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Life cycle assessment of energy consumption and GHG emissions of olefins production from alternative resources in China

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ABSTRACT

Olefins are important platform chemicals widely used in industry. In terms of the short supply of oil resources, natural gas and coal are two significant alternative feedstocks. In this paper, energy consumption and GHG emissions of olefins production are analysed with life cycle assessment methods. Results showed the energy consumption and GHG emissions of natural gas-to-olefins are roughly equivalent to those of oil-to-olefins, while coal-to-olefins suffers from higher energy consumption and serious GHG emissions, including 5793 kg eq. CO_2/t olefins of direct emissions and 5714 kg eq. CO_2/t olefins of indirect emissions. To address the problem, the effect of carbon capture on coal-to-olefins is investigated. In comprehensive consideration of energy utilization, environmental impact, and economic benefit, the coal-to-olefins with 80% CO_2 capture of the direct emissions is found to be an appropriate choice. With this carbon capture configuration, the direct emissions of the coal-to-olefins are reduced to 1161 kg eq. CO_2/t olefins. However, the indirect emissions are still not captured, which should be strictly monitored and significantly reduced. Finally, a scenario analysis is conducted to estimate resource utilization and GHG emissions of olefins production of China in 2020. Several suggestions are also proposed for policy making on the sustainable development of olefins industry.

1. Introduction

Olefins production is one of the most important petrochemical processes. With the quick development of olefins industry, Chinese ethylene and propylene capacity accounted for 9.4% and 16.8% of the world total in 2010, respectively. The self-sufficiency rates of ethylene and propylene in China would be only 53% and 74% by 2015 [1].

Olefins are generally produced by naphtha cracking process. However, the fossil energy reserves of China are characterised by richness in coal, while scarcity in oil and natural gas. As shown in Fig. 1, coal, oil, and natural gas accounted respectively for 75.1%, oil 15.2%, and 2.8% of the total energy production [2]. It was reported that China has imported 271 Mt oil in 2012, accounting for 56% of the total oil consumption (478 Mt) [3]. The sustainable and healthy development of olefins industry requires diverse resources from both domestic and oversea.

The natural gas-to-olefins (NTO) has two alternatives in China, natural gas based domestic methanol-to-olefins (NDMTO) and natural gas based oversea methanol-to-olefins (NOMTO). Due to the shortage of natural gas, the Chinese government encourages its use as urban fuel gas to relieve the increasingly serious air pollution in major cities, while limits its use as industrial feedstock [4]. On the other hand, oversea methanol produced from natural gas could be an attractive alternative to produce olefins in coastal areas of China. The NOMTO process has been drawing the attention of the chemical processing industry, in light of its advantages of less investment and environmental pollution. Until 2013, there have been two sets of NOMTO plants under operation in China. It was predicted that there would be several NOMTO projects with a total capacity of 5.6 Mt/a by 2020 [5].

The proven reserves of coal in China were 114.5 billion tons in 2011, equivalent with 13.3% of the world total [6]. It is widely accepted that China will keep a coal-dominant energy structure for a long time. Consequently, developing coal-based olefins industry is regarded as an important direction for the sustainable development of the chemical processing industry. Coal-to-olefins (CTO) technology has been successfully implemented in three sets of CTO plants by the end of 2013. Many other CTO plants will be established by 2020 with a total capacity of 12.04 Mt/a [5].

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Nomenclature

D_{CH_4}	CH_4 direct emissions factor for process energy
D_{CO_2}	CO_2 direct emissions factor for process energy
D_{N_2O}	N_2O direct emissions factor for process energy
EC	process energy consumption
I_{CH_4}	CH_4 indirect emissions factor for process energy
I_{CO_2}	CO_2 indirect emissions factor for process energy
I_{N_2O}	N_2O indirect emissions factor for process energy
PFCF	primary fossil consumption factor

Subscripts

i	primary fossil type
j	process energy type
s	sub-stage
direct	direct emissions
indirect	indirect emissions

Abbreviations

CCR	carbon capture rate
CCS	carbon capture and storage
eq. CO_2	equivalent CO_2 emissions
CTG	cradle to gate
CTO	coal-to-olefins
CTOwCCS	coal-to-olefins with carbon capture and storage
LCA	life cycle analysis
MTO	methanol-to-olefins
NDMTO	natural gas based domestic methanol-to-olefins
NOMTO	natural gas based oversea methanol-to-methanol
NTO	natural gas-to-olefins
OTO	oil-to-olefins

One of major causes of GHG emissions is energy processing and consumption. The consumption of oil in olefins industry accounts for as much as 10% of the total oil consumption in China [7]. With the increase of olefins demand, there will be large amounts of olefins supplied and produced from coal and natural gas. A comparative analysis of energy consumption and GHG emissions is imperative for promoting energy conservation and emissions reduction in olefins industry.

Life cycle assessment has become an important decision-making tool for promoting alternative fuels since it could systematically analyses energy use, environmental impacts, and cost benefit before implementing a fuel policy [8]. With the combination of energy consumption and GHG emissions analysis, comparing life cycle performance of various products will be conducive to the study of energy saving and emissions reduction. Many LCA studies have been carried out on energy consumption and GHG emissions. Ou et al. examined life cycle energy consumption and GHG emissions of automotive fuel and electric power in China [9,10]. A similar study on dominant secondary energy pathways was also conducted by Li et al. [11]. Han [12] and Yang et al. [13] carried out cost analysis of CTO plants. Ren et al. [14,15] performed a techno-economic analysis of olefins production from oil, coal, and methane. The techno-economic performance of the oil-to-olefins, coal-to-olefins, and methanol-to-olefins in China was also studied in the author's previous work [16–18]. They paid more attention to analysing the process itself. However, literature on comparative analysing of Chinese olefins production from the life cycle standpoint does not seem to exist.

In this paper, the life cycle analysis method is used to study energy consumption and GHG emissions of alternative olefins routes in China, and the oil-to-olefins (OTO) is adopted as the benchmark. The effect of carbon capture and energy efficiency on life cycle performance of alternative olefins production is also analysed. The strength of this paper is to analyse life cycle performance of Chinese olefins production at present and in the near future, attempts to elucidate advantages and bottlenecks of each route, and give several suggestions on olefins industry for policy making. However, this paper pays more attention to olefins production in China rather than world olefins industry.

2. Methodology

The framework for life cycle energy consumption and GHG emissions of olefins production is depicted in Fig. 2 according to the references [19,20]. This involves determining the overall objectives and boundaries of olefins production, collecting energy consumption data for each stage and GHG emissions factors for each energy fuel, calculating life cycle energy consumption and GHG emissions, and evaluating each route to support policy making of olefins production pathways.

2.1. Life cycle boundary

LCA expands the scope of the investigated processes to its upstream and downstream. Assuming that the competitive

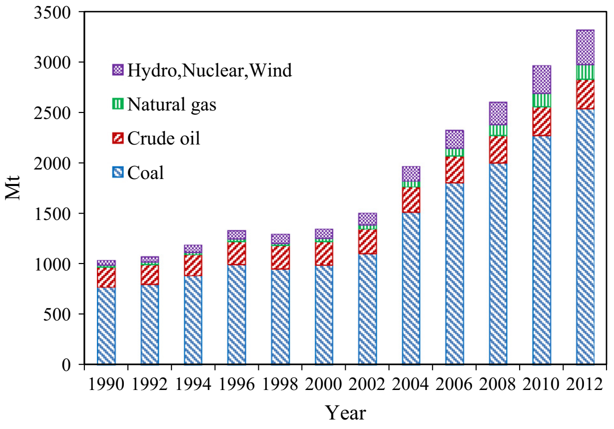

Fig. 1. Coal has been dominant in energy production in China in the past 20 years [2].

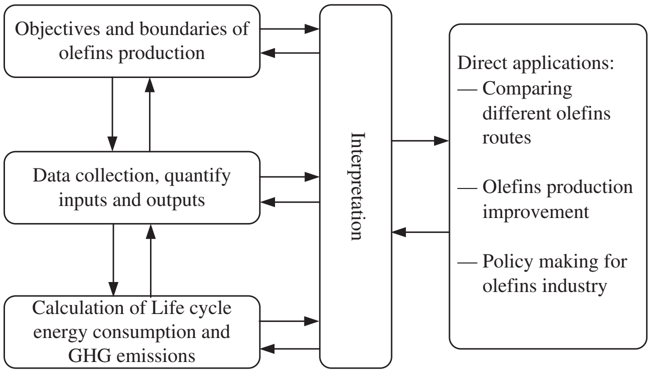

Fig. 2. Framework of life cycle energy consumption and GHG emissions for olefins production.