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Flex fuel polygeneration: Integrating renewable natural gas into Fischer–Tropsch synthesis

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HIGHLIGHTS

- Economics of energy plants with multiple feedstocks and products were analyzed.
- Monte Carlo simulations were used to assess effect of uncertain variables.
- Plants using multiple feedstocks and renewable resources generated the highest NPVs.

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ABSTRACT

Flex Fuel Polygeneration (FFPG) is the use of multiple primary energy sources for the production of multiple energy carriers to achieve increased market opportunities. FFPG allows energy supply adjustments to meet market fluctuations and increase resilience to contingencies such as weather disruptions, technological changes, and variations in supply of energy resources. As an example of FFPG, we explored natural gas and municipal solid waste as the primary energy sources converted into electricity and transportation fuels as the energy carriers through the processes of anaerobic digestion, Fischer–Tropsch synthesis (FTS), and combined cycle power. We combined previous techno-economic analyses of conventional energy production plants to obtain equipment and operating costs, and then evaluated the economic performance of the FFPG plant designs. We investigated the effect of changing operating parameters on economic performance of the baseline FTS and FFPG systems.

1. Introduction

Flex Fuel Polygeneration (FFPG) is the use of multiple primary energy sources for the production of multiple energy carriers to achieve greater market opportunities. Processing plants of all types are susceptible to fluctuations in the costs of energy sources and the prices of energy carriers. Reducing the risks associated with energy production technologies via input and output diversification can increase the net present value (NPV) of processing plants. Single feedstock production pathways are especially susceptible to price volatility due to the erratic nature of many energy commodity prices. Facilities that utilize multiple feedstocks and/or create multiple products can potentially decrease the risk of unfavorable prices and thereby increase their NPVs [1].

Factors that determine the success or failure of commercial energy production include capital and operating costs, government policies, available technology and resources, sustainability, industrial and consumer acceptance, weather, and location [2–4]. Resilience is defined as the ability of an entity or system to withstand, adjust to, and reduce the consequences of contingencies while still retaining function [5–7]. Severe weather events can temporarily disrupt petroleum, natural gas, and biomass supply chains as well as product markets, potentially resulting in increased feedstock or product prices [8–10]. Weather can also affect crop production and harvesting, supply chain infrastructure, processing, refining, and distribution [11]. While energy security, climate change, and fossil fuel depletion are likely to provide new investment opportunities for alternative energy routes, venturing into new energy sectors also increases financial risk [12]. If energy production plants are designed so that they are able to adapt to market supply and demand fluctuations, the risk involved with investing in these plants decreases. If an energy plant is flexible enough to shift towards lower consumption of expensive feedstock while adjusting

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Nomenclature

AD	anaerobic digestion	kW h	kilowatt hour
BTL	biomass-to-liquids	LFG	landfill gas
Btu	British thermal unit	LO	livestock operations
CTL	coal-to-liquids	MJ	megajoule
DCFROR	discounted cash flow rate of return	MM	million
EIA	Energy Information Administration	MSW	municipal solid waste
EPA	Environmental Protection Agency	MW	megawatt
FCI	fixed capital investment	NETL	National Energy Technology Laboratory
FFPG	Flex Fuel Polygeneration	NG	natural gas
FTS	Fischer–Tropsch synthesis	O&M	operating and maintenance
GTL	gas-to-liquids	RIN	renewable identification number
IRR	internal rate of return	RNG	renewable natural gas
kPa	kilopascal	WGS	water gas shift

its products portfolio to maximize profits, it is more likely to obtain greater financial returns.

Since the 19th century, stationary combustion systems have been at the heart of producing energy that can be introduced and utilized by the electrical grid [13]. Along with electricity, other product avenues from processing primary energy sources are fuels and chemicals. In 2012, fuel from petroleum made up around 99% of the energy used in the U.S. transportation sector [14]. However, this has changed in recent years. Along with petroleum, natural gas and coal are mined and used as gaseous or liquid fuel sources for transportation, electricity, or heating/cooling applications. Technologies such as coal-to-liquid and gas-to-liquid convert feedstocks into longer-chain hydrocarbons and alcohols depending on the catalysts and operating conditions. However, these primary energy processing technologies often transform one feedstock into one main product and can be susceptible to market volatility. As an example, in 2012 a drought occurred in the U.S. that negatively impacted corn growers and associated industries. The price per bushel of corn rose to over $8, causing corn ethanol production margins to fall sharply since producers were unable to utilize a different, less expensive feedstock [9].

Polygeneration, the conversion of an energy source into multiple energy carriers, has been previously explored as a way to respond to such swings in market demand for various energy products [15,16]. Polygeneration represents a means of effectively utilizing available resources in a manner that is both more cost effective than traditional pathways and less sensitive to supply shortages and product price volatility. The most familiar example is co-generation, where steam can be diverted to either electric power generation or production of process heat. Flex fuel, the use of multiple primary energy sources for production of an energy carrier, is most prominently practiced by electric utilities that fire combinations of coal, fuel oil, natural gas, and wood pellets in steam boilers or meet peak power demand by firing fuel oil or natural gas in gas turbines that can rapidly come online [17]. FFPG can employ both multiple energy primary sources (including fossil and renewable energy) and technologies to produce multiple energy products (fuel, electricity, chemicals, and heat). As Floudas et al. [18] state in their study on hybrid and single feedstock energy processes, hybrid (or FFPG) systems have the opportunity to increase their energy resource portfolio and the flexibility to generate additional products from multiple sources. Along with this, hybrid systems can substitute renewable resources for fossil fuels, thereby reducing GHGs. Cai et al. [19] have shown that combining multiple energy plants into a single system has the ability to decrease overall equipment, installation, and labor costs. Liu et al. [20] state that the important economic parameters in analyses comparing polygeneration with stand-alone production are the price of products. The value of the products relative to each other and the reliance of the product portfolio on each are key variables when determining project NPV and plant flexibility of product production. There are many technologies to be considered when creating FFPG plants, the choice of which depends on plant location, feedstock availability, product demand, and other factors that influence the functionality of the plant. The technologies and feedstocks utilized can be tailored to specific locations when designing FFPG plants.

Polygeneration plants come in a variety of forms, integrating multiple products or feedstocks, renewable and fossil energy sources, and alternative processing technologies. A study done by Jana [21] delivers multiple outputs from a single input of agricultural waste. Performance estimates from the investigation show that turning agricultural residues into a range of products such as electricity, refrigeration, utility heat, and ethanol can improve sustainability and efficiencies. Polygeneration for a rural community provides an economically feasible, decentralized energy production scenario by maximizing feedstock utilization and conversion efficiency [21]. Another study done by Swanson et al. [22] integrated biomass gasification into two FTS plants and analyzed the fuel product value. The analysis simulated processing 389 MW of biomass in a low temperature, fluidized gasifier and a high temperature, entrained flow gasifier. These systems required between $500 and $650 million in investment and resulted in a product value of $4–5 per gallon of gasoline equivalent. Of the factors considered in the study, those that had the largest impact on the product value were feedstock cost and return on capital investment. Another biomass processing plant analyzed by Zhang et al. [23] focused on pyrolysis as the core technology. The study simulated the polygeneration of monosaccharides, hydrogen, and transportation fuels from turns 2000 tons/day of lignocellulosic material. The pathway of biomass to products included pretreatment and processing of the feedstock via pyrolysis, following by liquid/solid separation and recovery. The components of the system that influenced the internal rate of return (IRR) were feedstock costs, product yields, and product credits.

Previous related studies [24–27] explored biomass and natural gas as flex fuels in the production of transportation fuels with a focus on environmental performance. In a study done by Liu et al. [24], it was found that supplementing natural gas conversion to transportation fuels with biomass gasification can reduce GHG emission prices needed to cost effectively employ carbon capture and sequestration. By including biomass, emissions from the production process are significantly reduced, which therefore creates an attractive system for low-carbon natural gas power. Another study by Borgwardt [25] considers integrating biomass gasification with natural gas into methanol production. From the study, it was found that the use of natural gas and biomass, as opposed to coal,