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ANALYSIS

Comparison of supply and demand constraints on U.S. biofuel expansion

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ABSTRACT

This paper compares supply and demand constraints on the ramp-up of biofuels in the United States. Three recent supply-side developments are assessed: (1) build-out of commercial-scale cellulosic biorefineries, (2) incremental improvements to existing ethanol and biodiesel biorefineries, and (3) use of waste oils for renewable diesel and biodiesel. From a technical perspective, we estimate these developments could increase domestic biofuels production by up to 4.3, 2.3, and 1.3 billion gallons of gasoline equivalent (BGGE) by 2030, respectively. This corresponds to 3.7% of final energy in the U.S. transportation sector in 2013. On the demand side, the main technical constraints to biofuel growth involve the blend rate of ethanol with gasoline. Rapid removal of E85 and E15 vehicle and infrastructure barriers could generate room for an additional 13.0 BGGE of ethanol and 2.7 BGGE of biodiesel consumption by 2030. There is no demand constraint on drop-in biofuels. Both supply and demand constraints limit the expansion of biofuels, but demand constraints can likely be relaxed at a faster pace than supply constraints. Whether the further expansion of biofuels is socially, economically, or environmentally justifiable is not a research question examined here.

1. Introduction

Since the 1970s, the expansion of domestic biofuels has been a policy objective in the United States. This objective has been based, in part, on a broader goal to increase U.S. energy independence[1] [1]. Today, domestically produced biofuels account for 4.7% of final energy in the U.S. transportation sector,[2] or 4.9% of liquid fuels for transportation [2]. In the future, the contribution of U.S. biofuels to U.S. energy independence remains uncertain as concerns about the impact of biofuels on agricultural sustainability, criteria emissions, greenhouse gas emissions, and competition with food come to light. Additionally, given that the price of most biofuels has not been consistently lower on an energy basis than petroleum products in the last 20 years, a compelling economic incentive for a transition has been lacking, and the expansion of biofuels has been largely a policy-driven phenomenon.

Beyond these societal challenges for expanding the use of biofuels, there are number of other near-term technical constraints on how quickly the industry can ramp up. These include constraints on both the supply and demand side. The Energy Information Administration (EIA) hinted at a number of these constraints in its 2013 Annual Energy Outlook (Reference Case) when, between 2012 and 2013, it drastically lowered the projected volume of biofuels in the future (Fig. 1), citing "diminished flex-fuel vehicle penetration, a smaller motor gasoline pool for blending ethanol, and reduced production of cellulosic biofuels…" [3 p. 8].

The purpose of this paper is to examine the near-term technical supply and demand constraints in detail and to estimate how quickly

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[1] We use energy independence generically in this paper. The US increases its independence when it is less reliant on foreign sources of energy. This could mean both volume dependencies and price dependencies. For the purposes of our analysis, we focus on the potential contribution of U.S. production to energy independence, following existing U.S. policy objectives, as laid out in the Energy Independence and Security Act (EISA). An important consideration is that demand reduction (e.g., a reduction in aggregate miles traveled) can also lead to greater energy independence.

[2] Final energy is the same as delivered energy. This value includes ethanol, biodiesel, renewable diesel and gasoline, biobutanol, liquids from biomass and subtracts exported ethanol. Other options to diversify transport energy are available and are being pursued, such as fossil or renewable natural gas, electricity, and hydrogen. Discussion of these alternative fuel strategies lies beyond the scope of this paper.

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Glossary

BGGE	billion gallons of gasoline equivalent. Used to place liquid fuels with different energy contents into common volume metrics.
Biodiesel	a methyl ester fuel from oil feedstocks used as a substitute for conventional diesel fuel
E10	typical transportation fuel for light-duty vehicles in the U.S. blended at up to 10% ethanol by volume. E10 accounts for the majority of gasoline sold in the U.S. and contains mostly gasoline.
E15	ethanol–gasoline blends with up to 15% ethanol, by volume.
E85	ethanol–gasoline blends with up to 83% ethanol, by volume, per ASTM D5798 (often erroneously thought to include up to 85% ethanol).
Flexible fuel vehicles (FFVs)	vehicles capable of running on E85 fuel or conventional E10 fuel.
ICO	inedible corn oil. ICO is a co-product from the majority of corn ethanol facilities.
Renewable diesel	a chemically-similar fuel as conventional diesel produced from hydro processing of oil feedstocks.

biofuels could feasibly ramp-up by 2030. Market conditions will ultimately determine if these become binding constraints or whether the market finds an equilibrium point below the constraints. We estimate the constraints over time using feasible technology turnover rates along with reasonable consumer adoption for the demand side and potential capacity expansion rates on the supply side. A side-by-side comparison of these constraints helps illuminate which (supply or demand) is more constraining in the near-term and where future policy should be directed.

An important supply-side constraint is that cellulosic biofuel companies have struggled to transition from lab and demonstration-scale to commercial scale projects. In 2013, less than one *million* gallons of cellulosic biofuels were produced in the U.S., while the original Renewable Fuel Standard (RFS) mandate called for one *billion* gallons in 2013.[3] However, at least 11 cellulosic firms have constructed or are in the midst of constructing commercial-scale biorefineries. Additionally, many corn starch biorefineries have purchased technologies and processes that increase the ethanol yield per input bushel of corn (i.e., incremental improvements). Biodiesel and renewable diesel from waste oil is also experiencing a surge.[4] For each development, we discuss 4both the maximum potential and the pre-2030 potential.

On the demand side, the key near-term technical constraint is the "blend wall" – a market saturation point above which no additional ethanol can be blended with gasoline due to federal blending requirements or vehicle warranty limits, driven by the different molecular structure of ethanol that necessitates separate delivery infrastructure for higher ethanol blends. Most gasoline sold in the U.S. is E10 (up to 10% ethanol and 90% or more gasoline, by volume) meaning the blend wall was effectively reached in 2013 when the U.S. consumed 13.7 billion gallons of ethanol and 133 billion gallons of gasoline [1]. This demand constraint could be overcome through a combination of: (1) increasing the number of flex-fuel vehicles (FFVs), (2) expanding the number of service stations that offer higher blends of ethanol fuel such as E15 and E85, (3) making ethanol considerably cheaper than gasoline, or (4) producing "drop-in" biofuels[5,6] that can be blended to any ratio with petroleum fuels. Biodiesel consumption faces some, but less serious demand constraints (discussed further below).

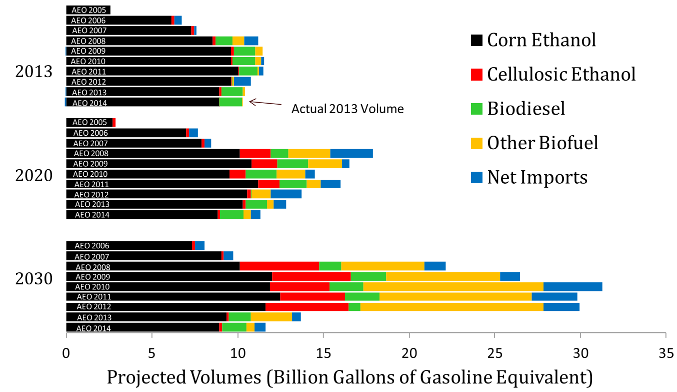

Fig. 1. Biofuel projections to 2030 from past Annual Energy Outlooks (Ref. Case) [2–12]. "Other" biofuel category refers to "green liquids," "liquids from biomass," and "renewable diesel" and includes drop-in fuels from cellulose, algae, and other non-corn feedstocks.

Section 2 discusses supply constraints. Section 3 discusses demand constraints. In Section 4, we compare the constraints over time. Finally, in Section 5 we conclude. Because of length requirements, the majority of the analysis is presented in the Supplementary information (S.I.) and in the Supplemental spreadsheet.

2. Supply constraints

In estimating supply constraints, an important distinction must be made between food crop-based biofuels and those derived from other (non-food) feedstocks. An assumption we make in our calculations is that no additional biorefineries will be constructed that use food crops as feedstocks (such as corn and soybean), due to concerns about food-fuel competition. U.S. corn ethanol already consumes around 40% of annual U.S. corn production[7] and construction of new corn ethanol biorefineries has plummeted since the decade between 2000 and 2010. Thus, our focus here is on identifying additional sources of domestically produced biofuels that do not compete directly with the food production system.[8]

2.1. Expansion of commercial-scale cellulosic biorefineries

At least two studies estimate the maximum nation-wide resource availability of cellulosic biomass using geographically detailed, feedstock-specific models [15,16]. DOE [15] suggests that up to 1.4 billion dry tons of cellulosic biomass could be available in the contiguous United States by 2030 for less than $60 per ton. This includes

[3] The mandated target would have represented industry growth beyond what corn ethanol experienced, despite the pioneering nature of the cellulosic technologies. Foreseeing this possibility, the legislation instating the RFS allowed for downward waivers of the cellulosic mandate annually to match expected production, in the event that commercialization lagged.

[4] Waste oil refers to animal fats, oils, and greases (FOG). More detail given below.

[5] Almost all gasoline sold in the U.S. has 5–10% ethanol by volume. Most cars on the road can also run on up to 15% ethanol blends while flex-fuel vehicles can use up to 83% blends [13]. More is discussed below.

[6] Drop-in biofuels are molecularly similar to petroleum-based fuels like gasoline and diesel. Thus, they do not require the same infrastructure and vehicle changes as other types of biofuel.

[7] While 40% of corn acreage goes is used for ethanol production, the value could be reported as much lower if co-product production is considered (namely dried distillers grains and solubles, which can substitute for corn in animal feed). Mumm et al. [14] estimate that using this alternate method, 25% of today's corn crop goes to ethanol production.

[8] Energy crops can be grown on marginal land, less suitable for food crops, but policy action may still be required to avoid displacing food crops.