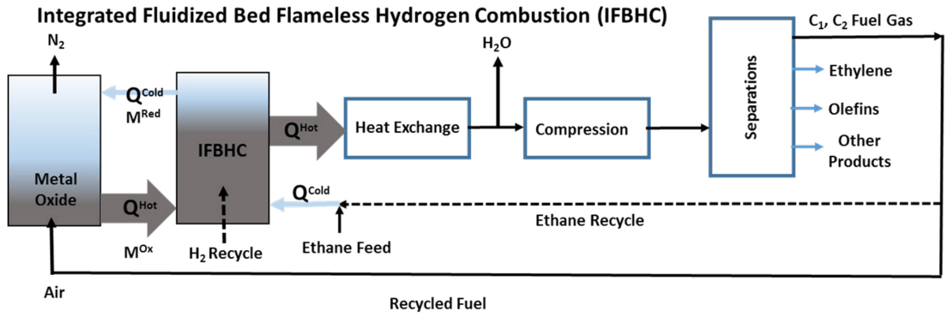
Integrated Hydrogen Combustion with Energy-Efficient Ethylene Production



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

Ethylene is the highest volume chemical commodity used as a building block to develop every-day products such as plastics, paints, adhesives, and solvents. In 2016, about 27 million tons of ethylene were produced in the United States and with growing extraction from shale deposits, additional ethylene production capacity is currently under development. Traditionally, ethylene is produced in steam cracking furnaces powered by natural gas and recycled fuel gas. This production method is highly energy-intensive and generates carbon dioxide (CO_2) and nitrogen oxide (NOx) emissions. Ethylene producers have started blending hydrogen fuel with the furnace fuel to reduce overall plant CO_2 emissions, however this practice increases NOx emissions. Ultra-low NOx burners or selective catalytic reduction units can offset this NOx increase, however these solutions increase both operational and maintenance costs.

This project intends to advance a new alternative to steam cracking through the validation of the Integrated Fluidized Bed Flameless Hydrogen Combustion (IFBHC) technology for energy-efficient, low-emission conversion of ethane to ethylene. This work builds on the well-known and proven process to produce electricity using fluidized bed boiler technology and chemical looping fluidized bed flameless combustion. The IFBHC will apply this body of knowledge to produce a higher valued product - ethylene. By combusting hydrogen in the IFBHC process, the ethane-to-ethylene chemical equilibrium is favorably shifted such that higher ethane conversions can be obtained.

Benefits for Our Industry and Our Nation

The IFBHC process under development can optimize hydrogen combustion to improve ethane conversions to ethylene. Higher conversion rates allow for smaller required reactor sizes and compressors, which leads to a reduction in compression energy consumption and greenhouse gas emissions. IFBHC would also enable producers to avoid expensive cryogenic processes to separate the hydrogen from the ethylene product stream, reducing capital costs and refrigeration energy. Compared to state-of-the-art steam cracking, the IFBHC is expected to accomplish the following:

- Reduce CO_2 emissions by more than 80% and eliminate NOx emissions through energy-efficient and higher-yield ethane to ethylene conversions
- Reduce capital and maintenance costs with the potential to replace up to 10 typically-sized steam cracking furnaces with a single fluidized bed reactor

Applications in Our Nation's Industry

In addition to ethylene production, the knowledge gained in scaling up this process could be used directly for hydrogen combustion units that target the power markets. This mode of ethylene production generates valuable derivatives for high-value polymers and specialty chemicals. This technology also provides an advanced platform technology that can be applied to ethylene production through oxidative coupling of methane (OCM) and other processes such as oxy-combustion for carbon capture.

Project Description

The primary project objective is to validate and evaluate the technical and economic potential of the IFBHC process for converting ethane to ethylene with reduced energy consumption. Technical objectives will optimize the IFBHC family of catalysts and scale up production of an advanced catalyst at a commercial level. The performance of the IFBHC prototype will be evaluated under varying conditions to ensure optimal yields. A techno-economic analysis will be conducted to compare the IFBHC process to the state-of-the-art ethane steam cracking process.

Barriers

- Demonstrate a kinetic and hydrodynamic model in a continuous prototype reactor at reaction temperature.
- Demonstrate OTA attrition resistance and maintain activity when scaled up for the prototype.
- Rigorous testing of heat transfer rates in the commercial-size prototype.

Pathways

To validate and advance the IFBHC process and technology toward commercial scale-up, the project team will evaluate critical scale-up technical challenges, conduct a comprehensive techno-economic analysis, and develop recommendations for a commercialization pathway.

The first scale-up task will optimize the solid material catalysts, the OTAs, for desired commercial characteristics. Second, the team will evaluate whether the transport of the OTAs in fluidized reactor beds is suitable for delivering the catalysts to the prototype unit. After de-risking the catalyst performance and solids transport control, the prototype unit will be modified and operated with a baseline OTA to test ethylene yield performance. An advanced OTA will then be synthesized and tested in the prototype for its ethylene yield performance.

The advanced OTA and its performance data will be evaluated to develop a comprehensive techno-economic analysis of a commercial-scale IFBHC process. The analysis will also recommend technical design and commercial pathways for the next phase of development. A high-level commercialization plan will identify the size and site of the next process scale-up, along with a funding strategy for the next phase of technology development.

Milestones

This two-year project began in September 2018.

- Optimize OTA catalysts for 65%-72% yields and demonstrate its synthesis at a commercial scale and within cost targets (2019)
- Commission prototype and test catalyst performance under varying conditions (2020)
- Demonstrate over 100 hours of continuous operation with the advanced OTA, maintaining an optimal 65%-72% conversion (2020)
- Conduct techno-economic analysis, identify next steps and site for scale-up site, and develop commercialization plan (2020)

Technology Transition

EcoCatalytic Technologies is partnering with Southwest Research Institute and the Dow Chemical Company, a global leader in chemical manufacturing and one of the largest ethylene producers worldwide, to scale the IFBHC process to an existing prototype unit. Upon successful performance of the prototype, the next step in advancing the technology into the market would be a debottlenecking unit at an existing facility on the order of one-tenth of a typical full-scale production unit. After successful validation at commercial scale, the technology may be considered the best available control technology (BACT) standard for CO_2 and NOx emissions from ethane steam cracking plants, which would enhance the adoption of this technology.

Project Partners

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