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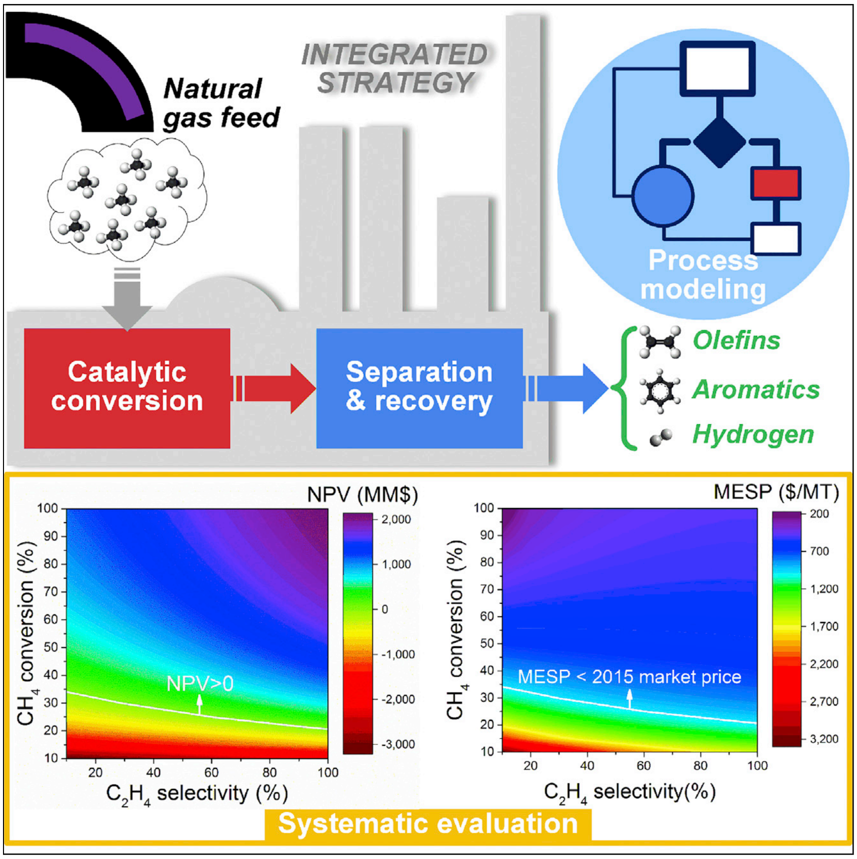
A General Framework for the Evaluation of Direct Nonoxidative Methane Conversion Strategies



Natural gas is a versatile chemical feedstock. While the direct conversion of methane to olefins and higher hydrocarbons has received significant attention, there exist a number of open questions regarding the development of cost-effective methane-to-chemicals integrated processes. To address some of these questions, we develop a general systems-level framework for the systematic evaluation of various strategies and the identification of key technology gaps and economic drivers.

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HIGHLIGHTS

A framework for the analysis of natural gas conversion strategies is proposed

A general systems-level model is developed and economic feasibility is assessed

Coke formation appears to be the major technical bottleneck

Methane one-pass conversion and ethylene selectivity are the major economic drivers

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A General Framework for the Evaluation of Direct Nonoxidative Methane Conversion Strategies

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SUMMARY

In this paper, we study single-step natural gas conversion technologies that directly convert methane to olefins and higher hydrocarbons. Despite the relative simplicity of these technologies, the development of processes based on these approaches remains challenging. Accordingly, we utilize process synthesis and modeling to assess the economic feasibility of direct nonoxidative methane conversion strategies. We develop a flexible approach that allows for the systematic evaluation of various technology alternatives and for the identification of the key technology gaps that must be overcome. The results of our analyses demonstrate that an economically feasible direct methane conversion process is contingent upon fundamental research advances in the area of catalytic conversion to increase methane conversion to hydrocarbon products (e.g., coke formation less than 20% and a minimum conversion to products of 25%). Upon this development, further efforts can be devoted to improve ethylene selectivity as well as reduce catalyst cost and overall capital costs.

Context & Scale

Natural gas is a versatile and relatively clean chemical feedstock. The development of natural gas conversion technologies has recently received significant attention due to the increase of natural gas supply in the United States and low natural gas prices relative to crude oil. The conversion of natural gas into chemicals presents a promising means of utilizing an abundant resource while achieving energy security and mitigating pollutant emissions. Yet the direct conversion of methane to olefins is still at the basic research level, and it is unclear which of, and to what extent, these technologies must be improved to develop a commercial process. Toward this goal, we develop a simple yet flexible framework that allows for the systematic evaluation of various process alternatives and the identification of the key technology gaps.

INTRODUCTION

Natural gas, which is primarily composed of methane (80%–95% by volume) and other light alkanes, is used mainly as a direct fuel for household and industrial heating and power generation. In 2016, proven global reserves of natural gas were estimated to be 6,879 trillion cubic feet.[1] According to the International Energy Outlook 2016, worldwide annual natural gas consumption is projected to increase from 120 trillion cubic feet in 2012 to 203 trillion cubic feet in 2040. However, natural gas is underutilized as a feedstock for the production of liquid transportation fuels and chemicals, including synthetic materials and plastics. These "chemical uses" account for only 5% of the total natural gas consumption, 70% of which is used for ammonia manufacturing, 20% for methanol synthesis, and the remainder for a variety of chemicals such as hydrogen cyanide, acetylene, oxo chemicals, and others.[2]

Before distribution through pipelines, natural gas is first dehydrated, then stripped of carbon dioxide, hydrogen sulfide, and higher alkanes to produce a fairly pure methane stream (~93 vol%).[3] Besides the primary methane component (for hydrogen, ammonia, and methanol production), the ethane component can be converted to ethylene by steam cracking. Likewise, propane and butane components can be converted to propylene and butadiene. These olefins are building blocks for a wide variety of industrial and consumer chemicals, including resins, plastics, and adhesives. Globally, ethylene production was about 150 million tons in 2015, and the worldwide olefin demand is predicted to grow steadily at a rate of