Isobutanol

Biofuel of the Future

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Current federal mandates will increase the amount of renewable fuels required to be blended with gasoline by about 150 percent by 2022.

Ethanol, today's biofuel of choice, has some limitations in the current vehicle population and refueling infrastructure at concentrations higher than 10 percent. What is needed is a fuel that is compatible with existing vehicles and infrastructure. Without such a fuel, meeting the mandated biofuel volumes will be a significant challenge. Isobutanol, an alternative alcohol that can be produced from the same biomass feedstocks as ethanol, is such a fuel.

This article will summarize the current renewable fuel mandates and provide an overview of the benefits and synergies that can be achieved with isobutanol. We also will review the reliability testing that has been done and is in progress to ensure that isobutanol is indeed compatible with today's vehicles and fuel distribution infrastructure.

Biofuels Background

The Renewable Fuel Standard (RFS) established by the Energy Policy Act of 2005 (EPAct) mandated blending renewable fuels into gasoline. The Energy Independence and Security Act of 2007 (EISA) substantially expanded the renewable fuels mandates and incorporated specific biofuel categories. Under these expansions (called RFS2), the total blending requirement for refiners increases each year from the current 15 billion gallons to 36 billion gallons (ethanol equivalent) of renewable fuel in gasoline and diesel by 2022.

While RFS2 mandates volumes of renewable fuels, it does not authorize new fuel formulations or mandate changes to vehicles. Most vehicles on the road in the United States, as well as the nation's fuel distribution infrastructure, have been designed for compatibility with gasoline and 10 percent ethanol blends (E10). RFS2 leaves it to the market to solve


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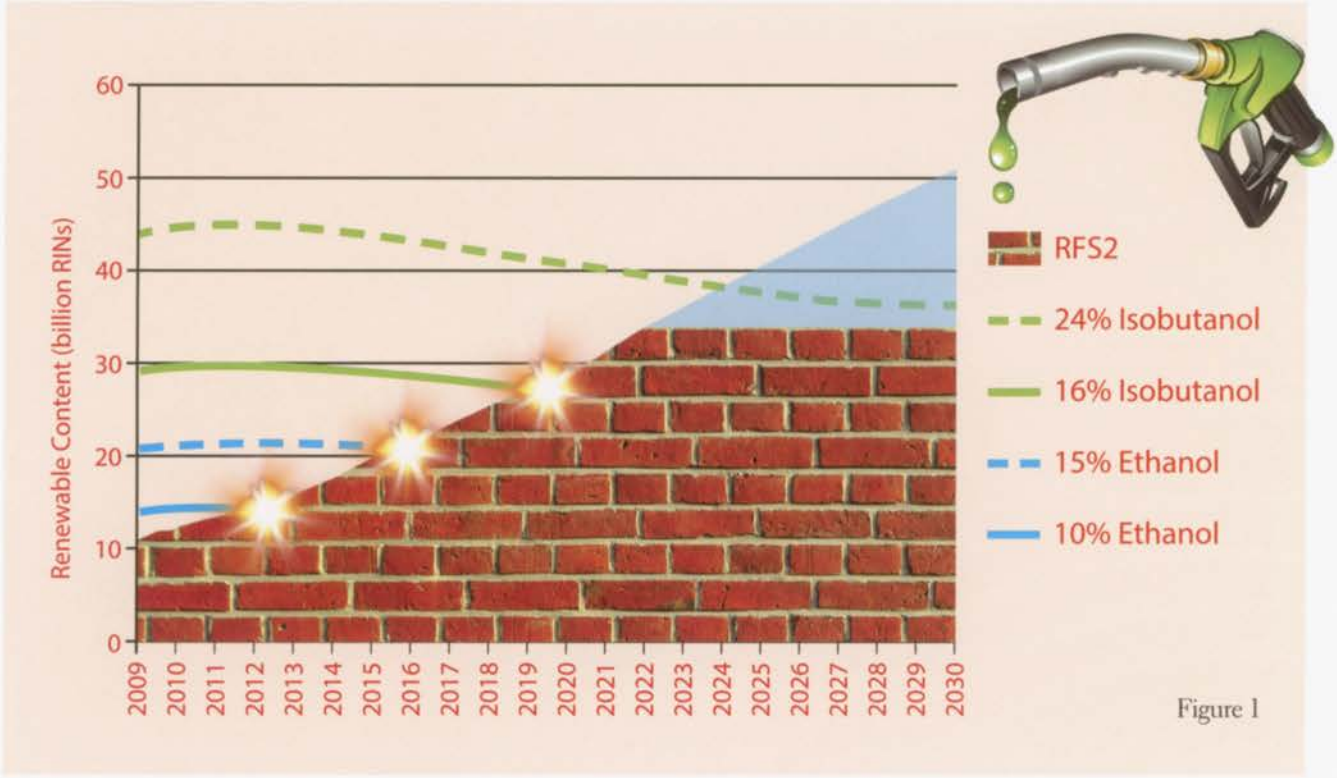

Figure 1

the many questions surrounding the increasing biofuel requirements—including infrastructure compatibility.

Figure 1 shows the required quantity of renewable fuels over time under RFS2. It indicates that we will reach the

Biofuel engineers monitor isobutanol production at a pilot plant in Hull, UK.

"E10 blend wall" this year. Beginning next year, the annual RFS2 renewable fuel requirement exceeds the amount of ethanol that can be blended as E10 into the available gasoline pool. While the United States Environmental Protection Agency (EPA) has approved the use of E15 in 2001 and newer light-duty vehicles (subject to certain restrictions), E15 may not be fully compatible with all materials found in the existing refueling distribution system. In addition, there certainly will be confusion among retail customers faced with choosing between E10 and E15, as well as potential hardships for the station operators who will have to finance infrastructure changes that may be required to achieve E15 compatibility.

If ethanol remains the primary renewable gasoline blending component, another "blend wall" approaches in 2016 even if all domestic fuel were to be blended with 15 percent ethanol. Meeting the mandated goals requires a biofuel that can be blended at higher concentrations while remaining compatible with existing vehicles and infrastructure. In order to eliminate "blend wall" constraints, this new biofuel must be available in significant quantities in a relatively short time frame and be capable of cost-competitive production.

Isobutanol Overview

One solution to increasing the use of biofuels worldwide is isobutanol—a biologically produced four-carbon alcohol that delivers the same benefits as ethanol, as well as additional product attributes that overcome some of ethanol's current limitations. The key properties of isobu-

Isobutanol Properties

	Gasoline	Ethanol	Isobutanol
Anti-knock Index (R+M)/2	87	120*	100*
Reid Vapor Pressure RVP (psi)	7-15	~19*	~6*
Energy Content (% compared to gasoline)	100	66	84
Oxygen Content (%w/w)	N/A	34.7	21.6
Water Solubility	Insoluble	Infinite	Low

*blending values in gasoline

tanol, as compared to gasoline and ethanol, are presented in the table above. A lower blending octane value is offset by its higher allowable blending ratio of 16 percent versus 10 percent for ethanol. At these blending ratios, the fuels approach octane parity in finished gasoline.

Isobutanol may be produced from feedstocks currently used for the production of ethanol, and work is underway to enable future production from cellulosic materials. In addition, many existing ethanol plants can be converted to isobutanol production with a relatively low-cost retrofit technology package, thereby enabling rapid scale-up of isobutanol production to meet demand growth.

Isobutanol also enables renewable fuels growth by eliminating the need to modify distribution infrastructure or vehicles. If all future gasoline is blended as iBu16 (16 percent isobutanol), we will reach the RFS2 "blend wall" in 2020. If the isobutanol content is increased to iBu24 (24 percent isobutanol), the full RFS2 mandate can be met. EPA allowance for iBu16 blends already exists under a current waiver of the Clean Air Act (the so-called "Octamix Waiver"). Additional approval will be required for iBu24 blends.

Benefits of Isobutanol

Isobutanol benefits every part of the petroleum equipment industry, its customers and the environment. Among these benefits are the following:

Refineries: The lower vapor pressure of isobutanol allows refiners to more easily and profitably comply with requirements to make low-emission, low-vapor-pressure gasoline. The low vapor pressure also results in lower VOC (volatile organic compound) emissions throughout the supply chain and especially during product handling operations.

Terminals: Since isobutanol can be blended at the refinery, terminals will have less need to dedicate scarce tankage to biofuels. Isobutanol also is more resistant to water absorption and less susceptible to separating from fuel in the presence of water than ethanol, so it can be easily transported via pipelines, a more efficient and cost-effective delivery method than truck or rail.

Retail: Isobutanol is less aggressive chemically than ethanol, so it can be blended at higher percentages without requiring retailers to replace or modify existing equipment. Under current rules, up to 16 percent isobutanol can be blended into gasoline and meet U.S. fuel specifications. With additional testing, higher-level blends may be approved as well. Because isobutanol does not separate from gasoline in the presence of water, it also presents fewer fuel quality issues.

Automakers: Vehicles on the road today are compatible with iBu16 blends. Since iBu16 has the same oxygen content as E10, the isobutanol fuel maintains the same level of fuel oxygen content for which vehicles were designed and calibrated and minimizes the risks of onboard diagnostic system malfunctions.

Consumers: Because of isobutanol's high energy content, iBu16 offers fuel economy comparable to E10 while doubling the renewable energy content of the fuel. In addition, isobutanol's compatibility with vehicle materials allows this increase in renewable content without risk to vehicle operating life.

Environment: Isobutanol's chemical properties mean it can be blended with gasoline at higher concentrations than ethanol, displacing more gasoline per gallon of fuel than the standard E10. The iBu16 blend has the potential to reduce GHG (greenhouse gas) emissions more than E10.

Isobutanol-Ethanol Synergies

Isobutanol can be produced from the same agricultural feedstocks as ethanol (e.g., sugar cane, corn, wheat, sorghum and, in the future, dedicated energy grasses). The production process is similar to that used with ethanol and, therefore, offers the possibility that relatively low-cost retrofits to existing ethanol plants can rapidly scale up isobutanol production.

Isobutanol and ethanol-blended fuels also are mutually compatible if commingled, a likely occurrence if distribution systems are switched over from ethanol to isobutanol. The commingling of the alcohols will not introduce new incompatibilities with either vehicles or refueling infrastructure materials and systems.

Butamax's 40,000 gallon-per-year technology demonstration plant in Hull, UK.

Isobutanol Testing

BP and DuPont have pursued a rigorous technology development program since 2003, covering all aspects of isobutanol production and use in the fuels market. The two companies formed Butamax Advanced Biofuels, LLC as a 50/50 joint venture to commercialize isobutanol for the fuels market.

Extensive fleet and fuel performance tests in the United States and Europe have demonstrated that butanol works with existing vehicles and fueling infrastructure. In terms of vehicle performance testing, more than 1.5 million miles have been driven in 135 cars (model years from 1999 to 2009 and ranging from brand new to over 200,000 miles of service) using a range of gasoline-butanol blends. In a 2008 through 2009 retail demonstration in the United Kingdom, butanol blends meeting all European and U.K. fuel specifications were supplied to 10 retail gasoline stations. Over the course of the demonstration, approximately 250,000 vehicles were filled and 80 million miles driven using butanol blends of fuel.

Other important results from extensive fuels product and performance testing in the United States have shown that iBu16 blends provide the same fuel economy as E10 blends and the energy security that would be delivered by E20. While it is believed that 24 percent butanol can be blended into gasoline for cars that are compatible with E15, additional testing and regulatory approvals will be required to bring an iBu24 blend to market.

Butamax has been working with both Underwriters Laboratories and the Oak Ridge National Laboratory since early last year in conducting parallel tests on materials exposed to isobutanol-gasoline blends. While the final reports on the work are expected to be released later this year, preliminary results indicate that most commonly used equipment materials exposed to iBu16 will show similar or less degradation than E10 blends. Materials being tested include more than 30 different formulations among families of metals and alloys, elastomers, plastics, and sealants, all of which were previously tested with elevated levels of ethanol-gasoline blends.

With a large and growing body of successful tests behind it and exceptional environmental and supply-chain benefits, isobutanol is indeed the drop-in fuel needed to achieve the RFS2 goals and mandates.

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