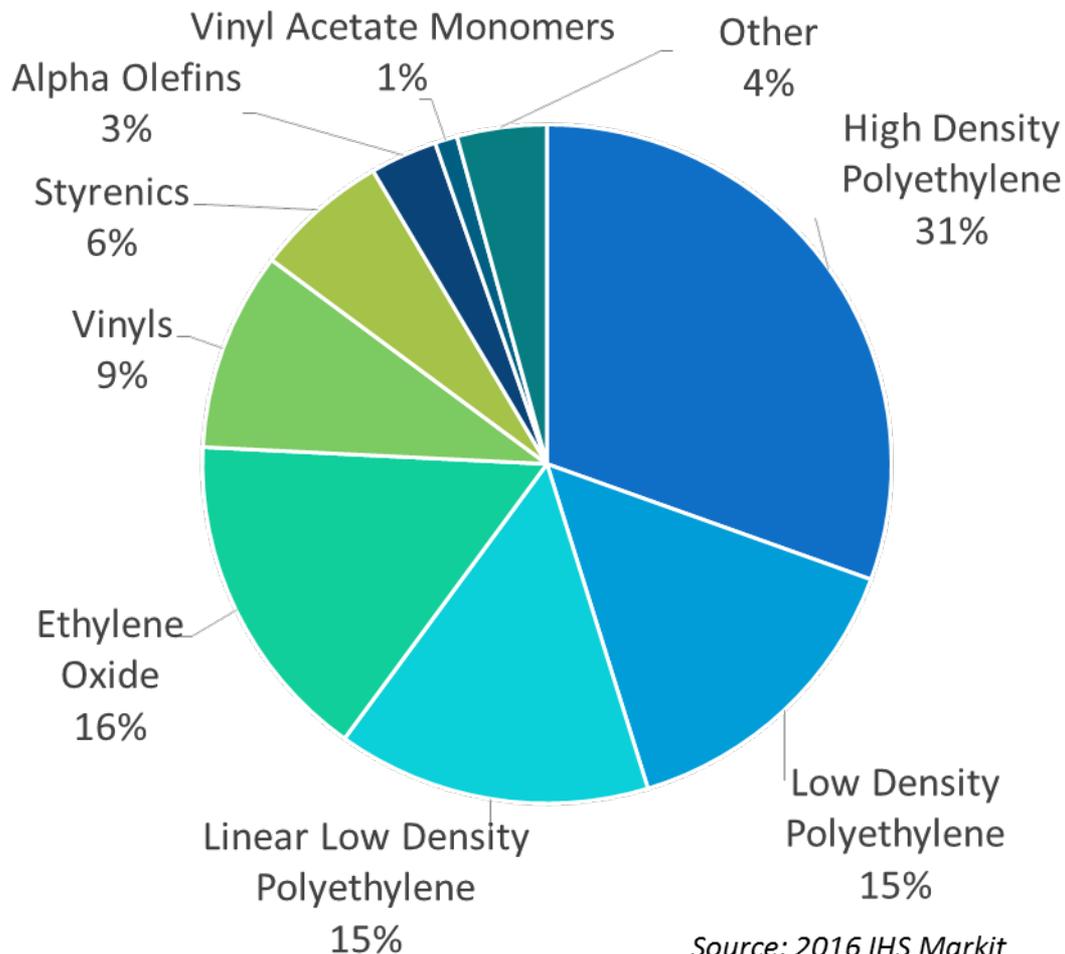
Barriers

- For technology scale-up, the kinetic and hydrodynamic model needs to be demonstrated in a continuous prototype reactor at reaction temperature

Project Objectives

- Traditionally, **ethylene is produced by steam cracking** at a total cost of \$600-800/ton and is a **highly energy intensive** process with a **large CO₂ footprint**.
- Furthermore, ethylene has been identified as **one of largest chemical manufacturing sectors for energy reduction improvements through the development and implementation of novel technologies**, as reported in Chapter 6 of the recent 2015 DOE Quadrennial Technology Review.
- In this project, **EcoCatalytic's IFBHC (Integrated Fluidized Bed Hydrogen Combustion) technology** will address the goals of the DOE's Office of Energy Efficiency and Renewable Energy (EERE)'s Advanced Manufacturing Office (AMO) to **reduce the energy consumption** "by 50% in 10 years" of manufactured goods.
- Through the IFBHC process' increased energy efficiency, this **project's scale-up demonstration will accelerate commercial deployment** and will establish its value proposition to potential manufacturers.
- The success of project will aid in AMO's mission to "**capture [the] U.S. competitive advantage**" by providing an **advanced platform technology** that can be applied for multiple processes such as oxy-combustion for carbon capture and OCM for the U.S. manufacturing industry 2015 DOE Quadrennial Technology Review

Uses for Ethylene



Source: 2016 IHS Markit

Ethylene is a building block to everyday products and is the highest volume building block chemical commodity.

Overall worldwide demand in 2017:
~150 million metric tons ethylene/year and produces 1-1.5 ton CO₂ per 1 ton ethylene*

Current production emits up to **0.15-0.28 Gt CO₂/year***

EcoCatalytic's IFBHC Technology will reduce costs and would emit **0.03-0.04 Gt CO₂/year** if adopted.

*Sources: Tao Ren MP. Olefins from conventional and heavy feedstocks: Energy use in steam cracking and alternative processes. Energy 2006;31:425-51; Ullman's Encyclopedia of Industrial Chemistry (2016)

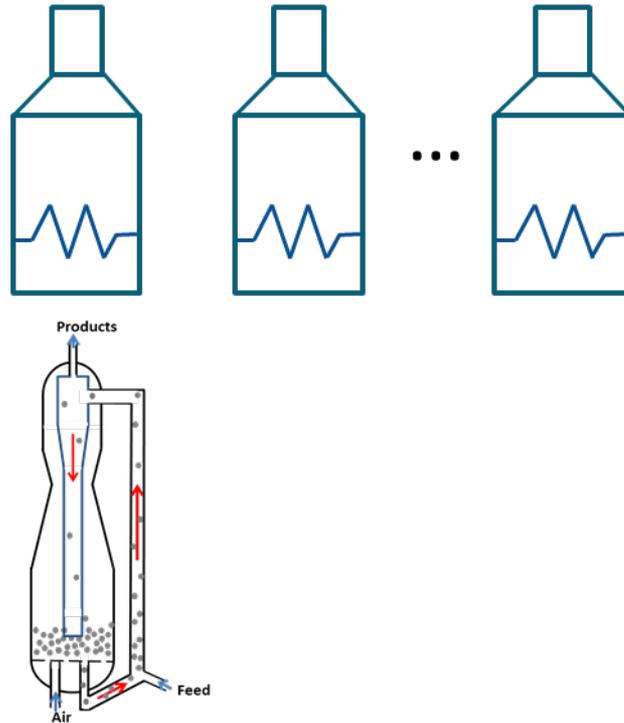
Technical Innovation

- Lower capital costs due to lower energy requirements
- Much lower greenhouse gas emission
- Much higher on-stream time
- Lower number of high temperature reactors
- Easy integration to existing plants due to similar chemical products
- Reduced barrier to entry as EcoCatalytic's reactor similar to FCC design (largest petroleum refining process)

Conventional Steam Cracking

Ethane

EcoCatalytic's IFBHC



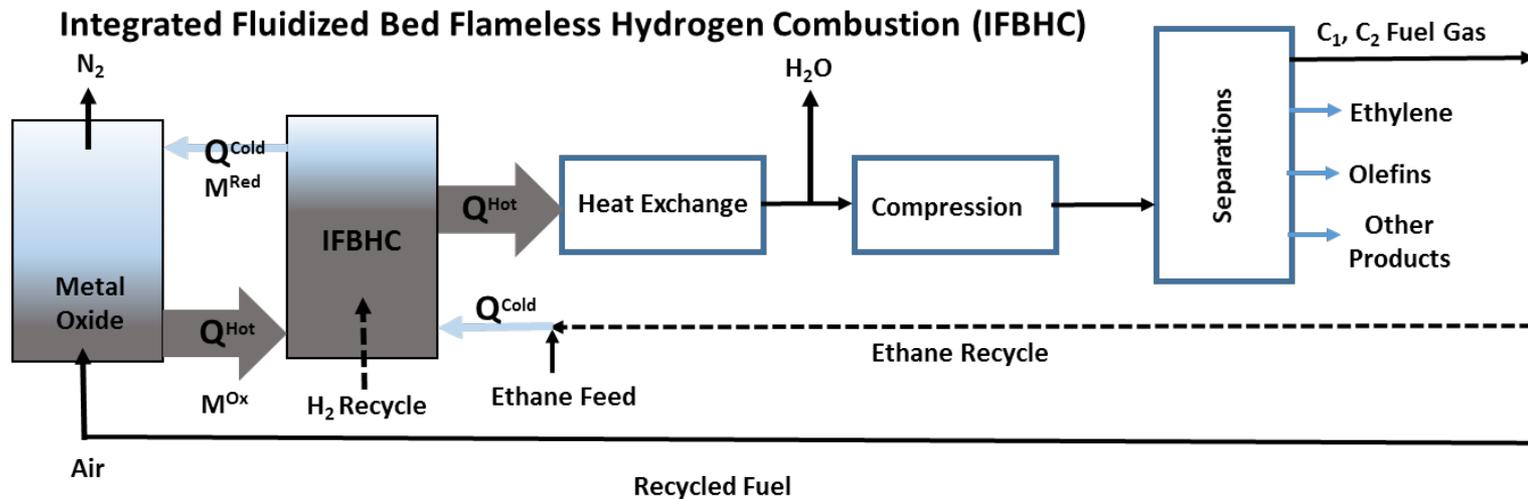
For 1,000,000 t/year Ethylene:

CO ₂ Emissions*	NO _x Emissions
1-2 x 10 ⁶ t/year	5-200 ppm – requiring additional costly removal
1-2 x 10 ⁵ t/year	~0.1 ppm

*Sources: Tao Ren MP. Olefins from conventional and heavy feedstocks: Energy use in steam cracking and alternative processes. Energy 2006;31:425–51; Ullman's Encyclopedia of Industrial Chemistry (2016)

Novel Chemistry :

Rather than cracking ethane, EcoCatalytic uses oxygen transfer agents (OTAs) to convert ethane to ethylene via *the selective combustion of hydrogen in the presence of hydrocarbon feed and products*.



Technical Approach

Team Members:

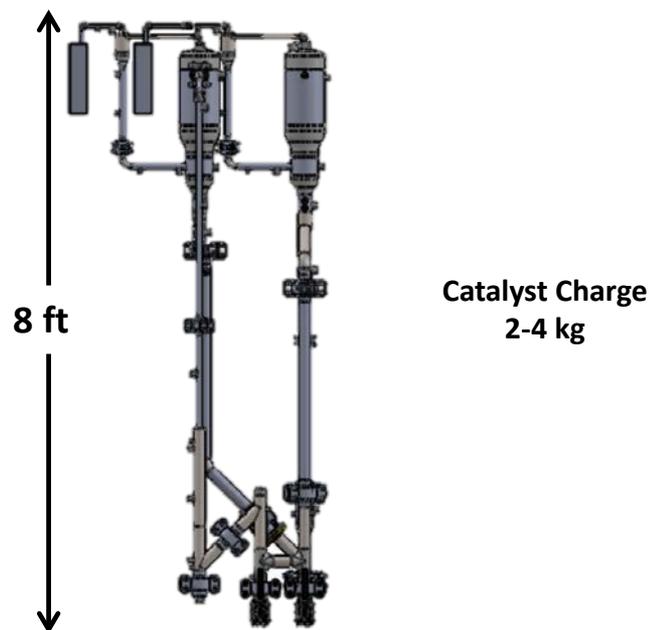


EcoCatalytic Inc is the lead organization and early stage start-up company, developing sustainable technologies for the conversion of natural and bio-based gas to marketable liquid fuels, chemicals and electrical power. EcoCatalytic has experience with similar redox selective oxidation processes.



The Dow Chemical Company is a global leader in chemical manufacturing and is one of the largest ethylene producer worldwide. Dow has experience with similar R&D process scale-up.

Project Demonstration Unit



**Current Step: Prototype TRL 3
Commissioned Q1 2018
at SwRI (San Antonio, TX)**



Results and Accomplishments

Planned milestones

- Defining and meeting the critical commercial characteristics of the OTAs;
- Demonstrating catalyst robustness and performance in a 10 kW_{th} circulating fluidized bed (CFB) reactor; and
- Confirming economic and environmental attractiveness of the proposed process through the development of a comprehensive techno-economic model.

Comparison of target performance metrics

Metric	State-of the Art Ethane Steam Cracker	IFBHC Process
Single pass yield of ethylene (weight %)	56	65
Energy intensity of upstream process including the ethane conversion unit (GJ _{th} /tonne)	7.6	-3.3
Ethane conversion unit(s) capital cost (\$ MM/MM t), based on external capital cost estimates	313	121



10 kW_{th} CFB at SwRI

Transition

2017 Global Capacity: ~150 million metric tons ethylene

Current U.S. price: \$590/t ethylene

Total average industry revenue: ~\$120 billion/year

Sources: 2016 IHS Markit, ICIS News (June 4, 2018)

Unit Description	Prototype Implementation TRL 3	Demonstration Unit TRL 5	1 st Commercial Debottleneck	Full scale Commercial
Ethylene Production, T/yr.	10	3,280	100,000-200,000	1,000,000
Size, MW _{th} (ΔH Feed-Products)	.004	1.3	40-80	400
Scale, % of Commercial	0.001	0.33	10	100
Scale-up Factor	250X	1,500X	30X	10X
Start-up	2018	2020	2023 (est.)	2025 (est.)
Location	San Antonio, TX	Bloomfield, CT	Strategic Partner (Ethylene Producer) Operating Site	TBD



EcoCatalytic's Current Step

Questions?
