Applied Energy 228 (2018) 1009–1019

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Energy use, greenhouse gases emission and cost effectiveness of an integrated high– and low–temperature Fisher–Tropsch synthesis plant from a lifecycle viewpoint☆

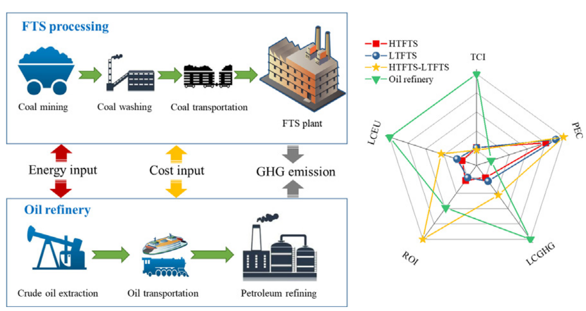
Yi Huang[a], Qun Yi[a,*], Guo-qiang Wei[a,b], Jing-xian Kang[a], Wen-ying Li[a,*], Jie Feng[a], Ke-chang Xie[a,c]

[a] Training Base of State Key Laboratory of Coal Science and Technology Jointly Constructed by Shanxi Province and Ministry of Science and Technology, Taiyuan University of Technology, Taiyuan 030024, PR China
[b] Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences (CAS), Guangzhou 510640, PR China
[c] Chinese Academy of Engineering (CAE), No. 2 Bing Jiao Kou HuTong, Beijing 100088, PR China

HIGHLIGHTS

- Lifecycle evaluation of energy-CO_2-economy between coal to oil and oil refinery.
- HTFTS–LTFTS coproduction shows high flexibility and strong market adaptability.
- HTFTS–LTFTS is superior to oil refinery in economy at a current low oil price.
- HTFT–LTFTS is an economic way for coal to oil with low CO_2 emission per GDP.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Coal-based Fischer–Tropsch synthesis
Co-production
GHG emission
Energy use
Economic performance

ABSTRACT

The lifecycle assessment of energy–greenhouse gases emission–economic performance for single low–-temperature Fischer–Tropsch synthesis (LTFTS), high–temperature Fischer–Tropsch synthesis (HTFTS) and HTFTS–LTFTS co-production from coal are investigated and compared to the oil refining process. This covers feedstock supply chain and oil production at the oil refinery and Fischer–Tropsch synthesis (FTS) plants. Results show that the energy input and CO_2 emission are mostly from coal mining and washing and oil production at the plant for FTS plants or oil refinery. Cost input is largely from feedstock cost and capital cost for FTS plants, crude oil cost, and transport cost for oil refining process. Compared to oil refinery pathway, FTS to oil currently presents no advantages in the aspect of lifecycle of energy use and greenhouse gases emission. However, the HTFTS-LTFTS demonstrates a favorable economic feasibility especially at a low oil price, indicating that the combined system presents high flexibility and strong market adaptability compared to traditional stand–alone HTFTS, LTFTS and oil refinery plant. Furthermore, in comparison with single HTFTS and LTFTS plants, HTFTS–LTFTS makes a big progress in CO_2 emission per unit profit due to its excellent economic benefits. Such an alternative way of coal to oil has an enormous potential to simultaneously satisfy requirements of oil safety and standard of CO_2 emission reduction in China.

☆ The short version of the paper was presented at ICAE2017, Aug 21–24, Cardiff, UK. This paper is a substantial extension of the short version of the conference paper.

* Corresponding authors.
E-mail addresses: yiqun@tyut.edu.cn (Q. Yi), ying@tyut.edu.cn (W.-y. Li).

https://doi.org/10.1016/j.apenergy.2018.07.007
Received 23 March 2018; Received in revised form 16 June 2018; Accepted 1 July 2018

Nomenclature

Abbreviations

bbl	barrel, equals to 159 L
B{a}	best value in set a
BP	British Petroleum
Cx	a hydrocarbon with x carbon
CO_2 eq	equivalent CO_2 emission
e	the equipment factor
$E_{i,j}$	the *j* type of energy consumption in the *i* sub–process
$EF_{i,j,k}$	emission factor of the k GHG in the i sub–process consumption j energy type
FEF_k	the fugitive emission
HHV	high heat value
I_i	the reference cost
IF	install factor
n	the plant life time
NCF_t	the net cash flow of year t
P	the annual profits
Q_i	the reference scale
Q_k	the equipment scale of the studied system
Q_j	the scale in newly designed process
Q_k/Q_j	the number of parallel equipment
RE	revenue
t	ton
W{a}	worst value in set a
y	year
z	the scaling factor

Acronyms

AIC	annual investment cost
ASU	air separation unit
CTL	coal to liquid
CCS	carbon capture and storage
DCL	direct coal liquefaction
DR	discount ratio
ECUST	East China University of Science and Technology gasification technology
EUPUP	energy use per unit product
FT	Fischer-Tropsch
FTS	Fischer-Tropsch synthesis
GDP	gross domestic production
GHG	greenhouse gas
GHGUP	GHG emission per unit product
HTFTS	high–temperature Fischer–Tropsch synthesis
LCA	lifecycle assessment
LCC	life cycle cost
LCEU	lifecycle energy use per profit
LCGHG	lifecycle GHG emission per unit profit
LCI	life cycle inventory
LCIA	life cycle impact assessment
LHV	low heat value
LPG	liquid petroleum gas
LTFTS	low–temperature Fischer–Tropsch synthesis
Mt	million ton
O&MC	operation and management cost
PEC	production equivalent cost
PM	particulate matter
PP	polypropylene
PR–BM	Peng–Robinson–Boston–Matthias
RECH	revenue of the chemical
RKS–BM	Redlich–Kwong–Soave with Boston–Mathias
PY	product yield
ROI	the annual average of return on investment
SNG	synthetic natural gas
TAC	total annualized cost
TCI	total capital investment
USD	United States dollar
USD/L	United States dollar per liter
VAC	variable cost
WGS	water gas shift reaction
WTW	well-to-wheel

1. Introduction

The present global energy consumption mostly comes from fossil fuels (i.e. coal, petroleum, and natural gas), which share 86% of the primary energy source consumption in 2015 [1]. According to the British Petroleum's (BP's) prediction, China's oil import dependence will rises from 63% in 2016 to 76% in 2035 [2] due to petroleum as a long standing transportation fuel. The energy sector of China is facing the challenge of high crude oil import dependence and insecurity about the stability of the oil supply chain. In addition, the high level of the greenhouse gases emission, mainly CO_2 emission due to fossil fuel consumption in China is an obstacle to achieve the carbon reduction goal ahead of the scheduled time to reduce its emissions of carbon per unit gross domestic product by 60–65% by the end of 2030, compared with the level in 2005 according to Paris Agreement [3].

The energy structure in China is regarded as relatively rich in coal, while deficient in oil, and lean in gas [4]. The appropriate development of advanced coal chemical industry, plays an important role in ensuring the energy security in China and promoting the diversification of chemical raw materials. To address some of these challenges, many studies have explored coal–based alternative liquid fuels processes such as direct coal liquefaction (DCL) [5–7], coal pyrolysis to oil [8–10] and Fischer–Tropsch synthesis (FTS) to oil [11–13]. Coal via synthesis gas (syngas) conversion to hydrocarbon through the FTS reaction is a promising alternative compared with the other coal to oil routes. FTS oil can be directly used to replace petroleum, which contains lower sulfur, nitrogen and aromatic, and contribute to lower emissions of SOx, NOx, and particulate matter (PM) [14].

Tens of millions tons of FTS oil projects have been planned under the motivation of a high oil price 0.63–0.69 USD/L (United States Dollar/Liter) (100–110 USD/bbl (United States Dollar/Barrel)) [15] during last decades. Only 5.5 million tons FTS oil projects are still running in China by the end of 2016 [16]. It is concluded that FTS processes producing mainly engine fuel are economically infeasible under a low oil price [17] (about 0.25–0.35 USD/L in the year of 2015–2017). An economic evaluation of coal to oil via FTS indicates that production costs of coal to liquid (CTL) break even when oil price rises above 0.377 USD/L [18]. Therefore, the coal to oil through the FTS pathway is very difficult to make any profit under a low oil price and has the weak capability to against risks of the fluctuation at an international oil market.

To compete with the petroleum–based fuel at a low oil price, many investigations have been focused on the high value-added chemical development [19–24] and the system design, integration and optimization [18,25,26] to promote the economic performance of the FTS process. Jiao et al. [19] and Torres et al. [22] considered to improve the production of C2–C4 (a hydrocarbon with 2–4 carbons) olefins by improving the catalyst performance and optimizing reaction conditions. In such cases, the C2–C4 selectivity can reach as high as 80% under the best condition in the high–temperature Fischer–Tropsch synthesis