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.
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.

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. 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.

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%). 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...
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