Fuel 117 (2014) 989–995

Contents lists available at ScienceDirect

Fuel

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

Techno-economic impacts of shale gas on cellulosic biofuel pathways

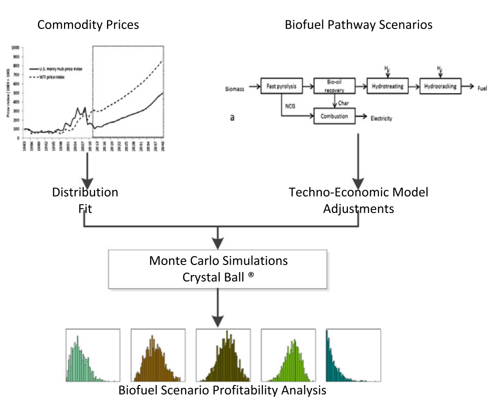
Tristan R. Brown [a], Mark M. Wright [b,*]

[a] Bioeconomy Institute, 3116 Biorenewable Research Laboratory, Iowa State University, Ames, IA 50011, USA
[b] Department of Mechanical Engineering, 2078 Black Engineering, Iowa State University, Ames, IA 50011, USA

HIGHLIGHTS

- We quantify the impact of U.S. shale gas on eight cellulosic biofuel pathways.
- Two economic scenarios are developed based on EIA projections.
- The economic feasibility of the pathways is quantified under price uncertainty.
- We compare the pathway scenario results under each economic scenario.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 30 July 2013
Received in revised form 4 October 2013
Accepted 14 October 2013
Available online 30 October 2013

Keywords:
Cellulosic biofuel
Shale gas
Techno-economic analysis
Uncertainty analysis

ABSTRACT

This analysis quantifies the economic feasibility of cellulosic biofuel pathways under fossil fuel price uncertainty. Eight pathway scenarios are developed on the basis of existing techno-economic analyses and projected fossil fuel commodity prices from the Energy Information Administration's (EIA) 2010 Annual Energy Outlook (AEO). A 20-year net present value (NPV) is then calculated for each pathway scenario. Uncertainty distributions are developed for each pathway scenario by fitting historical monthly price variance distribution curves for each fossil fuel commodity to their projected annual prices. Finally, a sensitivity analysis is completed by replacing the EIA's AEO 2010 projected prices with those from its AEO 2013, the latter incorporating recent exploitation of U.S. shale gas reserves into its projections. The results of this analysis indicate that fast pyrolysis scenarios see the greatest increase in estimated NPV value followed by gasification and acetic acid synthesis scenarios. Fischer–Tropsch synthesis scenarios remain largely unaffected by the updated EIA projections. Methanol-to-gasoline and enzymatic hydrolysis NPVs decrease as a result of lower projections for fossil fuel prices.

1. Introduction

The widespread deployment of technology enabling the inexpensive extraction of shale gas has caused U.S. natural gas production to increase substantially in recent years, with annual U.S. production currently at a level never seen before [1]. One effect has been significantly lower U.S. monthly wellhead gas prices, which in April 2012 fell below $2/MMBTU for the first time in the 21st century [2]. This development signifies a fundamental shift in the dynamic between the prices of petroleum and natural gas.

Abbreviations: AAS, acetic acid synthesis; AEO, Annual Energy Outlook; DCFROR, discounted cash flow rate of return; DHG, direct-heat gasification; EH, enzymatic hydrolysis; EIA, Energy Information Administration; FPH, fast pyrolysis and hydroprocessing; FTS, Fischer–Tropsch synthesis; HTG, high-temperature gasification; IHG, indirect-heat gasification; IRR, internal rate of return; LCA, life cycle assessment; LPG, liquefied petroleum gas; LTG, low-temperature gasification; MMBTU, million British thermal units; MT, metric ton; MTG, methanol to gasoline; NCG, non-condensable gases; NPV, net present value; RFS2, revised Renewable Fuel Standard; RIN, Renewable Identification Number; SMR, steam methane reforming; TEA, techno-economic analysis; TPEC, total purchased equipment cost; TPI, total project investment; WTI, West Texas Intermediate.

* Corresponding author. Address: 3033 Black Engineering, Iowa State University, Ames, IA 50011, USA. Tel.: +1 515 294 0913; fax: +1 515 294 8993.
E-mail address: markmw@iastate.edu (M.M. Wright).

0016-2361/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2013.10.032

Natural gas has historically been a byproduct of petroleum extraction, resulting in a strong correlation between the prices of the two commodities [2,3]. Divergences in their price movements over the last 25 years have been characterized by their brevity and infrequency, usually corresponding to extreme weather events and rarely lasting for more than a few months (see Fig. 1). Starting in 2009, however, this correlation in price movements began a monotonic divergence. By 2012 the price of WTI petroleum had increased 200% over the previous decade on a nominal basis, while the wellhead price of U.S. natural gas on the same basis had fallen to a 13-year low [2]. Meanwhile both U.S. natural gas production and proved reserves have reached historical highs [4], with the increase in the latter almost entirely attributed to an increase in proved reserves of shale gas [5].

The EIA forecasts this price divergence to be the start of a new multi-decade trend (see Fig. 2). The U.S. natural gas wellhead price in 2035 is currently projected to be only 58% that of the commodity's trend based on the historical correlation between U.S. natural gas and WTI prices [6]. Should these projected prices occur then this new price relationship will represent a complete reversal of the historical relationship.

The wide gap between projected natural gas and petroleum prices has caused some U.S. policymakers to question the wisdom of investing in high-cost cellulosic biofuels at a time when domestic natural gas is available as an inexpensive feedstock for production of fossil fuel-based synthetic transportation fuels (synfuels). Congressional legislation introduced in 2012 would expand the RFS2 to include both biofuels and synfuels [7]. Two would-be cellulosic biofuel producers announced in the same year that they were switching from biomass to natural gas as alternative fuels feedstock in part due to low natural gas prices [8,9]. The domestic economics of synfuel pathways are more attractive at present than in the past due to lower input costs (natural gas and coal) and higher output prices (gasoline and diesel fuel). While LCA of synfuels pathways such as gas-to-liquids (GTL) and coal-to-liquids (CTL) report higher greenhouse gas (GHG) emissions than for petroleum-based transportation fuel pathways [10–12], the absence of a national carbon tax or price program in the U.S. limits the negative impact that this has on the fuels' economic feasibility.

Largely ignored in the discussion of the impact of shale gas on the economics of alternative transportation fuel production is its potential ability to improve the economic feasibility of biofuel production. U.S. biofuels policy has undergone a major shift over the last decade, greatly expanding its scope to include hydrocarbon-based cellulosic biofuels in addition to cellulosic ethanol [13]. Hydrocarbon-based biofuel pathways directly utilize hydrogen in either one- or two-step processes of deoxygenation and depolymerization to increase overall yields of monomeric hydrocarbons. Hydrogen can be derived from a number of sources although the least expensive source with current technology is produced via the SMR of natural gas [14,15]. The new relationship between natural gas and petroleum prices can therefore be expected to directly impact the economic feasibility of hydrocarbon-based biofuel pathways.

Based on current facility construction, U.S. cellulosic biofuel production will reach 215 MM gallons gasoline-equivalent in 2014, slightly more than half of which will be hydrocarbon-based [16]. These cellulosic biofuel facilities will employ several different pathways, including gasification and FTS; gasification and MTG; and EH and fermentation. This analysis quantifies the impact of U.S. shale gas production on the economic feasibility of these pathways, in addition to fast pyrolysis and hydroprocessing and gasification and AAS. Spreadsheet models were created using pathway data in the techno-economic literature to quantify the economic feasibility of each pathway under two different economic scenarios based on the EIA's price forecasts from its AEO 2010 and AEO 2013. Uncertainty analysis was employed using historical price variation data in conjunction with the price projections to quantify scenario performance under uncertainty.

2. Methodology

This study proceeds as follows: (1) process and economic data of select biofuel pathways were collected and adjusted, (2) historical data on monthly commodity price variation distributions were gathered and fit to probability distributions, (3) a range of NPVs were estimated for each pathway scenario based on stochastic analysis of the commodity prices and economic parameters. Fig. S1 outlines the steps taken in this study.

Seven different cellulosic biofuel pathways were selected to develop eight pathway scenarios: (1) HTG and FTS; (2) LTG and FTS; (3, 4) stand-alone FPH; (5) DHG and AAS; (6) IHG and AAS; (7) EH and fermentation; and (8) gasification and MTG synthesis. The two gasification and FTS scenarios were developed using data from the high- and low-temperature scenarios presented by Swanson et al. [17]. Two separate TEAs of the FPH pathway were used to develop Scenarios 3 and 4: Brown et al. [18] and Jones et al. [19] (referred to here as "BFPH" and "JFPH", respectively). The direct- and indirect-heat gasification scenarios presented by Zhu and Jones [20] were used to develop the two gasification and AAS scenarios. The EH and fermentation scenario was based on work by Kazi et al. [21].

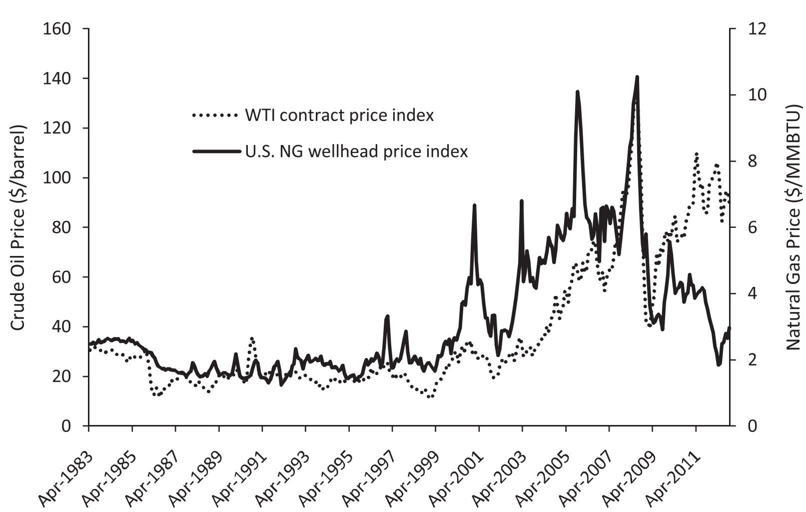


Fig. 1. Monthly U.S. natural gas wellhead and WTI contract nominal price, 1983–2012 [2,3].