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Feasibility assessment of diesel fuel production in Egypt using coal and biomass: Integrated novel methodology

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ABSTRACT

Diesel fuel shortage is one of the main energy crisis components in Egypt as it is heavily employed in the electricity and transportation sectors. CtL (Coal to Liquids) and CBtL (combined Coal and Biomass to Liquids) are promising routes which can be currently applied for diesel production in Egypt. This paper will propose a novel methodology to drive the CBtL/CtL routes forward in Egypt. The methodology is based on using Miscanthus as biomass material and utilizing the Egyptian "Maghara" coal. It recommends some measures to improve project economics and simultaneously provide solutions to other strategic national problems including the poor sewage infrastructure and the unutilized desert areas. Eight scenarios were studied; four for each route with variable production capacities (450, 900, 1,350, 1,800 t_{diesel}/d). To evaluate the scenarios, the diesel price was fixed at $50 below its current import price, and the corresponding discount rate and payback period were calculated. At high capacities, both routes are economically feasible (discounted interest rate of about 17%) and less sensitive to the price variation of equipment, raw materials and byproducts. Implementing the CBtL route can be regarded as a strategic project as besides being economically feasible, it offers crucial social and environmental benefits.

1. Introduction

The anticipated depletion of petroleum reserves and the consequent responsibility of providing secure access to liquid fuels is a problem which is imposing increased stresses on the politicians worldwide. This problem is currently one of the main national challenges facing Egypt. Egypt is the largest oil producer in Africa outside the OPEC (Organization of the Petroleum Exporting Countries) and the second-largest African natural gas producer. On the other hand, Egypt is the largest oil and natural gas consumer in Africa and it has shown a rapid growth of energy consumption in the previous few decades. The consumption has increased to the extent that the oil consumption has surpassed the production since 2010. In addition, the natural gas consumption in Egypt has remarkably increased in the previous period mostly because of being the major energy source for generating electricity. Accordingly, the Egyptian natural gas exports declined by an annual average of 30% from 2010 to 2013. Nevertheless, the energy situation in Egypt is more complicated than those figures. Egypt is still extensively subsidizing the energy, which cost about $26 billion in 2012, and this has a big contribution to the country's high budget deficit. This deficit made the country unable to pay off its debt to foreign oil and gas operator companies, and accordingly, the oil and gas production has been greatly declined [1].

Diesel fuel appears as a crucial energy source both in the transportation and electricity sectors in Egypt. Diesel fuel is used in vital applications including fueling the vehicles transporting both citizens and goods in addition to electricity generation for both grid-connected and off-grid systems. Accordingly, when there is a shortage in supplying diesel fuel, many sectors are affected. According to the Egyptian Ministry of Petroleum, the daily national diesel fuel consumption is about 37,000 tons, nearly half of which is imported. In 2012, the diesel fuel imports constituted about 9% of the national imports, while it was only 2.5% in 2007 [2]. The high diesel fuel imports represent major problem due to the high diesel

Abbreviations: CtL, coal to liquids; CBtL, combined coal and biomass to liquids; FT, Fischer–Tropsch; BtL, biomass to liquids; GHG, greenhouse gas; ASU, air separation unit; WGS, water gas shift; LTFT, low-temperature Fischer–Tropsch; LPG, liquefied petroleum gas; PSA, pressure swing adsorption; CSTP, centralized sewage treatment plants; HCWWW, holding company for water and wastewater; EOR, enhanced oil recovery; PCC, precipitated calcium carbonate; FCI, fixed capital investment; HHV, higher heating value; HRSG, heat recovery steam generator; DCFROR, discounted cash flow rate of return.

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prices in addition to the shortage in the foreign currency. The conventional solution of setting up a huge petroleum refinery to help mitigate the diesel fuel availability problem is opposed by the shortage of the national crude oil resources, high price of importing crude oil, and the bad economic status of the country. To save some of the money devoted for importing and subsidizing the diesel fuel, the Egyptian government has few months ago implemented energy subsidy reforms which included decreasing the diesel subsidies by about 63%. However, together with these reforms, the application of alternative technology(ies) to locally produce diesel fuel is also essential.

Synthetic fuels generally, and diesel fuel specifically can be produced by FT (Fischer–Tropsch) synthesis of syngas, which can be generated from natural gas reforming or coal/biomass gasification. The abundance of coal and biomass resources worldwide compared to the crude oil and natural gas gives them a significant advantage to be used as feedstocks for the production of synthetic fuels. Different biomass feedstocks including energy crops, organic wastes and agricultural residues [3] can be transformed into synthetic bio-fuels by combining biomass gasification and FT technologies in what so called BtL (Biomass to Liquids) route. The increased awareness about the GHG (greenhouse gas) emissions generated using fossil fuels in the transportation sector catalyzes the shift towards the BtL route [4–6]. However, biomass gasification technologies are still in the pilot and demonstration scale, and the combination of biomass gasification and FT is still far from commercialization [7–10]. In addition, some logistical problems like availability, handling, transportation and storage of the low energy density biomass constitute major challenges facing the BtL commercialization [11]. On the other hand, combining coal gasification with FT, known as CtL (Coal to Liquids) route, is more mature technology for the production of alternative liquid synthetic fuels [12]. On the contrary to biomass gasifiers, industrial-scale coal gasifiers are currently commercially available, with more than 420 gasifiers in about 140 facilities worldwide [13]. The products of these facilities differ between FT liquid fuels, ammonia, methanol and SNG (synthetic natural gas) [14]. The high energy density of coal, its abundant reserves worldwide, and its low price compared to the crude oil and natural gas give more advantages for CtL [12]. However, CtL technology is always being criticized due to its big contribution to the GHG emissions, and for not being sustainable route regarding the finite coal reserves [15]. The co-processing of coal and biomass using the CBtL (Combined Coal and Biomass to Liquids) technology is currently being considered as a transitional step to overcome the challenges and disadvantages of BtL and CtL technologies respectively [12]. The co-gasification of coal and biomass was successfully employed in the Dutch Buggenum IGCC (integrated-gasification combined cycle) facility [16] using a coal-biomass blend mass ratio of 70–30 [17]; hence, it is considered a commercially-proven technology.

To assess the potentiality of solving the current diesel fuel shortage problem in Egypt using CtL, BtL, or CBtL technologies, a techno-economic feasibility study should be performed. The technical and economical feasibility of the production of FT-liquids from either coal or biomass or a mixture of both in different locations has been the subject of previous researches [4,6,8,12,18–35]. In a previous work [35], the authors have studied the technical feasibility of the production of diesel fuel in Egypt using three different routes; BtL using Miscanthus energy crop, CtL using “Maghara” Egyptian coal, and CBtL using a “Maghara” coal-Miscanthus mass ratio of 70–30. Miscanthus energy crop was chosen as it has high material and energy yields, can sustain the Egyptian dry and arid climate, suitable for the Egyptian basic nature soil, and has low irrigation water requirements [36] which is an advantage regarding the low Egyptian water resources. The first main conclusion of this previous work was the exclusion of BtL technology from the list of current potential routes for the production of diesel fuel in Egypt. In addition to not being yet commercialized, BtL suffers from bad performance indicators including low liquid fuel yields, low export power, and huge wastewater amounts. The second main conclusion was the comparable and promising performance of both CtL and CBtL routes, a result which necessitates an economic assessment to have a more comprehensive insight about the feasibility of these routes for the current production of diesel fuel in Egypt [35].

This paper will propose a novel methodology to drive the CBtL/CtL routes forward in Egypt through offering solutions to few other Egyptian strategic problems in addition to recommending some measures to improve project economics. It will also focus on finding solutions for the Egyptian decision makers to save fraction of the foreign currency currently used for importing diesel fuel through implementing the CBtL/CtL project. This paper will also show some measures to encourage the investors to implement the CBtL/CtL project.

2. Methodology

The methodology proposed to facilitate the development of the CBtL/CtL project in Egypt involves technical and political components. The technical component includes the accurate process design and careful technology selection for the different process sections; the part which was covered in the authors' previous work, and summarized in the following sub-section. The technical component also includes some solutions to reduce the costs of biomass raw material, and to increase the project's profitability through better marketing of the byproducts. The political component of the methodology suggests some initiatives to be taken from the Egyptian government to encourage the private sector to invest in the CBtL/CtL project. These suggested governmental initiatives will simultaneously provide solutions to other three strategic national problems; namely, the poor sewage infrastructure, vast unutilized desert areas, and the untapped “Maghara” coal mine in what can be called turning problems into opportunities. The different aspects of the proposed methodology are discussed in the following subsections.

2.1. Process design

2.1.1. Process description

The detailed process description has been shown elsewhere [35], and it will be presented in brief. As shown in Fig. 1, the solid feed (coal in CtL and coal/biomass in CBtL) is first handled and grinded to the desired particle size before being directed to an entrained flow gasifier together with oxygen and steam which act as gasifying agents. A feeding rate of 115 t/h was selected to be the “base case scenario” which can be duplicated in case of working on higher capacities. The hot syngas in the radiant section is utilized to generate high pressure steam, then the cooled syngas is quenched with water in order to remove any particulates which may clog the downstream equipment. Part of the syngas is then routed through a WGS (water gas shift) reactor to adjust the H_2/CO ratio to 2:1 required for FT reactor. Before the FT reactor, the water vapor in the syngas is condensed, and then the CO_2 and H_2S are being separated using Rectisol system. The cleaned syngas is then directed to LTFT (Low-temperature FT reactor) whose conditions are adjusted to maximize the diesel fuel yield. Three different phases are produced from the FT reactor; unconverted syngas, liquid product, and wastewater. The unconverted syngas stream is rectified to separate the light gases from any accompanying light liquid fuels (naphtha + LPG). The light gases are used in the power island which is utilizing combined cycle.