U.S. DEPARTMENT OF
ENERGY

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ENERGY EFFICIENCY & RENEWABLE ENERGY

Low-Energy, Low-Cost Ethylene Production by Low-Temperature Oxidative Coupling of Methane

Ethylene, one of the highest volume production chemicals in the U.S. and globally, is an essential chemical building block that is used to manufacture countless products, from packaging to antifreeze to tires. Most ethylene is produced via a process called steam cracking, where the feedstock (mostly ethane, sometimes naphtha or propane) is heated to high temperatures over a catalyst. The naphtha feedstock typically comes from petroleum refineries, while ethane is becoming increasingly used as a feedstock in the U.S. due to the rise in domestic natural gas production from shale resources. However, steam cracking is energy intensive and occurs in large- scale facilities.

Low-temperature oxidative coupling of methane (LT-OCM) is an alternative ethylene production method that converts methane (natural gas) and optionally ethane to ethylene in a single-step, energy-producing conversion system using an innovative process. While OCM has been studied for over 30 years due to its potential to reduce ethylene production cost, past efforts did not result in a viable catalyst with performance needed for commercialization. These catalysts, while at times achieving promising yield and selectivity, were hampered by very high operating temperatures, low activities, and short lifetimes on the order of hours to days.

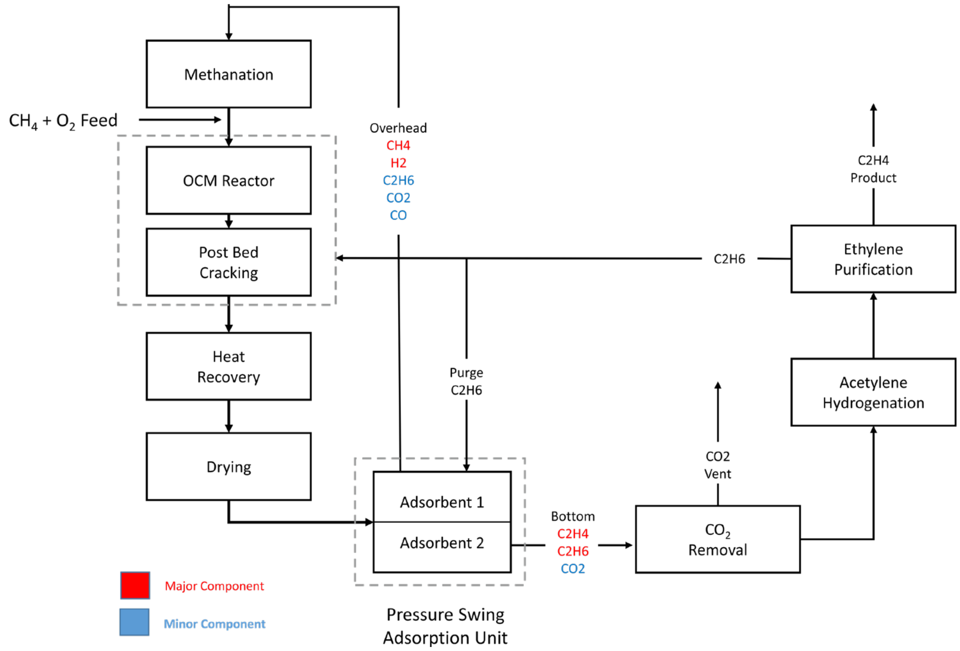

Figure 1. Final modeled process configuration using two-layered bed approach (Adsorbent 1 and 2) and ethane (C_2H_6) purge to regenerate the adsorption bed. The light product stream (Overhead) is sent into the methanation reactor where H_2 is used to convert CO and CO_2 back into methane.
Graphic courtesy of Siluria Technologies Inc.

Recognizing this, Siluria applied a combination of new innovations in catalyst development and a thorough definition and understanding of the problem to develop unique catalysts that enable commercialization of OCM. The OCM catalysts operate at significantly lower temperature (several hundreds of degrees lower) and practical operating pressures (5-10 atmospheres), have high activities and standard lifetimes of years under said conditions. In addition, the simple process (Figure 1) provides excellent scalability and flexibility, especially when compared to today's mega-scale steam crackers, thus enabling small- volume "distributed scale" reactors for on-demand ethylene production for applications such as on-site conversion of ethylene to high value polymer derivatives.

Benefits for Our Industry and Our Nation

This innovative technology has many potential benefits, including:

- Improved ethylene manufacturing energy efficiency
- Reduced lifecycle emissions of carbon dioxide and other pollutant emissions compared to traditional ethylene production methods
- Tapping ubiquitous natural gas reserves as feedstock for production of high value petrochemicals, lowering the dependence on crude oil
- Enabling economically competitive, distributed, small-scale production of ethylene for on-site generation of high-value derivatives such as polymers

Applications in Our Nation's Industry

Ethylene is an important chemical that is produced upstream by a small number of large-scale facilities, consumed downstream by many producers, and converted into various products. This project offers a distributed, small-scale ethylene production solution for the downstream consumers, due to its unique combination of utilizing cheap feedstock (natural gas), and simple overall process design.

Project Description

This project developed a new process for distributed small-scale production of ethylene by oxidative coupling of methane at low temperatures using the advanced OCM technology developed by Siluria Technologies. The original design showed excellent scalability for regional-world scale ethylene capacities. However, the specific operating and capital costs increased sharply for lower capacities. This project overcame the hurdles for small-scale implementation of ethylene production through oxidative coupling of methane by developing novel metal organic framework (MOF) adsorbents and incorporating a pressure swing adsorption based separation system (Figure 1).

Barriers to small-scale production

- Certain unit operations in the original design require minimum capital expenditure and are cost efficient only at large scale.
- Changes to the process scheme to address the above issues necessitated a complete re-evaluation and optimization of the current large–scale OCM process scheme.

Pathways

The project was completed over the course of three phases: detailed process analysis for scalability of the current OCM design to identify roadblocks for small-scale implementation; process design and materials development using alternative process concepts that overcame the bottlenecks identified in the first phase; and refined conceptual design and techno-economic analysis for the final optimized process model.

Milestones

This project began in October 2015 and completed successfully in September 2017.

- Identified alternative process concepts/technologies that demonstrate potential to meet performance and cost targets at small-scale
- Refined alternative process concepts/technologies, validated with refined experimental laboratory data suitable for application in small-scale OCM process
- Validated LT-OCM process concepts for small-scale ethylene production with simulations and experimental laboratory data
- Completed techno-economic analysis of final modeled process with total feed and energy consumption lower than 20 million BTU per ton ethylene and cost advantaged to merchant ethylene produced by cracking

Accomplishments

- Identified and evaluated a novel metal organic framework (MOF) class adsorbent with remarkable ethylene separation capabilities which was integrated into a pressure swing adsorption (PSA) based separation process.
- Economic analysis of the final configuration suggests a potential significant energy savings (>15%) and an improved down-scalability below 60 kilotons/year enabling small scale distributed production of ethylene via OCM process that uses natural gas as its feedstock.

Technology Transition

Siluria and research partners are looking for partners interested in supporting the next steps toward deploying the technology. Further research to mature the MOF class materials is needed to make them ready for commercial use, especially when compared to traditional zeolite adsorbents. Setting up a pilot plant that is fully integrated with an OCM reactor will verify the current observations and assist in investigating the behavior of minor species in the gas stream. Finally, more detailed simulations will be needed to make a final commercial design and process configuration. Adsorbent based separation systems have a multitude of operation parameters that affect the recovery and purity of the product. This requires reconfiguration of the downstream units, and ultimately understanding the impact on the economics of the overall unit.

Project Partners

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Project final report available at:
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