THE U.S. BIOFUEL RACE

HYPE OR REALITY?

By Rohan Nath and Kevin Adams

In recent years, the U.S. has engaged in an experiment to reduce its reliance on hydrocarbon-based transportation fuels and associated greenhouse-gas (GHG) emissions. The goal is to replace fuels derived from crude oil with alternative, renewable biofuels and natural gas.

Federal and state governments have jumped into the race by passing legislation to drive this evolution. Two notable examples are the federal Renewable Fuel Standard (RFS) in 2005 and California's Low Carbon Fuel Standard (LCFS) in 2007. The RFS seeks to reduce GHG emissions by mandating that specific volumes of biofuel be blended into U.S. gasoline and diesel; the LCFS seeks to reduce GHG emissions by mandating annual reductions in the carbon intensity (CI) of the gasoline and diesel sold in California.

In response to government regulation and optimistic commercial expectations, the venture capital (VC) and private equity (PE) industries have invested in a number of renewable-energy technologies, including wind, solar, and biofuels. VC and PE investments in this sector collectively averaged $5.6 billion annually from 2006 through 2012, with a cumulative annual growth rate exceeding 20 percent. Similarly, oil and gas giants such as Valero Energy have signaled their intent to take advantage of the opportunities by directly investing in promising technologies and commercialization—for example, Diamond Green Diesel is a renewable-diesel joint venture between Valero and Darling International.

Some of these early-stage technologies are beginning to see success. Clean Energy Fuels, the largest provider of natural-gas-based transportation fuel in North America, serves more than 30,000 vehicles each day at more than 360 fueling stations throughout the U.S. and Canada. Ineos Bio, a cellulosic-ethanol manufacturer based in Florida, initiated commercial operations in 2013. Similarly, two renewable-diesel manufacturing facilities in Louisiana—Diamond Green Diesel (the joint venture of Valero and Darling mentioned earlier) and

Dynamic Fuels—began commercial operations in 2012 and 2013, respectively. The biofuel experiment appears to be off to a successful start.

But will biofuels live up to the promise they showed out of the gate? Although the RFS has succeeded in increasing the degree of biofuel blending (largely using corn ethanol and biodiesel), it has been unable to achieve its cellulosic-ethanol-blending mandate, which has been revised downward annually. Similarly, although the LCFS has succeeded in driving a nominal migration to lower-CI fuels in 2012 relative to 2011, its CI reduction targets do not appear to be achievable in the years to come. In response to this reality and recent litigation, California froze its 2013 LCFS targets through 2014 and may consider amendments to the regulation.

In spite of the recent progress and the current momentum, numerous hurdles still need to be addressed before the U.S. will see large-scale renewable-fuel adoption. Economic and technological constraints exist across almost all of the alternative-fuel categories, and regulatory uncertainty serves as a damper to ongoing biofuel investments.

In this article, we consider the three most promising transportation-fuel alternatives—natural gas for alternative-technology vehicles (ATVs) to displace gasoline and diesel, ethanol to complement gasoline, and renewable diesel (RD) and biodiesel (BD) to replace diesel—and the potential adoption of these technologies through 2020.[1]

ATVs: A Promising Approach

Conversion to ATVs will be driven by three technologies—each of which presents significant challenges that will limit ATV adoption:

- *Hydrogen-fuel-cell vehicles* are unlikely to see widespread adoption in the near term because of high capital costs, the low efficiency of hydrogen production processes, and the requirement for a large investment in production and refueling infrastructure.
- *Electric vehicles* are unlikely to see rapid, broad-based adoption because of their high capital costs, the lack of a widespread recharging infrastructure, and limited vehicle-mileage ranges.
- *Natural-gas vehicles* (NGVs) are limited by the very high capital costs required to convert large numbers of vehicles to run on natural gas (NG) and to scale the refueling infrastructure as needed.

In spite of these constraints, we are optimistic about NGVs, because they are beginning to make headway in achieving consumer penetration. They offer compelling economics and the benefits of a relatively mature technology. Of all the ATV approaches, NGVs have the greatest potential to achieve significant adoption by 2020.

Over the past decade, NG has emerged as a viable transportation fuel in North America as a result of the availability of vast quantities of low-cost shale gas. NG production in the U.S. has skyrocketed and is forecast to reach 11.1 billion cubic feet per year by 2020—a 24 percent increase from 2013. Shale gas can be profitably sold at less than $4 per million British thermal units, or about $24 per barrel of oil equivalent. Given NG's low cost relative to crude oil, NG-based transportation fuels can be sold at highly competitive prices, roughly 35 to 40 percent less than gasoline or diesel in 2012 on an equivalent-gallon basis.

Heavy-duty vehicles and fleets offer prime opportunities for NG adoption. Heavy-duty NGVs can provide very short payback periods (often less than five years) because of their high annual mileage and low fuel efficiency. And vehicle fleets that include medium-duty and light-duty NGVs that return to a central refueling hub offer the benefits of high infrastructure utilization and positive returns on investment. Additionally, government incentives such as tax credits, tax exemptions, and research and vehicle grants are helping to spur adoption across various vehicle classes.

Still, NGVs have a very small installed base (much less than 1 percent penetration in most vehicle classes), a limited number of commercially available engines, and a very limited refueling infrastructure. Although NGVs offer a viable alternative to traditional fuels, we believe that, given the remaining challenges and required investments in vehicle and infrastructure technology, overall NGV penetration rates will not exceed 0.5 percent by 2020.

Ethanol: Abundant in Supply but Limited by Blend Constraints

Ethanol is expected to come from three primary sources: cellulose, sugarcane, and corn. Cellulosic ethanol is produced from "waste" feedstock such as corn stover, woody biomass, and switchgrass. Most sugarcane ethanol is produced in Brazil and shipped to the U.S. by marine freight. Corn ethanol is produced from edible corn in the U.S. and is widely available.

Widespread ethanol adoption is constrained by three factors: overall U.S. gasoline consumption, blend wall limitations (that is, the amount of ethanol that can safely be blended into gasoline), and flex-fuel vehicle-penetration rates (that is, vehicles that can consume up to 85 percent ethanol). The U.S. Energy Information Administration (EIA) predicts that the U.S. will consume less than 9.5 million barrels per day (bpd) of gasoline by 2020 (approximately 4 percent less than in 2011), about 1.1 million bpd of which we expect to come from ethanol.

Currently, gasoline can be blended with up to 10 percent ethanol (for most vehicles). Increasing the blend wall limit to either 12 percent or 15 percent is frequently discussed, but that shift is not likely to occur soon given technology and regulatory constraints. Although flex-fuel vehicles can consume gasoline blends with up to 85 percent ethanol, their future penetration will be constrained by high vehicle costs, high fuel costs (on an energy-equivalent basis), and station upgrade costs. We expect overall 2020 ethanol-blending rates, including flex-fuel penetration, to be nearly 12 percent of the total gasoline pool.

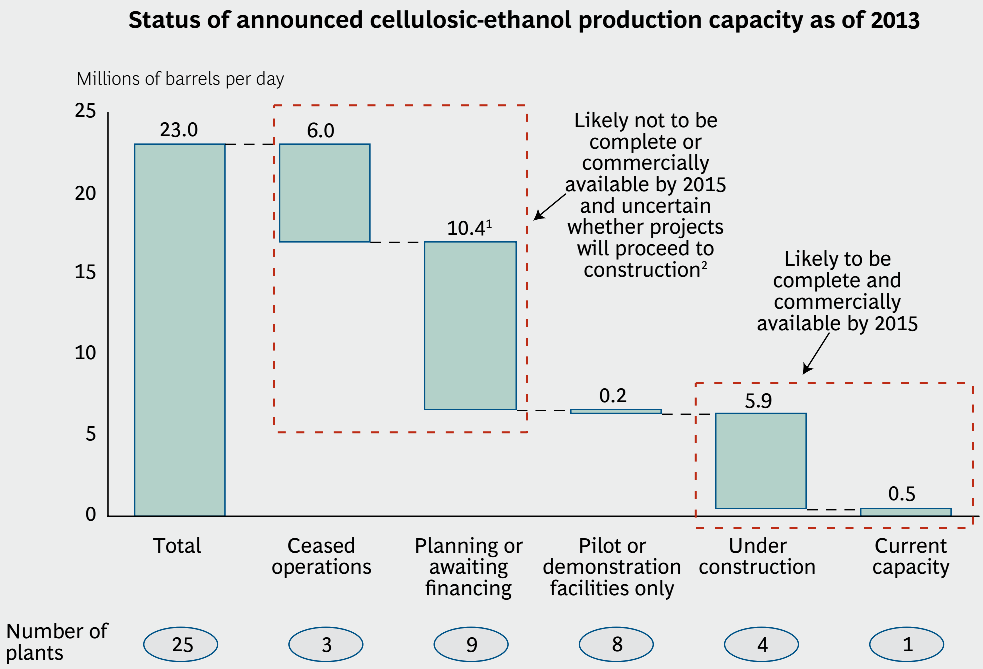
Commercial cellulosic ethanol is still in its early days. The industry has been attempting to develop scalable, economically viable cellulosic ethanol for nearly a decade. Government and industry sources, however, have consistently overestimated potential output. The first commercial production did not occur until 2013, and, although numerous new cellulosic plants have been announced, a majority of the plants are either awaiting financing or in the early planning stages. (See Exhibit 1 for a near-term perspective.)

Very limited quantities are expected to come online by 2020. Projects are constrained by high capital- and operating-expenditure requirements, nascent technology that is still in development, and an economic model that is heavily reliant on government subsidies. We expect cellulosic-ethanol production to contribute less than 20,000 bpd by 2020.

Brazilian sugarcane ethanol faces several challenges that are likely to limit its export potential to the U.S. Ports in Brazil are congested and in need of capital investment; shipping is often delayed by 15 days or more. Logistics costs are high, and much of the current road infrastructure is underdeveloped and unsurfaced. Most significantly, sugarcane faces strong demand—from the food industry; from other international jurisdictions, such as Europe; and from the domestic ethanol-manufacturing sector—posing significant competition for supply. We expect less than 220,000 bpd of imports by 2020.

Corn ethanol is abundant and likely to fill the gap between cellulosic- and sugarcane-ethanol availability and overall ethanol demand. However, similar to sugarcane, corn is in demand both as a food and as an

Exhibit 1 | With Cellulosic-Ethanol Production in Early Stages, Limited Supply Will Be Available by 2015 and Post-2015 Projects Are Uncertain



Sources: Environmental Entrepreneurs; press search; BCG analysis.
Note: The total reflects the projected capacity reported by Environmental Entreprenuers in *Advanced Biofuel Market Report 2012: Meeting U.S. Fuel Standards.*
[1]Includes one plant with a projection for 2015.
[2]Assumes an average construction time frame of 18 to 22 months, if not stated otherwise by the company.

ethanol feedstock. Further, there is public demand to limit corn's use in ethanol production because of concerns about escalating food prices. Lastly, corn ethanol has a relatively high CI, meaning that, on an absolute basis, it reduces GHG emissions less than other biofuels. We expect about 880,000 bpd of U.S. corn-ethanol consumption by 2020.

RD and BD: Limited in Supply for the Near Term

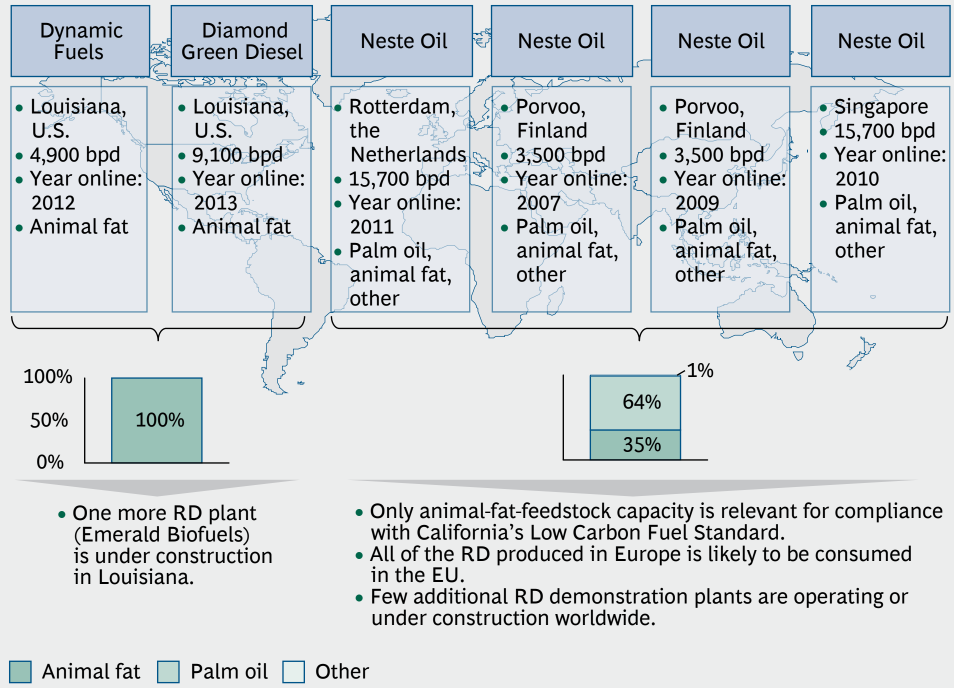
The EIA predicts that the U.S. will consume approximately 4.1 million bpd of diesel fuel by 2020. Of this total, we expect, about 3 percent, or 115,000 bpd, will be supplied by RD and BD.

RD is a highly flexible drop-in biofuel, meaning that it can replace hydrocarbon diesel on a one-for-one basis without requiring further engine certifications or approvals. BD, however, requires certification and can be blended only in limited quantities. Currently, all vehicle manufacturers certify B5 (5 percent BD and 95 percent hydrocarbon diesel) engines; however, starting in 2013, most new engines are certified for B20 blend levels.

Currently, RD-manufacturing capacity is very limited. Only a small number of large commercial facilities are operational worldwide: two in the U.S., one in Asia, and three in Europe. (See Exhibit 2.) An additional plant is expected to come online in the U.S. by 2015 and will moderately increase supply. Feedstock materials are likely to remain unconstrained through 2020.

However, faster growth in capacity is constrained by a number of factors. RD relies on proprietary technology that is very capital intensive relative to refining crude oil, and capital costs are not expected to decline significantly by 2020. The majority of the operating expense is

EXHIBIT 2 | Limited RD Production Exists Today



Sources: Company websites and reports; Argonne.
Note: bpd = barrels per day; RD = renewable diesel. Totals reflect commercially operational plants only.

driven by feedstock costs, which are highly correlated with oil prices and are expected to remain high. The industry relies heavily on government subsidies for economic viability, a factor that will constrain further investment through 2020. Lastly, various infrastructure constraints limit adoption, including labeling requirements and transport issues such as concerns about common-carrier commingling. We expect less than 35,000 bpd of RD production by 2020.

Similarly, BD has established itself as a meaningful part of the fuel value chain in recent years. However, few new plants are in development in the U.S., with limited capacity increases expected before 2015. Similar to RD, BD feedstock materials are unconstrained in the short run but have alternative uses and will likely become constrained as demand grows. Also similar to RD, operating expenses are largely driven by feedstock costs, which are expected to remain high. The industry relies heavily on government subsidies.

Lastly, several infrastructure constraints impede further adoption, including replacing older storage tanks that are not BD compatible, installing segregated tanks on common distribution infrastructure, and Federal Trade Commission labeling laws for blends above B5 and below B20. We expect about 80,000 bpd of BD production by 2020.

A Slow and Steady Pace for This Race

It is clear that the U.S. biofuel experiment is having an effect. The race has begun and progress is being made. Major truck manufacturers, such as Volvo, have announced that they will be bringing natural-gas engines to market, and fuel providers are building out the refueling infrastructure nationwide. Larger quantities of renewable fuels are available to the U.S. consumer today than at any time in history. In 2013, ethanol will make up nearly 10 percent of total gasoline sales and biodiesel is expected to exceed 1 percent of total diesel sales. Commercially viable cellulosic ethanol is now a reality, albeit in limited quantities.

However, equally real are the constraints that will hinder and impede further progress. High capital and operating costs, regulatory uncertainty, and technology limitations will all apply a brake to the speed at which biofuel adoption occurs in the U.S.

NOTE
1. Note that natural gas, although not a renewable fuel, has significantly lower GHG emissions than other hydrocarbon fuels.

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