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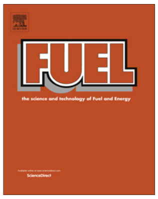

Full Length Article

A standardized methodology for the techno-economic evaluation of alternative fuels – A case study

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ABSTRACT

Greenhouse gas emissions in the transport sector can significantly be reduced by replacing fossil based fuels with green alternatives. Various alternative fuel concepts have been developed differing in used sustainable feedstock, synthesis technology and final fuel characteristics. Whether these fuels can succeed in the market will depend on the fuel net production costs, the expected cost reduction potentials and the political intention to mitigate climate change. Results of previous studies for the techno-economic assessment of alternative fuels are difficult to compare due to significant differences in the applied methodology, level of detail and key assumptions in terms of economic factors and market prices. In this work, a standardized methodology for techno-economic analysis of fuel production processes is presented and exemplarily applied on sustainable fuels from Fischer-Tropsch (FT) synthesis. The methodology was adapted from a best practice approach from chemical industry and consists of three main steps: (A) literature survey on feasible production designs, (B) flowsheet simulation and (C) techno-economic assessment with the in-house software tool TEPET (Techno-Economic Process Evaluation Tool). It is shown that the standardized approach enables qualitative and quantitative statements regarding the technical and economic feasibility of fuel synthesis concepts including the identification of the appropriate fuel production concept due to predefined framework conditions. Results from the case study on green FT fuels reveal that Biomass-to-Liquid (BtL) concepts have lowest production costs at high electricity costs, whereas the Power-to-Liquid (PtL) and Power and Biomass-to-Liquid (PBtL) concepts are superior at low electricity prices. Fuel production costs in the range of 1.2 and 2.8 $€_{2014}$/l were estimated.

1. Introduction

In 2012, 95% of the energy consumed in European transport was supplied by crude oil products [1]. Greenhouse gas (GHG) emissions from transportation account for about 25% of total European GHG emissions [2]. In order to keep global warming below 2 °C, the European Union has set binding targets for cutting GHG intensity of fuels by 6% compared to 2010 [3] and to increase the share of renewable energies in the transport sector to 10% until 2020 [4] with special requirements regarding indirect land use change [5]. While electric vehicles may become a viable option to reach these goals in private car traffic, aviation and heavy duty transportation will continue to rely on liquid fuels due to the required high volumetric energy density and the high investment costs for changing today's engine technology and infrastructure [6]. It is therefore expected that a large amount of alternative "drop-in" fuels are required to significantly decrease the carbon footprint in these transportation sectors. Most alternative fuels available on the market today are so-called 1st generation fuels, which predominantly are made from energy crops raising the issue of competition for farmland and low technical expansion potential in Europe. Hence, future fuels have to preferably be made from renewable electricity, residues and waste wood to decrease the effect of indirect land use change.

Multiple 2nd generation production paths for alternative liquid fuels have been developed in the recent years such as Fischer-Tropsch fuels, Dimethylether (DME) based fuels such as Methanol-to-Gasoline (MtG) or alcohols (ethanol, butanol), to mention only a few examples. Though, the "optimal" alternative future fuel remains to be identified. One the one hand, requirements regarding main fuel characteristics and total fuel demand varies considerably among the specific application areas (road transport, aviation, astronautics etc.). On the other hand, political framework conditions such as support schemes and tax advantages significantly affect the development of the fuel market and therewith also predefine the feasibility of alternative fuels. In order to evaluate and compare the prospects of emerging alternative fuel

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Nomenclature

Abbreviations

ACC	annualized capital cost
ASF	Anderson-Schulz-Flory distribution
BtL	Biomass-to-Liquid
CAPEX	capital expenditures
CEA	commissariat à l'énergie atomique et aux énergies alternatives
CEPCI	Chemical Engineering Plant Cost Index
CPI	commodity price index
CtL	Coal-to-Liquid
DME	dimethyl ether
EC	equipment costs
EEX	European Energy Exchange
FCI	fixed capital investment
FT	Fischer-Tropsch
GE	gasoline equivalent
GHG	greenhouse gas
GtL	Gas-to-Liquid
HEFA	hydro-processed esters and fatty acids
HTFT	high-temperature Fischer-Tropsch
IR	interest rate (%)
KIT	Karlsruhe Institute of Technology
LTFT	low-temperature Fischer-Tropsch
LHV	lower heating value
MtG	methanol-to-gasoline
NPC	net production costs
NREL	National Renewable Energy Laboratory
OL	operating labor
OPEX	operational expenditures
PBtL	Power and Biomass-to-Liquid
PEM	proton exchange membrane
PO	plant overhead costs
PSA	pressure swing adsorption
PtL	Power-to-Liquid
rWGS	reverse water gas shift
SI	supplementary information
SOEC	solid oxide electrolyzer cell
TCI	total capital investment
TEE	techno-economic evaluation
VTT	Technical Research Centre of Finland

Greek letters & variables

α	chain growth probability
ρ	density (kg/m^3)
ω	energy density (MJ/l)
γ_{BM}	biomass yield (t/(km^2 year))
η_C	carbon conversion
η_{Plant}	overall plant efficiency
η_{XtL}	X-to-Liquid efficiency
c	cost of raw materials, utilities, power, heat
cf_{plant}	capacity factor of X-to-Liquid plant
c_{labor}	labor costs (€/h)
d_i	digression factor of unit i
E_{power}	power consumption/production (MWh)
f_i	equipment cost function of unit i
F_{eco}	ratio factors for estimating FCI
F_{mat}	multiplier for material related equipment costs
F_{pre}	multiplier for pressure related equipment costs
h_{labor}	total working hours
ΔH_R^0	standard enthalpy of reaction (kJ/mol)
i, k, m, o	control variables
L_i	learning rate of unit i
$\dot{m}$	mass flow (t/h)
n	number of produced units
p	pressure (bar)
P	power (MW)
r	radius (km)
$S_{i,k}$	kth input variable of cost function of unit i
T	temperature (°C)
W	heat export (MWh)
w	mass fraction
x	molar fraction
y	plant operation time (years)

concepts, the German Aerospace Center (DLR) has launched the strategic project "Future Fuels". One main focus is on economic performance parameters such as capital investment cost and fuel production costs, which are considered to be one of the major factors for the market success of alternative fuels.

A large number of techno-economic studies on a wide range of different alternative and synthetic fuels already exist, which typically apply a methodology adapted from the power or chemical industry. Worth mentioning are the fundamental works on process economics of Peters et al. [7], Ulrich et al. [8], Smith et al. [9] and Turton et al. [10]. Despite the similar economic approach applied in cost calculation studies on alternative fuels, a common concern is the comparability of results. This issue was addressed by Haarlemmer et al. [11] using the example of biofuels production via Fischer-Tropsch synthesis from biomass (Biomass-to-Liquid, BtL), coal (Coal-to-Liquid, CtL) and gas (Gas-to-Liquid, GtL). The authors showed by comparing more than 20 recently published techno-economic studies that a reasonable comparison is impossible not only due to different methodologies used, but also because of unequal source data (cost data, ratio factors and economic assumptions such as plant lifetime, interest rate and inflation). Another problem is the lack of calculation details in most studies making it difficult to understand the underlying assumptions of the cost calculation [12]. Hence, economic results can hardly be normalized in terms of e. g. plant scale, depreciation method and economic assumptions such as raw material market prices and equipment costs.

A more consistent approach is to compare various synthetic fuel production option by applying a kind of superstructure-based methodology as proposed in the studies by Cheali [13] and Maravelias et al. [14,15]. The drawback of superstructure studies is that process steps typically are very simplified in order to obtain a mathematical correlation which can be used in commercial or new developed mathematical optimization algorithms. Great simplifications bear the risk that process limitations due to thermodynamic phenomena such as catalyst coking or the effect of recycle streams on reaction kinetics are neglected or underestimated.

Since no standardized methodology for comparing alternative fuels exists at present, a reliable and unbiased comparison schema for alternative fuels was developed in the course of the Future Fuel project. This paper presents first results in terms of a transparent methodology for the estimation of fuel net production costs (NPC), which was implemented in the in-house tool TEPET (Techno-Economic Process Evaluation Tool). The methodology is characterized by a high of level detail including experimental investigations of key process steps. Starting from a detailed description of the methodology for the techno-economic evaluation in chapter 2, the TEPET tool is applied in a case study on a comparison of key economic measures of three different Fischer-Tropsch fuel synthesis routes based on various feedstocks (Chapter