Integrated Hydrogen Combustion with Energy Efficient Ethylene Production

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EcoCatalytic Inc/Dow Chemical Company

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Overview Slide

EcoCatalytic

Integrated Hydrogen Combustion with Energy Efficient Ethylene Production

Project Timeline

- AMO Award issued February 2018
- Project Start Date: 9/1/ 2018
- Budget Period End Date: 08/31/2019
- Project End Date: 08/31/2020
- Project 37.5% complete

AMO MYPP Connection:

- Process Intensification

Barriers/Challenges that Project Addresses:

- Goal: Reduce energy intensity of the state-of-the-art
- Ethylene has been identified as **one of the 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.

Project Budget and Costs

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$2,000,000	$1,999,994	$3,999,994	50.0%
Approved Budget (BP-1)	$961,230	$961,042	$1,9222,722	50.0%
Costs as of 3/31/19	$250,591	$250,886	$501,477	50.0%

Overview

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. Dow is supporting the project through the resources at Dow's Hydrocarbons Research and Development organization.

Southwest Research Institute (SwRI) is a research institution equipped with laboratory-scale pilot scale testing facilities. SwRI has experience constructing, modifying and operating the IFBHC pilot unit.

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 CO_2 footprint**.

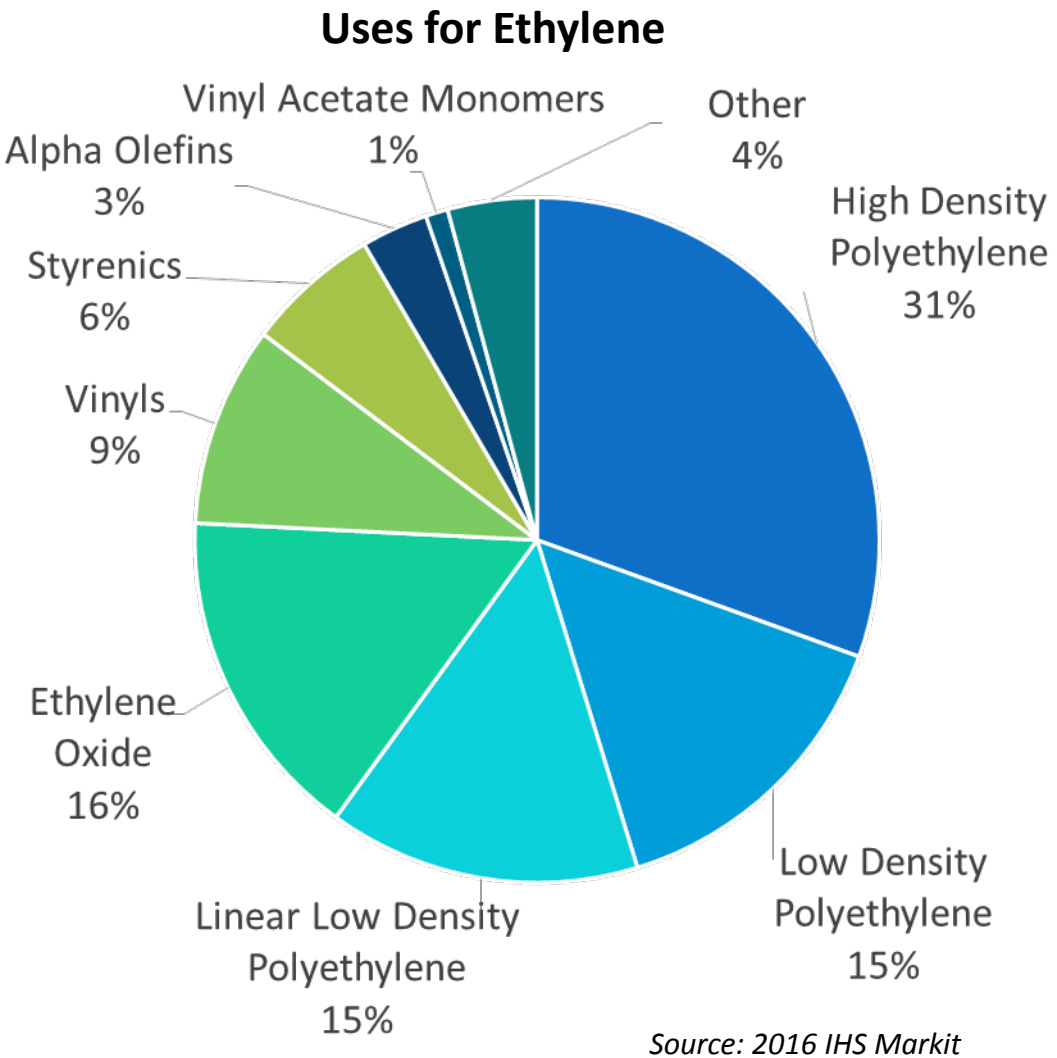
- Furthermore, ethylene has been identified as "**one of the largest chemical manufacturing sectors for energy reduction improvements through the development and implementation of novel technologies,"** as reported in Chapter 6 of the recent 2015 DOE Quadrennial Technology Review.

- In this project, **EcoCatatytic'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

Technical Innovation



Source: 2016 IHS Markit

Ethylene is a building block to every-day 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 CO_2 per 1 ton ethylene*

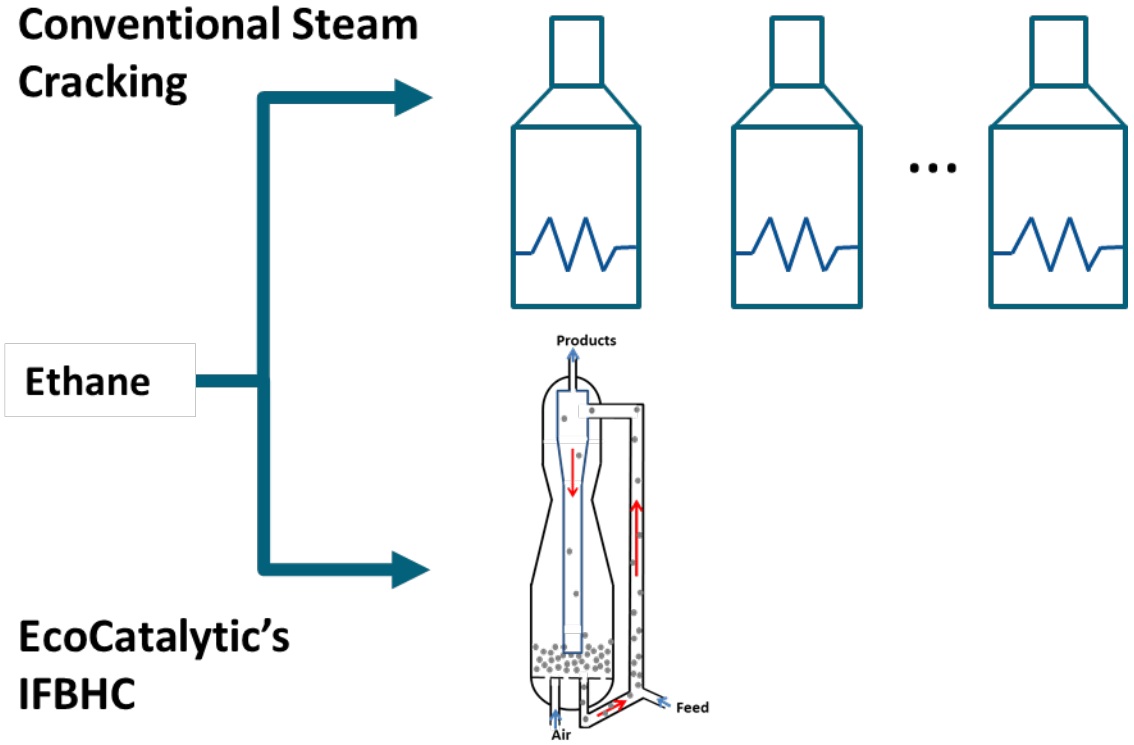
Current production emits up to **0.15-0.28 Gt CO_2/year***

EcoCatalytic's IFBHC Technology will reduce costs and would emit **0.03-0.04 Gt CO_2/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)



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)

Technical Approach

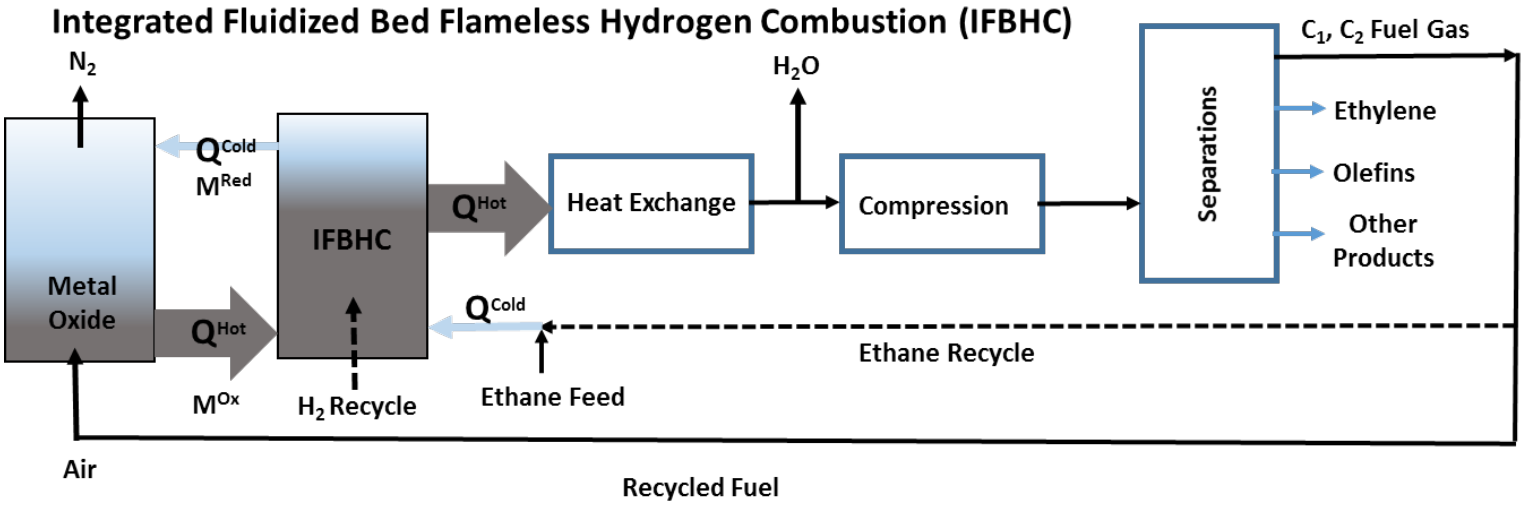
Novel Chemistry :

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***.

$H_2 + OTA^{Ox} \rightarrow OTA^{Red} + H_2O$

$O_2 + OTA^{Red} \rightarrow OTA^{Ox} + Q^{Hot}$

$Ethane + Q^{Hot} \rightarrow Ethylene + H_2 + Q^{Cold}$



Technical Approach

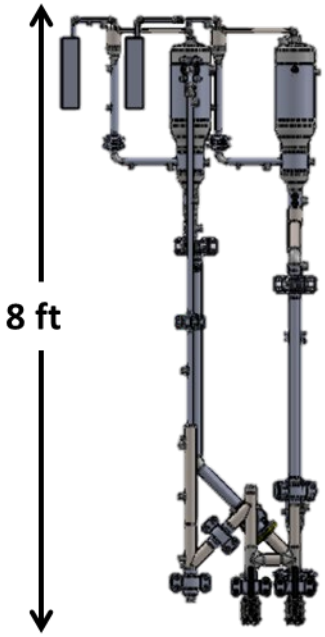
Team Members:

EcoCatalytic Inc is synthesizing catalyst and conducting catalyst evaluations, specifically on performance, scale-up and costs, for the demonstration unit with a commercial catalyst manufacturer.

The Dow Chemical Company is conducting commercial catalyst evaluations, specifically, for agglomeration, defluidization and attrition testing, aiding in demonstration unit engineering, and carrying out the techno-economic analysis of the IFBHC process.

Southwest Research Institute (SwRI) is modifying and operating the demonstration unit for the IFBHC process.

Project Demonstration Unit



Catalyst Charge
8-10 kg

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

Results and Accomplishments

EcoCatalytic

Completed milestones

- Synthesized and Scaled-Up Pre-Commercial Catalyst (9 kg)
- Nearly Completed Life Cycle Performance Testing (one month commercial) and Commercial Cost Evaluation of the Catalysts;
- Started Modifications of the Demonstration Unit

Fixed Bed Catalyst Testing Reactors at EcoCatalytic

Work to be Completed

- Develop Commercial Catalyst for the Process
- Demonstrate catalyst robustness and performance in a 10 kW_{th} circulating fluidized bed (CFB) reactor; and
- Confirm economic and environmental attractiveness of the proposed process via techno-economic model.

10 kW_{th} CFB at SwRI

Final Project Targets

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

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	1st 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

Technology IP Position

- EcoCatalytic is developing a technology platform position for the conversion of hydrocarbons to olefins and fuels using Chemical Looping systems
- Relies on background patents – 5 non-provisional published patents
- Coverage includes
  - Catalyst/Oxygen Transfer Agent composition of matter
  - Process and reactor design
  - Broad range of process conditions for C1 to C12+ hydrocarbon conversion
  - No licenses or sublicenses required from third parties for freedom to practice or license out
- Patent prosecution fully funded by private investment from EcoCatalytic founders