Testimony of Jeff Wasil

Evinrude Marine Engines

Sturtevant, Wisconsin

before the

Subcommittee on Energy and Environment

Committee on Science, Space, and Technology

United States House of Representatives

July 7, 2011

Good afternoon, Chairman Harris, Ranking Member Miller, other members of the subcommittee.

It is a pleasure to be here this afternoon. My name is Jeff Wasil and I am the Emissions Certification Engineer for BRP Evinrude Marine Engine division located in Sturtevant, Wisconsin . I am here today to testify on behalf of the National Marine Manufacturers Association, which represents over 1500 boat builders, marine engine, and marine accessory manufacturers. I ask that my full written testimony, with the attached exhibits, be made a part of the record of this hearing.

I am responsible for marine engine emissions certification testing: ensuring that all of our marine engines are compliant with US EPA, California, and other global marine emission regulations. Additionally, I ensure that the engines we sell will remain durable and perform to customers' expectations. Over the past 12 years, I have published several peer-reviewed technical papers on marine engine emissions, including particulate matter, gaseous emissions, green house gas emissions and alternative fuels. This experience and other marine testing I have done makes me uniquely qualified to tell you why I think it is a bad idea for the US Environmental Protection Agency to allow an increase in the volume of ethanol in gasoline and why I believe EPA has not followed proper procedures in either its decision to propose an ethanol increase in our gasoline supply or in their proposed warnings to consumers about the problems that they know would be caused by E15 gasoline.

As all of you most certainly know, EPA responded to a petition from "Growth Energy," which represents ethanol producers and supporters, by proposing to raise the percentage of ethanol in gasoline from 10 percent to 15 percent by volume. I am here today representing NMMA and my company, but in a larger sense, I am representing many different kinds of engine manufacturers -- marine, lawnmower, chain saw, snow blower, snow mobile. These types of engines that EPA refers to as "non-road engines" typically do not have combustion feedback sensors capable of adjusting the air/fuel ratio of the engine to match the specific requirements of the fuel. Ethanol is not gasoline, and the problem is that ethanol contains additional oxygen. As higher quantities of ethanol are blended into base gasoline, oxygen contained in the fuel increases, which leads to engine enleanment. Since many non-road engines do not have the capability of detecting the air/fuel ratio requirements of the fuel, the engine could face catastrophic failure. As a member of the team responsible for engine calibration, and the person responsible for emissions certifications, EPA requires me to design, certify, and lock-in with tamper-proof controls, the optimal fuel/air ratio needed to meet emission requirements. When the fuel changes in the marketplace and additional oxygenates added—such as by going from E10 gasoline to E15—engines run hotter, causing serious durability issues and increased emissions either in the form of increased Nitrogen Oxides (due to enleanment) or increased hydrocarbons (due to misfire). Additionally, ethanol is hygroscopic—meaning that it has an affinity for water. Obviously there is significant opportunity for fuel-related issues in the marine environment due to the presence of water near open-vented fuel systems and due to the inherent long-term storage and usage cycles unique to recreational boats. Ethanol only exacerbates these issues.

My concern is heightened by the EPA’s statutory mandate to increase the biofuel content in the nation’s gasoline supply to 36 billion gallons per year by 2022 and by the EPA’s efforts to achieve this mandate. As I mentioned, EPA has responded to the petition from Growth Energy by proposing a “partial waiver,” allowing E15 to be used in certain vehicles and not in others. As a result of this partial waiver, EPA has begun working on a rule that will change the certification fuel for our engines from a 0% ethanol-extended fuel to a 15% ethanol-extended fuel. In addition, last week, EPA finalized a label that would be required on fuel pumps at gas stations warning consumers that using E15 in certain types of engines may damage them. NMMA believes that the language in the label is severely inadequate and will do little to properly inform and educate consumers as to the serious consequences of using the wrong fuel. I have attached a copy of the label with our specific concerns as part of my full written testimony.

The reality is that if E15 becomes the standard gasoline in the marketplace, millions of consumers will run the risk of having their vehicles, boats, lawnmowers, and other gasoline-powered devices damaged, because they will not have the option of fueling them properly. Although NMMA and others petitioned EPA to require gas stations that offer E15 to also offer E10, EPA has denied this petition and has no plans to mandate the continued availability of E10. This will certainly lead to the very misfueling that EPA wants to avoid.

Growth Energy and other ethanol proponents will say that if there is a demand for E10, the marketplace will ensure that some stations will carry it, and this may be true to an extent. However, it is unlikely that every gas station would carry E10, and there might not be one anywhere near where you live or work. So that would inconvenience the consumer and increase the likelihood of misfueling.

Why have I been so insistent that increasing ethanol is almost certain to damage marine and other types of engines? As the person who works on calibrating these engines, I know first-hand how to damage them. I have seen some of the preliminary results of testing that has been conducted on such engines by the Department of Energy’s National Renewable Energy Laboratory. These results have not yet been made public, and we have been asked by DOE not to say anything specific until the report is final, but I can say that in these tests, the majority of the marine engines that were run on E15 suffered significant damage or exhibited poor engine runability, performance and difficult starting—none of which is acceptable when on a boat out at sea. Why did this happen? As I mentioned in my opening, from a technical standpoint the failures are due to changes to the calibrated stoichometric air/fuel ratio requirements of E15—which is different from the fuel on which the engine was intended and designed to run. The full results of the DOE tests are scheduled to be released in the fall, but from what we have already learned, E15 will cause many engines to fail well before they should. We know that, and the EPA knows that, and it's the reason we should slow down this abrupt move to introduce E15 into the marketplace.

So that I do not end my testimony today on a completely negative point, I'd like to mention an alternative fuel that is currently being evaluated. Last year, I published a technical paper on the effects of butanol-extended fuels in marine outboard engines. Butanol has an energy content closer to that of gasoline and is not hygroscopic—meaning that it is unlikely to absorb water and phase-separate like ethanol. Based on this preliminary study, the data are promising in terms of better compatibility with existing engines and fuel systems. Additionally, the National Marine Manufacturers Association and others are also currently evaluating the use of butanol-extended fuels in marine products. Butanol, considered an advanced biofuel in the Renewable Fuels Standard (RFS), can be produced from many different types of biomass feedstocks, including corn. Recent advances in microbial fermentation processes have increased the yields of butanol, which make this product more cost-effective. We don't know for sure whether butanol is going to be a long-term viable alternative to ethanol, but it certainly does have potential. Testing is being done this summer by the NMMA and the American Boat and Yacht Council. We have also learned that other groups that make small engines are planning to test this new type of fuel. Butanol may allow for continued use of biofuel without the disadvantages of ethanol. We would like to talk with you about this when we complete our evaluation of butanol and when the DOE report on marine engines is final and we are allowed to talk more specifically about the DOE testing.

I was specifically asked by the subcommittee to comment on the draft legislation that you will be considering. This legislation calls for the National Academy of Sciences to conduct a survey of all available scientific information relating to the effects on engines of ethanol blends greater than 10 percent. This seems to me to be a terrific proposal, as it would bring together in one place all that is known about E15 and higher ethanol blends.

To summarize what I have told you today,

First, an increase in the ethanol content of gasoline from E10 to E15 has been proposed by the EPA.

Second, EPA acknowledges that E15 gasoline is suitable only for a limited set of gasoline-powered vehicles and engines, specifically not including marine engines, snowmobile engines, engines on outdoor power equipment, and cars older than the 2001 model year.

Third, the warning label EPA has proposed for placement on gasoline pumps is completely inadequate. The label they propose will not properly warn and inform consumers about problems associated with E15, and it is almost certain result in massive misfueling and subsequent engine damage.

Fourth, unless continued availability of E10 gasoline is mandated by the EPA—which the EPA has declined to do—E15 will almost certainly become the common fuel in the marketplace, with E10 having very limited availability.

Fifth, there is no need to rush E15 into the marketplace. Let’s have a strategic pause while more testing is done to determine the effects of E15 on various kinds of engines and to see whether there might be alternatives to ethanol, such as butanol.

Thank you for allowing me to testify today.

Jeff R. Wasil

Exhibits

Exhibit A: Jeff R. Wasil, narrative biography

Exhibit B: Press Statement, National Marine Manufacturers Association, June 28, 2011, Subject: "EPA Finalizes Pump Label and Other Misfueling Guidelines for E15; NMMA concerned controls are inadequate to prevent misfueling as final rule makes way for retail sale"

Exhibit C: Proposed EPA E15 Label, June 28, 2011

Exhibit D: Jeff R. Wasil, Justin Johnson, and Rahul Singh, "Alternative Fuel Butanol: Preliminary Investigation on Performance and Emissions of a MarineTwo-stroke Direct Fuel Injection Engine"

Exhibit E: GEVO White Paper, Transportation Fuels

Exhibit F: Top Ten Reasons to use Isobutanol

Jeff R. Wasil

Jeff Wasil is currently employed as an Engineering Technical Expert, Emissions Testing, Certification and Regulatory Development at the Evinrude Product Development Center, Sturtevant, Wisc. Jeff is responsible for the marine outboard engine emissions testing and certification laboratory at Bombardier Recreation Products Evinrude Product Development Center. Jeff has twelve years experience in engine emissions testing and is intimately involved with global marine regulatory emissions development and harmonization. He is a member of the National Marine Manufacturers Association’s engine manufacturers division technical board, the International Council of Marine Industry Association (ICOMIA) marine engines committee, ICOMIA technical committee and is a project leader of NMMA’s greenhouse gas task force. Over the past ten years he has published and presented several technical papers on marine engine emissions including particulate matter, gaseous emissions, bioassay analysis, life-cycle emission and alternative fuels.

From 1995 to 1998 Jeff attended the Industrial Engineering Technology College of Lake County in Grayslake, IL, from which he received his Associates degree. He received a second Associates degree in “Environmental Sustainability” from Roosevelt University in Chicago.

Exhibit A

EPA Finalizes Pump Label and Other Misfueling Guidelines for E15

NMMA concerned controls are inadequate to prevent misfueling as final rule makes way for retail sale

WASHINGTON, D.C. – June 28, 2011 – Today, the Environmental Protection Agency (EPA) released its rule outlining a gas pump warning label as well as other misfueling controls for gasoline containing up to 15% ethanol, more commonly known as E15. Last October, the agency approved the use of E15 for model year 2007 and newer vehicles as part of its response to a waiver petition filed in the spring of 2009 by pro-ethanol lobby group Growth Energy. In January 2011, E15 was approved for model year 2001-2006 cars and trucks. Completion of this misfueling rule was one requirement that was stipulated in the partial waivers for E15 before the fuel could be sold at retail outlets. Fuel and fuel additive manufacturers now must register E15 with the EPA, which has not been done as of today.

While both partial waivers exclude marine engines and other non-road engines such as snowmobiles, lawn and garden equipment, the National Marine Manufacturers Association (NMMA) continues to be concerned that the measures outlined in EPA’s misfueling rule do not take significant steps to address anticipated problems with consumer confusion and the risk of misfueling. In addition, the rule does not ensure compatible fuels remain available for the nation’s 13 million registered boat owners or the hundreds of millions of owners of gasoline-powered equipment. These concerns were outlined in NMMA's full comments to EPA submitted earlier this year.

Specifically, NMMA is concerned that:

- **The EPA believes that misfueling will be mitigated solely through an English-only label on the gas pump.** The label does not identify the specific nature of the hazard and is not sufficiently strong enough to capture the user’s attention, especially among the many existing point-of-sale labels already competing for consumers’ attention. In addition, usage of the word “may” does not reflect EPA’s own conclusion that E15 will damage marine engines and equipment. The label, which was not tested through consumer focus groups, does not meet American National Standards Institute (ANSI) warning label standards that require recognizable warning symbols and icons.
- **The EPA is not requiring any physical misfueling controls for E15.** NMMA recommended that physical barriers such as electronic key pad confirmation, verbal cashier confirmation, radio frequency identification (RFID) tags on E15 compatible vehicles that would lock fuel dispensers for any non-compatible use such as boats and/or the establishment of segregated pumps for E15 be required. However, the EPA is not requiring any of these highly effective physical barriers to misfueling.
- **The EPA will not conduct a consumer education campaign.** While the agency notes that this is an important step to preventing misfueling, the agency is asking stakeholders to educate the public despite the fact that ethanol producers and corn-industry groups have aggressively marketed E15 with misleading consumer information in the past. Any fair and objective consumer education campaign must be led by the EPA and not stakeholders with a direct financial incentive to promote and sell their product.

- **The EPA will not require that E10 remains available in the marketplace.** The agency has denied

> NMMA's petition to require that E10 be sold at gas stations as the population of motor vehicles who are approved to use E15 grows over time. Without this requirement, fuel for boats and other non-road engines and equipment will become an expensive specialty fuel, discouraging consumers from buying it and thus exacerbating the risk of misfueling.

"As E15 becomes available for on-road vehicles, this greatly increases the likehood of misfueling in boats, the large majority of which are refueled at neighborhood automotive gas stations where E15 will be sold," said NMMA President Thom Dammrich. "NMMA is disappointed that EPA's only mechanism to protect consumers from confusion at the pump and consequent engine failures, emissions control failures and safety issues is a small label on the pump."

In December 2010, the NMMA filed suit in the U.S. Court of Appeals for the D.C. Circuit challenging EPA's partial waiver to approve E15 for certain motor vehicles. NMMA continues to work with the Outdoor Power Equipment Institute (OPEI), the Alliance of Automobile Manufacturers (AAM) and the Association of International Automobile Manufacturers (AIAM) in a coalition called the Engine Products Group (EPG) in pursuing this legal challenge.

For more information, contact Cindy Squires at 202-737-9766 or csquires@nmma.org.
Contact:Christine Pomorski 202.737.9774

2010-32-0054 / 20109054

Alternative Fuel Butanol: Preliminary Investigation on Performance and Emissions of a Marine Two-Stroke Direct Fuel Injection Engine

Jeff R. Wasil, Justin Johnson and Rahul Singh
BRP US Inc.

ABSTRACT

In pursuit of reducing dependencies on foreign oil coupled with U.S. renewable fuel standards and an overall focus and interest in greenhouse gas emissions, investigations continue on feasibility of replacement biologically derived fuels such as ethanol and butanol. Majority of existing recreational products such as marine outboard engines, boats, personal watercraft, all terrain vehicles and snowmobiles are carbureted or operate open-loop, meaning the engine does not have the capability to sense air-fuel ratio. Ethanol has a specific energy content that is less than gasoline. Without means to compensate for air-fuel ratio requirements of specific fuels, open-loop engines may suffer from a condition known as enleanment, in which catastrophic engine failure may result.

On the contrary, butanol has specific energy content closer to that of gasoline, suggesting open-loop engines may be less prone to negative effects of increased biologically derived fuel concentrations in gasoline.

This is a preliminary investigation into the effects of butanol/gasoline mixtures on a two-stroke direct injection recreational marine outboard engine. Additionally, ethanol/gasoline mixtures are also tested as comparison. Engine performance, combustion characteristics and emission results including overall effects of various butanol/gasoline and ethanol/gasoline blends will be explored.

INTRODUCTION

Engines used in a marine environment to power recreational craft are subject to very different operating conditions, usage cycles and overall physical running conditions than automotive engines. Therefore, it is important to understand these variations on how fuel blends primarily intended for automotive use may affect recreational marine engines and fuel systems.

Engine and drive weight is very critical for recreational marine products. Engine power to weight ratio has a direct effect on vessel performance and fuel economy. Additionally, it is not uncommon for recreational marine engines to be operated at wide open throttle (WOT) at rated speed for extended periods of time. During WOT, components are stressed more, not only from a mechanical standpoint, but also thermally. Subtle differences in combustion as a result of fuel properties can have a significant affect on performance, engine durability and emissions [1, 2].

According to the National Marine Manufactures association (NMMA), as of 2007, 12,185,568 gasoline powered recreational boats are currently registered in the United States [3]. Of that, approximately 225,000 have been retired from the fleet, which is less than 2% of the total powerboat fleet. The recreational marine industry as a whole has one of the oldest fleets of the engine sector. This results in a particularly difficult challenge in development of alternative fuels that will minimize engine run-ability issues, fuel system component issues or potential engine failures considering the wide range and age of products currently still in use.

Several different materials are used for boat fuel tank construction including aluminum, polyethylene and fiberglass. Alternative fuel compatibility with different types of fuel tank materials needs to be considered and understood [4, 5].

Most boat fuel systems are vented directly to the atmosphere, which allows moisture to enter the fuel tank during daily diurnal temperature changes. This is further complicated by the marine environment itself - in which water or salt water is more likely to be inadvertently introduced into fuel systems. Moreover, typical usage of boats, especially in northern parts of the US, equates to longer periods of storage and subsequently potential for more fuel system related issues [6].

With respect to the aforementioned vented fuel system issue, as compared to ethanol, butanol is not hygroscopic and is much less susceptible to phase separation. Figure 1 shows the difference between ethanol and butanol fuels when 10% H_2O is added to each fuel. A colorant was added to highlight differences between the two samples. As shown, the cylinder containing ethanol on left has phase separated, meaning water and ethanol have formed an aqueous mixture forcing the gasoline to the top of the cylinder. In the cylinder, on the right containing butanol, water has settled to the bottom of the cylinder, leaving butanol and gasoline for the most part unaffected. Phase separation with ethanol causes additional engine enleanment due to both the fact that gasoline is displaced and water is present in the fuel causing the engine to ingest an ethanol water mix. Lack of phase separation in presence of H_2O is a desirable basic property of butanol, not only for the recreational marine industry, but also for the overall fuel distribution network, as butanol could be successfully delivered in existing pipelines [7].

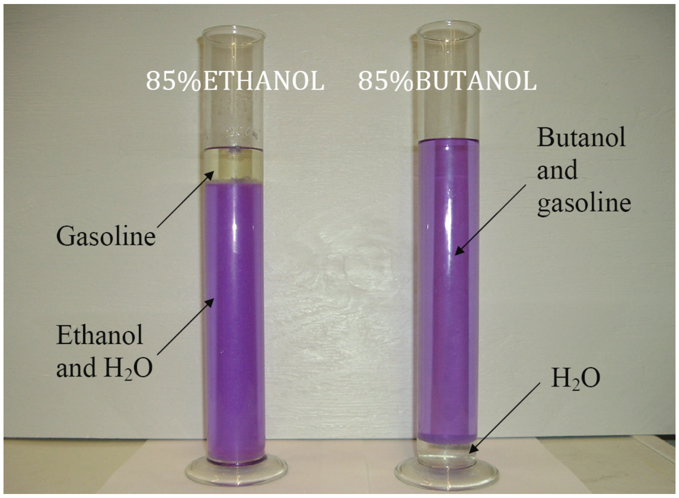


Figure 1. Effect of adding 10% water by volume to 85% ethanol and 10% water by volume to 85% butanol.

TEST SETUP

This section includes a description of the test engine, fuel flow system, test fuels, emissions analyzers, combustion analysis equipment, engine cooling water system, and overall test process. A schematic of engine test cell set-up is presented in Figure 2.

TEST ENGINE

A three cylinder 90 horsepower (67.1 kW) spray-guided stratified charge direct injection two-stroke production outboard engine was used for testing. The engine operates open-loop and does not have any type of combustion feed back sensor. This particular engine was chosen as it tends to be slightly more knock and fuel sensitive. Moreover, it is a scalable design, as this configuration forms 150, 175 and 200 horsepower V-6 outboard engine models. Engine specifications are shown in table 1.

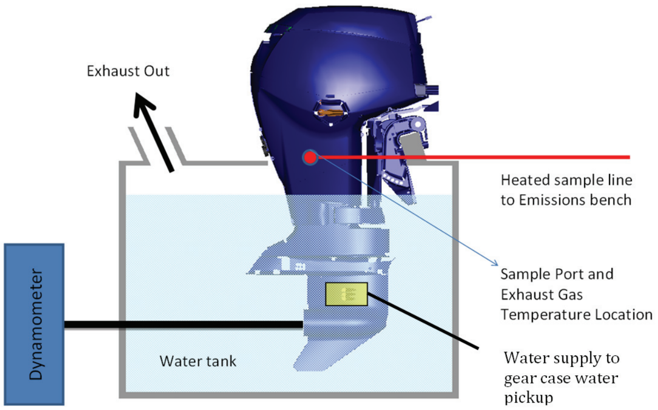


Figure 2. Engine test setup

Table 1. Test Engine Specifications

Model Year	2010
Fuel System	Gasoline Direct Fuel Injection (GDI)
Emissions Rating	California Three-Star Ultra-Low
Engine Cycles	2
Valves	Reed
Number of cylinders	3
Displacement	1296
Rated power HP (kW)	90 (67.1)
Full throttle operating range	4500 - 5500
Idle speed	650
Engine Hrs	175
Midsection length (inches)	20

FUEL AND FUEL FLOW INFORMATION

Fuel used for baseline emissions testing and as a base for blending is Indolene clear, which is a standardized gasoline test fuel that conforms to EPA CFR part 1065 requirements for certification testing [8]. Fuel flow is measured volumetrically using a Pierburg 60 lph fuel metering system along with a Calibron Densitrak DT625L density meter to arrive at fuel consumption in grams per hour. The fuel specifications are shown in Table 2. Calculated stochiometric air/fuel ratios for various alternative fuel blends are shown in Figure 3.

Various amounts of butanol or ethanol were blended with base indolene fuel to arrive at the desired concentrations of alternative fuel by volume:

- (B-10): 10% Butanol, 90% Indolene
- (B-15): 15% Butanol, 85% Indolene
- (B-20): 20% Butanol, 80% Indolene
- (E-10): 10% Ethanol, 90% Indolene
- (E-15): 15% Ethanol, 85% Indolene

Table 2. Test Fuel Specifications

Property	Gasoline	Ethanol (CH3OH)	n-Butanol (C4H9OH)	Indolene
Specific gravity @60F	0.72-0.75	0.79	0.8133	0.74
Net Lower Heating Value (BTU/lbm)	18700	11600	14280	19500
Octane Number Research	91-100	111	96	96
Motor	82-92	92	80	88
Stoichiometric AFR	14.6	9	11.1	14.3
Self-ignition Temperature (C)	450	420	343	450

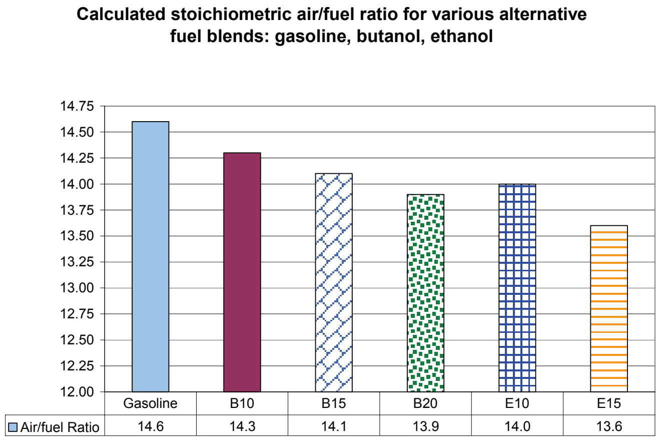


Figure 3. Calculated stoichiometric air/fuel ratio for various butanol and ethanol blends.

EMISSION ANALYZERS

A Pierburg AMA-2000 five-gas emissions bench was used for emissions analysis. A heated flame ionization detector (FID), heated chemoluminescence detector (CLD), non-dispersive infrared (NDIR) and paramagnetic analyzers were used for measurements of THC, NOx, CO, CO_2 and O2 respectively.

COMBUSTION ANALYSIS

An AVL Indicom 2 crank-based combustion analysis system was used to acquire 500 cycles of cylinder pressure on all three cylinders. Data was then processed to determine, burn rates, %COV of IMEP, misfire rate and to quantify knock characteristics.

WATER COOLING SYSTEM

Engine cooling water is supplied to the engine through the gear-case water pick up as shown in Figure 2. Water pressures are regulated with a Tescom ER-3000 electronic pressure controller to provide pressures typically seen at the gear case of a boat while underway.

TEST PROCESS

For each test fuel, the engine was run according to the International Council of Marine Industry Associations (ICOMIA) five-mode steady state test cycle as shown in Table 3 [9]. Two consecutive five mode emissions tests followed by two wide open throttle (WOT) power tests were conducted on each fuel blend. This was done in order to more accurately account for small deviations in test results. The average results from two tests on each fuel blend are reported. Five gas emissions HC, NOx, CO and CO_2, exhaust gas temperature, fuel flow, and combustion characteristics were recorded for each test mode and test fuel. EGT and emissions were sampled in the midsection megaphone, just below the base of the engine powerhead as indicated in Figure 2. No changes or modifications to the base engine calibration, spark timing or injection timing were made at anytime during the testing process.

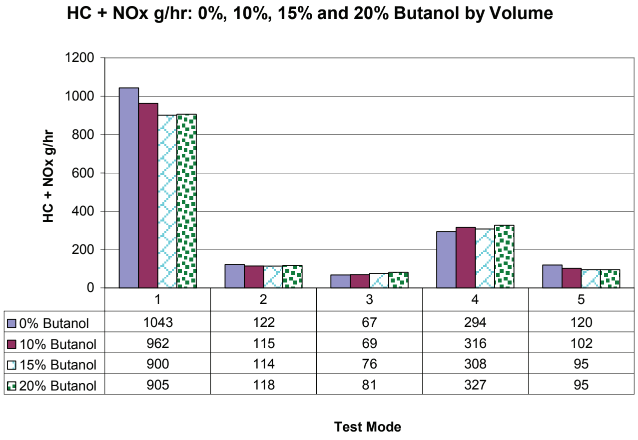
Table 3. ICOMIA five mode steady state marine test cycle [9].

Mode	% RPM	% Torque	% Weight Factor
1	100	100	6
2	80	71.6	14
3	60	46.5	15
4	40	25.0	25
5	Idle	0	40

RESULTS

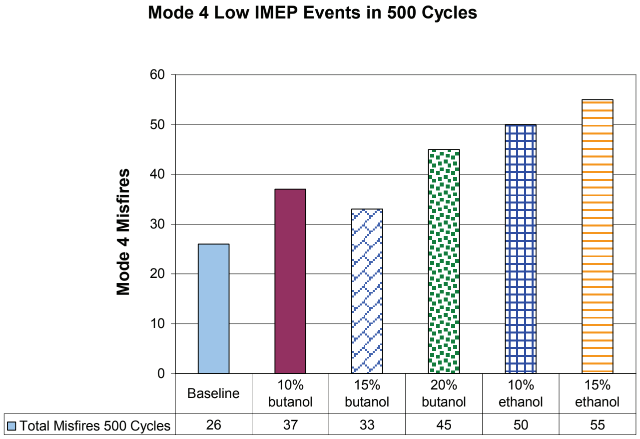
Figure 4 shows the result of increasing butanol percentages by volume on HC + NOx emissions at different test modes in g/hr. As shown, a noted decrease in HC + NOx was observed at wide open throttle (test mode 1). Increase in HC + NOx occurs at mode 4 with increasing amounts of butanol. This is due to a higher number of misfires which directly contribute to an increase in HC emissions. Combustion data shown in Figure 5 indicates that the number of misfires at mode 4 increases with increasing quantities of butanol. Mode 4 is operated in a spray guided, stratified mode of combustion where the fuel is injected late in the cycle (70-50 degrees BTDC) and ignited directly by the spark plug as the fuel cloud passes by. As a result, the running quality, or misfire rate of the engine is susceptible to the local AFR at the spark plug and to the vaporization & burn rates of the fuel [10].

ICOMIA five mode weighted HC + NOx in g/kW-hr for increasing amounts of butanol by volume is shown in Figure 6. As shown, gradual reductions in HC + NOx are achieved as the concentration of butanol in gasoline is increased with the greatest reduction occurring at 15% butanol by volume. Mode 4 emission increases are offset by reduction in emissions at Mode 1.



	1	2	3	4	5
0% Butanol	1043	122	67	294	120
10% Butanol	962	115	69	316	102
15% Butanol	900	114	76	308	95
20% Butanol	905	118	81	327	95

Figure 4. Total Hydrocarbons plus Nitrogen Oxides (HC + NOx) g/hr per test mode with increasing amounts of butanol by volume. (Average of two tests per test fuel)



	Baseline	10% butanol	15% butanol	20% butanol	10% ethanol	15% ethanol
Total Misfires 500 Cycles	26	37	33	45	50	55

Figure 5. Total engine misfire rate at Mode 4 with increasing volumes of butanol and ethanol. Misfire is calculated as an event <75% of average IMEP for the 500 cycle data sample. (Average of two tests per test fuel)

Carbon Monoxide emissions in g/hr per mode are shown in Figure 7 for increasing amounts of butanol by volume. As shown, reductions in CO emissions are due to the increased oxygen content of butanol. The overall ICOMIA five mode weighted CO emissions in g/kW-hr (Figure 8) was reduced by approximately 15% using B-20 as compared to the baseline fuel.

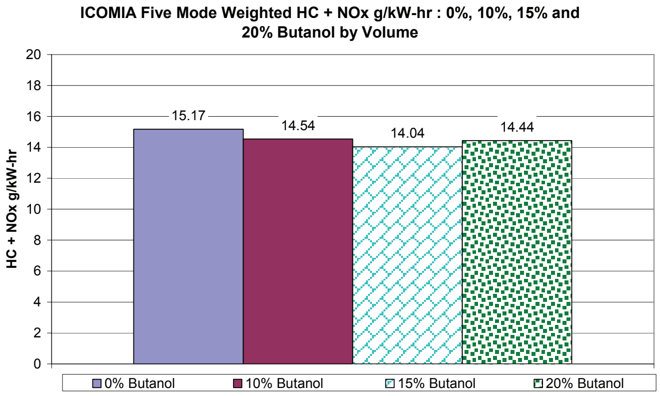
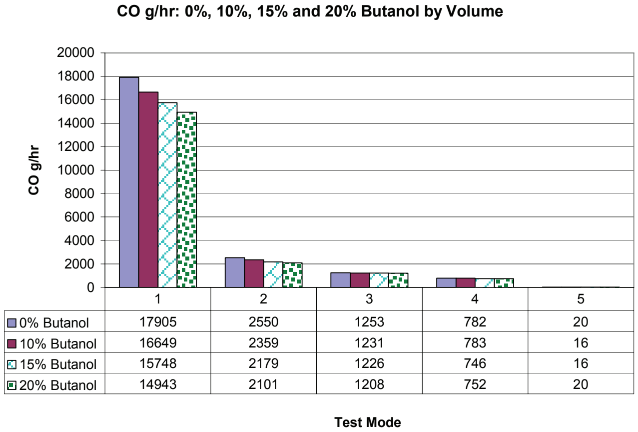


Figure 6. Total ICOMIA five mode weighted Hydrocarbons plus Nitrogen Oxides (HC + NOx) g/kW-hr with increasing amounts of butanol by volume. (Average of two tests per test fuel)



	1	2	3	4	5
0% Butanol	17905	2550	1253	782	20
10% Butanol	16649	2359	1231	783	16
15% Butanol	15748	2179	1226	746	16
20% Butanol	14943	2101	1208	752	20

Figure 7. Carbon Monoxide (CO) g/hr per test mode with increasing amounts of butanol by volume. (Average of two tests per test fuel)

Overall ICOMIA five mode weighted Carbon Dioxide (CO_2) emissions in g/kW-hr are presented in Figure 9. A minimal increase on CO_2 was observed with increasing amounts of butanol by volume.

Exhaust gas temperatures at 5 different modes are shown in Figure 10. A two percent increase in exhaust gas temperature was observed at mode 1 (WOT) with B-20 as compared to the baseline fuel. At Modes 2 and 3, on average, a six percent decrease in exhaust gas temperature was observed. At these test modes, the engine relies on post oxidation in which additional thermal reaction is occurring in the exhaust. This decrease in temperature is most likely due to the change in air/fuel ratio requirements of each specific test fuel. However, it appears this reduction in EGT at modes 2 and 3 do not significantly affect the HC + NOx emissions at these modes.

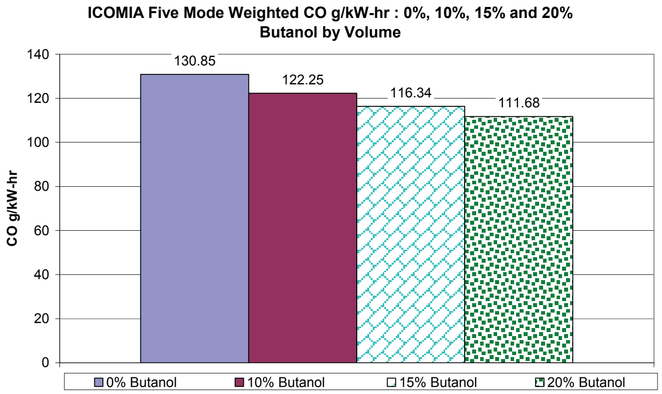


Figure 8. Total ICOMIA five mode weighted Carbon Monoxide (CO) g/kW-hr with increasing amounts of butanol by volume. (Average of two tests per test fuel)

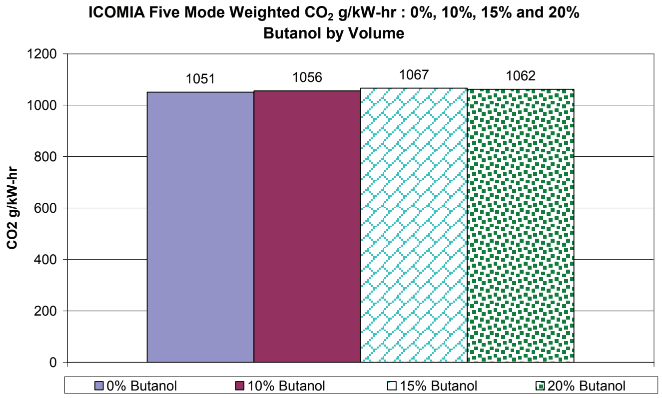
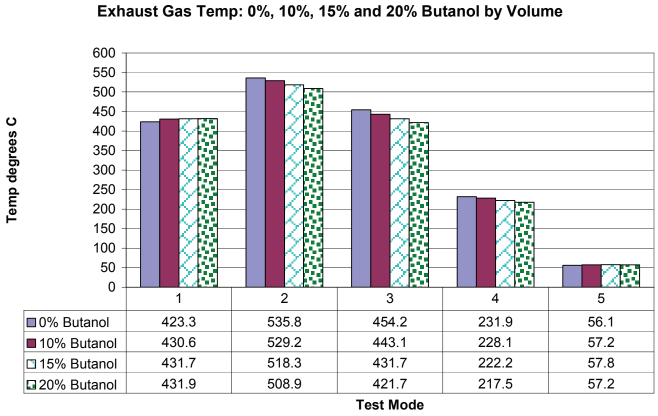


Figure 9. Total ICOMIA five mode weighted Carbon Dioxide (CO_2) g/kW-hr with increasing amounts of butanol by volume. (Average of two tests per test fuel)

Engine performance as indicated by wide open throttle corrected brake horsepower was maintained for increasing amounts of butanol by volume as shown in Figure 11.



	1	2	3	4	5
0% Butanol	423.3	535.8	454.2	231.9	56.1
10% Butanol	430.6	529.2	443.1	228.1	57.2
15% Butanol	431.7	518.3	431.7	222.2	57.8
20% Butanol	431.9	508.9	421.7	217.5	57.2

Figure 10. Exhaust gas temperature (EGT) per mode with increasing amounts of Butanol by volume. (Average two tests per test fuel)

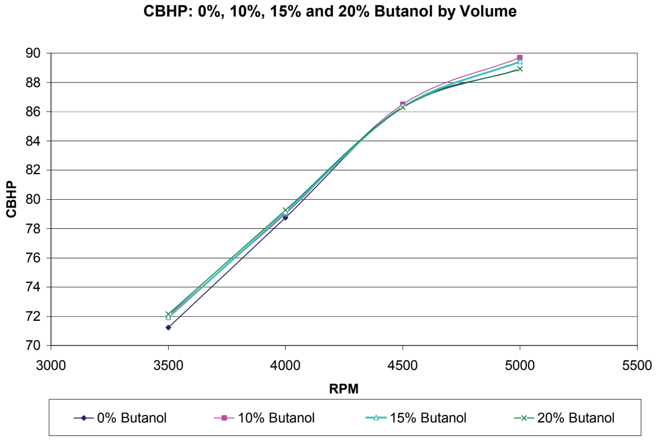


Figure 11. Wide open throttle corrected brake horsepower with increasing amounts of butanol by volume. (Average of two tests per test fuel)

COMPARISON BETWEEN BUTANOL AND ETHANOL

This section explores differences in emissions comparing B-10, B-15, B-20, E-10 and E-15. As shown in Figure 12, E10 and E-15 results in leaner running of the engine as indicated by raw CO percentage as compared to butanol. B-20 results in very similar raw CO in percent as E-10. A twenty percent reduction in raw CO using E-15 was observed at mode 1 (WOT) in comparison to a six percent reduction in raw CO using B-15. Figure 13 indicates the five mode weighted CO in g/kW-hr for the various fuel blends. Five mode weighted HC + NOx emissions were similar on both butanol and ethanol with a slight increase in emissions with ethanol as compared to butanol as shown in Figure 14. CO_2 emissions were generally lower with butanol blends as compared to ethanol blends as indicated in Figures 15 and 16.

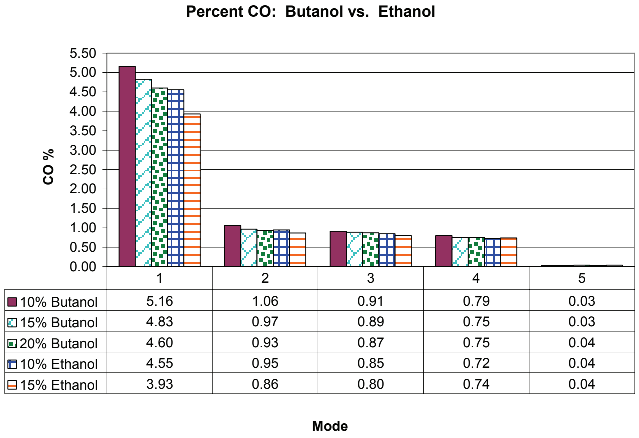


Figure 12. Percent Carbon Monoxide (%CO raw gas sampling) per mode comparing 10% butanol, 15% butanol, 20% butanol, 10% ethanol, and 15% ethanol by volume. (Average two tests per test fuel)

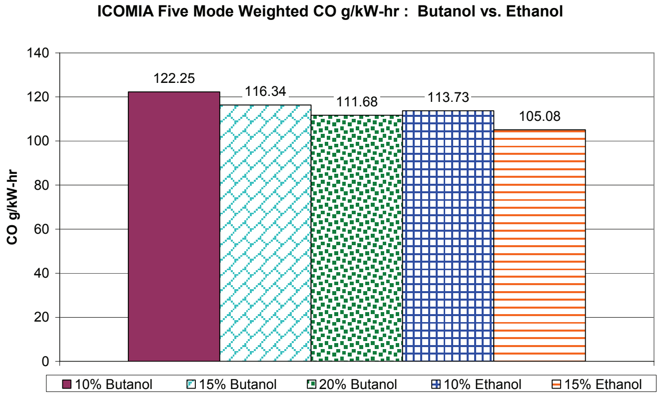


Figure 13. ICOMIA five mode weighted Carbon Monoxide (CO) g/kW-hr comparing 10% butanol, 15% butanol, 20% butanol, 10% ethanol, and 15% ethanol by volume. (Average two tests per test fuel)

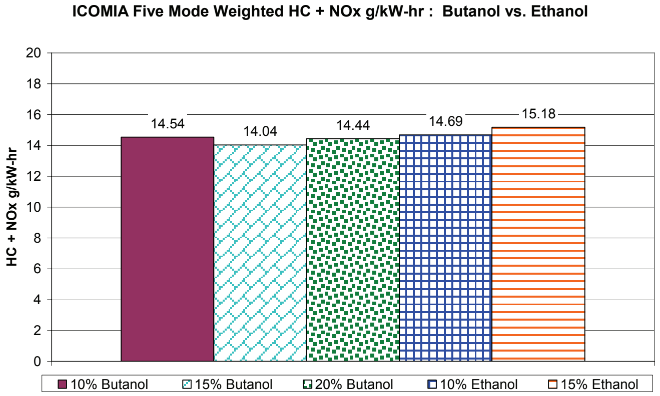


Figure 14. ICOMIA five mode weighted HC +NOx g/kW-hr comparing 10% butanol, 15% butanol, 20% butanol, 10% ethanol, and 15% ethanol by volume. (Average two tests per test fuel)

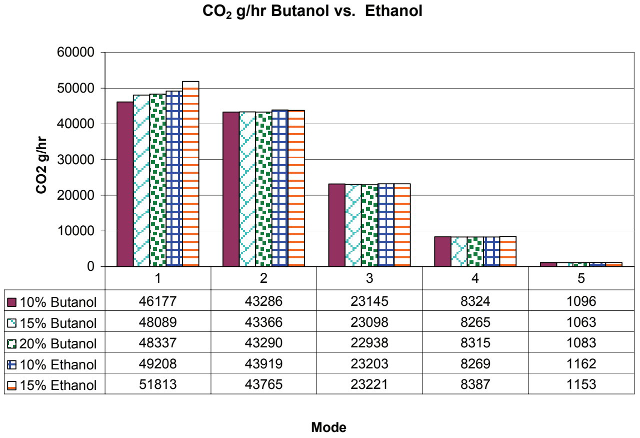


Figure 15. CO_2 g/hr per mode comparing 10% butanol, 15% butanol, 20% butanol, 10% ethanol, and 15% ethanol by volume. (Average two tests per test fuel)

Lambda was measured using the modified Spindt method based on raw five-gas emissions for the various alternative fuel blends [11]. Figure 17 indicates the measured Lambda for increasing amounts of alternative fuel blends. Notice that 20% butanol by volume yields similar Lambda values as 10% ethanol by volume at modes one and two.

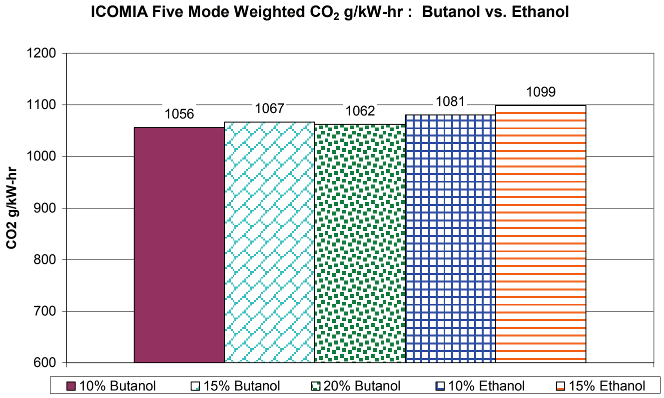
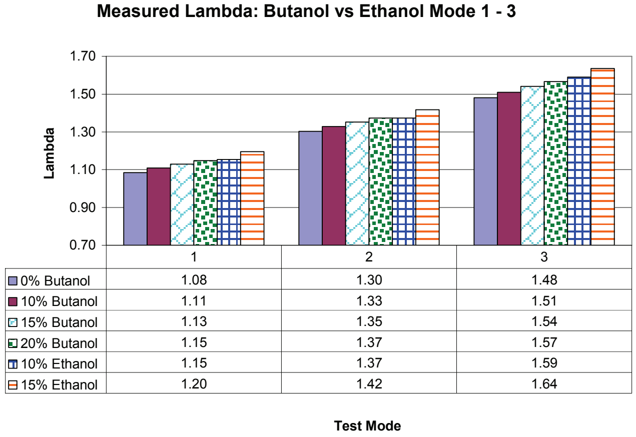


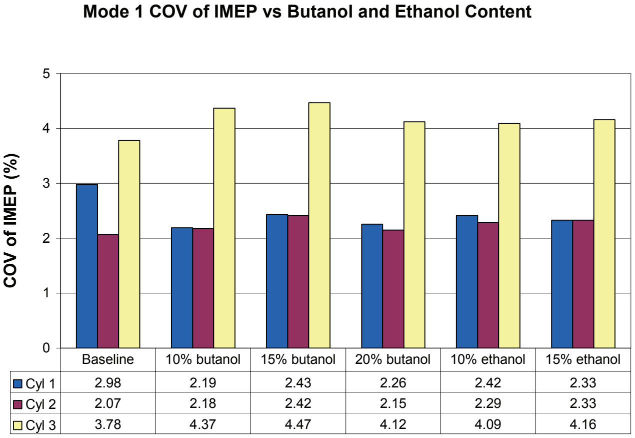
Figure 16. ICOMIA five mode weighted CO_2 g/kW-hr comparing 10% butanol, 15% butanol, 20% butanol, 10% ethanol, and 15% ethanol by volume. (Average two tests per test fuel)



	1	2	3
▥ 0% Butanol	1.08	1.30	1.48
■ 10% Butanol	1.11	1.33	1.51
▨ 15% Butanol	1.13	1.35	1.54
▩ 20% Butanol	1.15	1.37	1.57
▦ 10% Ethanol	1.15	1.37	1.59
▤ 15% Ethanol	1.20	1.42	1.64

Figure 17. Measured Lambda comparing baseline fuel to 10% butanol, 15% butanol, 20% butanol, 10% ethanol, and 15% ethanol by volume. (Average two tests per test fuel)

In addition, cylinder pressure data was analyzed at Mode 1 to evaluate the impact of butanol and ethanol concentration on combustion quality. Figure 18 indicates that the % COV of IMEP does not radically change with increasing quantities of butanol or ethanol which is consistent with the findings of direct fuel injection closed-loop automotive engine research [12]. Cylinder three has a slightly higher COV due to knock reduction strategies in the engine calibration.



	Baseline	10% butanol	15% butanol	20% butanol	10% ethanol	15% ethanol
■ Cyl 1	2.98	2.19	2.43	2.26	2.42	2.33
■ Cyl 2	2.07	2.18	2.42	2.15	2.29	2.33
□ Cyl 3	3.78	4.37	4.47	4.12	4.09	4.16

Figure 18. Mode 1 (WOT) %COV of IMEP by cylinder for increasing quantities of butanol and ethanol.

The Mahle Knock Index is calculated to determine changes in knock activity due to higher butanol or ethanol concentrations and is calculated by assigning a weighting to the Knock Peak value for each cycle. The weightings for each knock peak are then summed and divided by the number of cycles, which gives the Knock Index. A higher Knock Index value indicates more knock activity. The absolute value of the Knock index will vary depending on filtering frequencies and weightings applied to the Knock Peak value. The knock peak value is determined by filtering and rectifying each cylinder pressure trace so that only the oscillations from the knock event remain. The peak oscillation from that event becomes the Knock Peak Value for that cycle. This calculation is done for each cycle on each individual cylinder. Figure 19 shows that the Mahle Knock Index remained mostly unchanged. This is due to the increased octane rating of the higher butanol and ethanol content fuels. The engine was calibrated on a fuel similar to the baseline fuel, allowing the knock characteristics of the lower octane fuel to be minimized. As a result, any increase in octane number will reduce the knock activity.

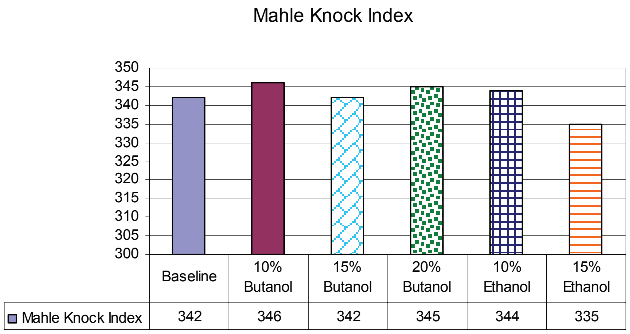


Figure 19. Mode 1 (WOT) Mahle Knock Index for all cylinders.

Mode 1 burn rates were also calculated for each concentration of butanol and ethanol. Figure 20 indicates the engine average burn rates for increasing quantities for butanol and ethanol. The peak burn rate for butanol was slightly reduced (0.5%/deg) and occurred 1-2 degrees earlier in the cycle. For increasing ethanol content, the peak burn rate is reduced the same amount, but phased 2-3 degrees earlier in the cycle.

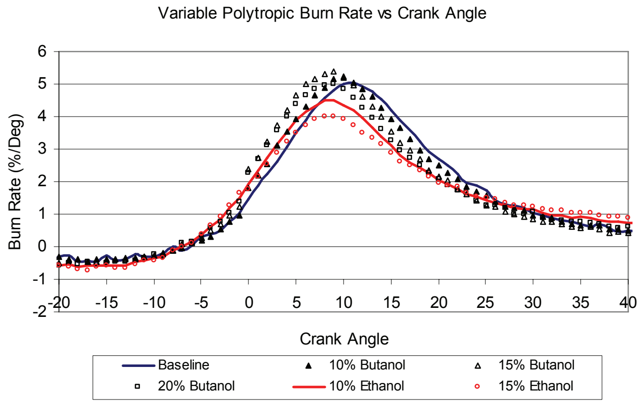


Figure 20. Mode 1 Engine average burn rate.

Figures 21, 22, and 23 show normalized cylinder pressures for each of the cylinders averaged over 500 cycles. In all instances, the higher concentrations of butanol and ethanol incrementally advance the combustion process, with peak cylinder pressure occurring 2 to 3 degrees earlier than the baseline fuel. This correlates with the advance in the burn rate for increasing butanol and ethanol content and is caused by a decrease in the ignition delay, or zero to 10% burn duration.

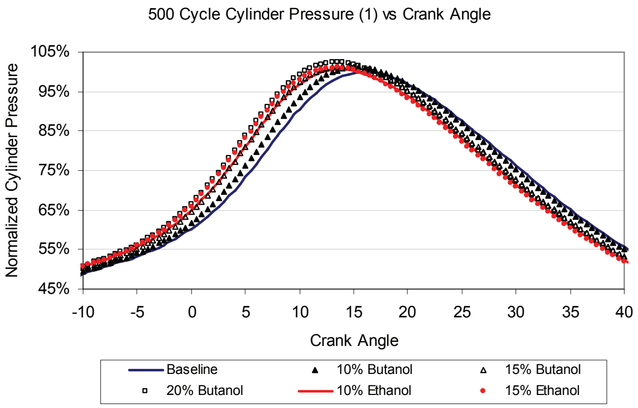


Figure 21. Mode 1 Cylinder 1 pressure averaged over 500 cycles.

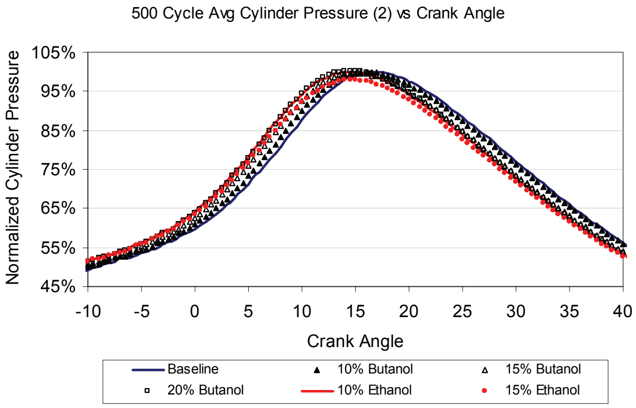


Figure 22. Mode 1 Cylinder 2 pressure averaged over 500 cycles.

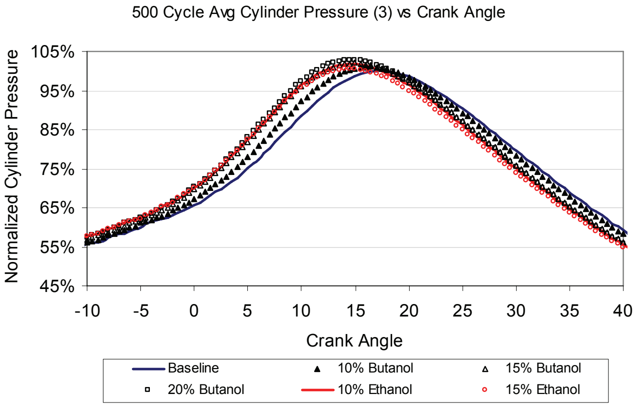


Figure 23. Mode 1 Cylinder 3 pressure averaged over 500 cycles

SUMMARY/CONCLUSIONS

This work was intended to be a first investigation assessing potential of butanol as a drop-in alternative fuel blend for direct injection two stroke recreational marine engines. A significant amount of work is needed to assess wide scale effects of butanol on gasoline recreational marine engine technologies and fuel systems prior to drawing any significant conclusions. However, based on this study, initial results look promising and are summarized below.

- Compared to the same percentage blend of ethanol, butanol blends result in less engine enleanment as indicated by CO and Lambda. This means butanol can be tolerated in higher blend percentages in open-loop engines as compared to ethanol.
- 20% butanol by volume resulted in similar emissions and engine power as 10% ethanol by volume.
- Misfire events at mode 4 (fully stratified) generally increased slightly with increasing amounts of butanol by volume but misfire events were more prevalent with ethanol than butanol.
- Compared to the same percentage blend of ethanol, butanol blends result in less Carbon Dioxide (CO_2), which is considered a form of green house gas emission. The reduction in CO_2 for butanol blends compared to ethanol blends is due in part to the stronger enleanment effects of ethanol, which cause HC emissions to decrease more substantially, NOx emissions to increase slightly and CO emissions to decrease. Because there is less HC, less CO and more NOx, this forces the carbon (as part of the carbon balance) to convert to CO_2.
- No discernable changes to the WOT COV of IMEP or knock characteristics were noticed, with higher concentrations of butanol or ethanol.
- Combustion phasing was slightly advanced with increased levels of butanol and ethanol.

REFERENCES

1. Orbital Engine Company, “Marine Outboard Driveability Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on a Small Batch of Engines” Market Barriers to the Uptake of Biofuels Study - Report to Environment Australia, February 2003

2. Knoll, Keith et al., “Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines” , Report 1 – Updated, February 2009 Oak Ridge National Laboratory

3. National Marine Manufactures Association (NMMA), Recreational Boating Statistical Abstract - U.S. Boat Registrations, 2008

4. Vatalaro, Michael, “A Serious Problem, a Corny Solution” Boat/US Magazine, July 2006

5. "Results of BoatU.S. Sponsored Fuel and Fiberglass Gas Tank Tests". Boat/US Seaworthy Magazine. 03/20/2010 http://www.boatus.com/seaworthy/fueltest.asp#results

6. “Recommendations on Storing Ethanol-Enhanced Gasoline” Boat/US Magazine – Seaworthy, 2010

7. "BP-Dupont Biofuels Fact Sheet". BP. 03/21/2010 http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/B/Bio_bp_dupont_fact_sheet_jun06.pdf

8. United States Code Of Federal Regulations CFR 40, Part 1065.710 - Test Fuel Specifications for Gasoline

9. ISO 8178-4:2007 Reciprocating internal combustion engines - Exhaust emission measurement Part 4: Steady-state test cycles for different engine applications

10. Smith, J., Sick, V., “The Prospects of Using Alcohol-Based Fuels in Stratified-Charge Spark-Ignition Engines” SAE 2007. 2007-01-4034

11. Roy Douglas, “AFR and Emissions Calculations for Two-Stroke Cycle Engines”, SAE paper 901599, 1990

12. Wallner, T., Miers, S., McConnell, S., "A Comparison of Ethanol and Butanol as Oxygenates Using a Direct-Injection, Spark-Ignition Engine" ASME: Journal of Engineering for Gas Turbines and Power, May 2009, Vol. 131 / 032802-1

13. Bata, R., Elrod, A., “Butanol as a Blending Agent with Gasoline for I.C Engines” SAE 1989. 890434

CONTACT INFORMATION

Jeff R.Wasil

BRP US INC

Evinrude Product Development Center

300 Sea Horse Drive

Waukegan, IL 60085

ACKNOWLEDGMENTS

The authors would like to thank Jerry Oliver, Bill Ziehm, Andy Findlay and Jon Servais for their help in this project.

WHITE PAPER

TRANSPORTATION FUELS

Renewable Solution

ISOBUTANOL—A RENEWABLE SOLUTION FOR THE TRANSPORTATION FUELS VALUE CHAIN

Executive Summary

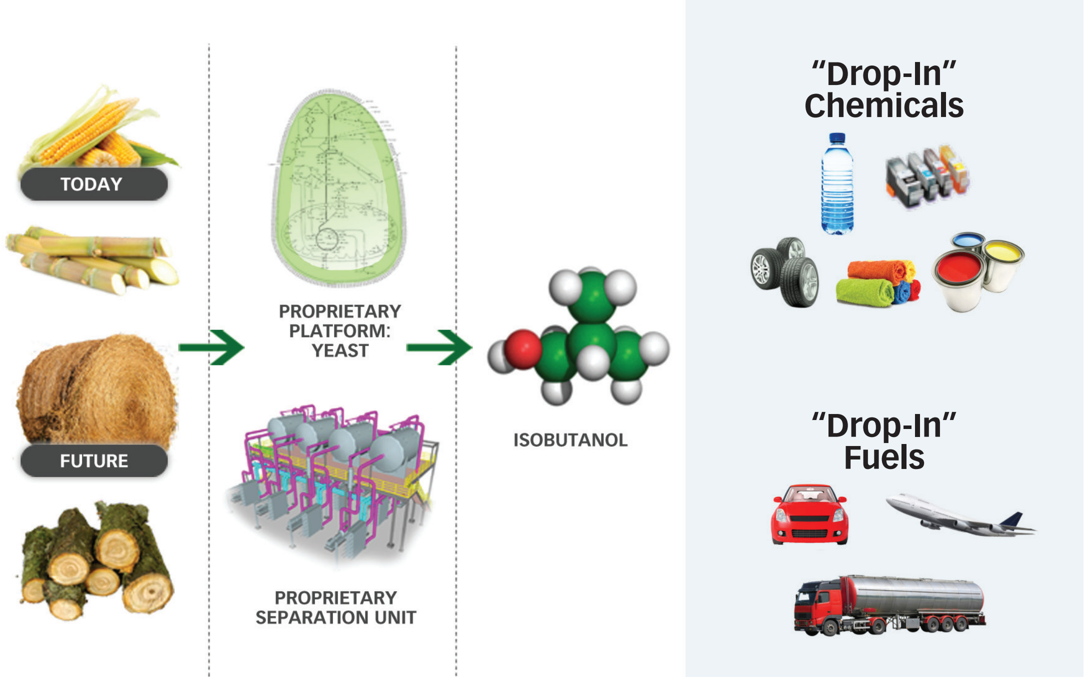
The demand for a clean, renewable biofuel increases as new benchmarks are legislated and increased pressure is placed on the petroleum industry to reduce America's dependence on imported fossil fuels for energy consumption.

Gevo®—a leader in next-generation biofuels—has developed and patented a cost-effective process, Gevo Integrated Fermentation Technology® (GIFT®), which converts fermentable sugars from sustainable feedstocks into isobutanol, a biobutanol product that provides solutions to many of the value chain issues highlighted by first-generation biofuels.

In this paper, you'll learn how isobutanol provides a renewable solution to improve the transportation fuels value chain.

What You Will Learn:

- Isobutanol is a dynamic platform molecule.
- Isobutanol ships in pipeline systems.
- Isobutanol can address future regulatory issues now.
- Isobutanol mitigates end-user challenges.



TRANSPORTATION FUELS

gevo™

WHITE PAPER

As the demand for renewable sources of fuels intensifies, it is imperative that the transportation fuels industry has the necessary solutions to optimize the value chain. Gevo's renewable isobutanol can potentially be applied across the entire transportation fuels industry and shipped through the pipeline, while complying with government regulations and mitigating end user issues.

To find out how isobutanol is the next-generation biofuel, contact us at:

345 Inverness Drive South
Building C, Suite 310
Englewood, CO 80112
303-858-8358

www.gevo.com

***Notice Regarding Forward-Looking Statements**
Certain statements in this document, including, without limitation, Gevo's ability to produce cellulosic isobutanol once biomass conversion technology is commercially available, may constitute "forward-looking statements" within the meaning of the Private Securities Litigation Reform Act of 1995. These forward-looking statements are made on the basis of the current beliefs, expectations and assumptions of the management of Gevo and are subject to significant risks and uncertainty. Investors are cautioned not to place undue reliance on any such forward-looking statements. All such forward-looking statements speak only as of the date they are made, and the Company undertakes no obligation to update or revise these statements, whether as a result of new information, future events or otherwise. For a further discussion of risks and uncertainties that could cause actual results to differ from those expressed in these forward-looking statements, as well as risks relating to the business of Gevo in general, see the risk disclosures under the section captioned "Risk Factors" in Gevo's final prospectus related to its initial public offering filed pursuant to Rule 424(b) under the Securities Act of 1933, as amended on February 9, 2011.

TABLE OF CONTENTS

Butanol Evolves

BACKGROUND ON BUTANOL

The use of butanols in gasoline goes back to the 1970s–’80s and has been approved under Section 211(f) of the Clean Air Act through the “Arconol,” “DuPont” and “Octamix” waivers. At that time, tert-butyl-alcohol (TBA), a man-made material, was the prime butanol used, although research suggests that isobutanol was also being evaluated. These butanols were produced from petroleum processes: Both n-butanol and isobutanol were produced using the oxo process, and TBA was a by-product of the PO process.

Gevo has developed a proprietary biochemical pathway to produce renewable isobutanol, a four-carbon alcohol with many attributes that may aid the transportation fuels industry across its value chain. It is now being evaluated as a next-generation biofuel.

Isobutanol should not be confused with the other isomers in the butanol family (n-butanol, sec-butanol, tert-butyl-alcohol [TBA]). It is a naturally occurring material with a musky odor found in many essential oils, foods and beverages (brandy, cider, gin, coffee, cherries, raspberries, blackberries, grapes, apples, hop oil, bread and Cheddar cheese).

Today, Gevo has developed a renewable method to produce a 98+ percent–purity product using sugars from any available source. The initial plan is to convert existing U.S. cornstarch ethanol plants into isobutanol plants for a fraction of the cost to build new facilities. Gevo also plans to upgrade some of these facilities to produce an isobutanol that will be classified as an advanced biofuel as defined by EPA under the U.S. Energy Independence and Security Act (EISA), to allow cellulosic sugars to be used as a feedstock as they become cost competitive, and to allow multiple products to be generated.

ISOBUTANOL IS A NEXT-GENERATION RENEWABLE FUEL AND A “BUILDING BLOCK” TO THE FUTURE FUELS VALUE CHAIN

To become a next-generation renewable fuel, it is paramount that the manufacture of a renewable product leverages existing infrastructure and extends the current fuels value chain. With the U.S. oil-and-gas downstream industry (inbound distribution, refining, outbound distribution and marketing) conservatively valued at over $500 billion, it would be inefficient to build an entirely new supply chain infrastructure to accommodate a renewable product industry valued at less than 10 percent of the downstream industry.

The optimal value chain for a transportation fuel, including renewables, might look like this [Figure 1]:

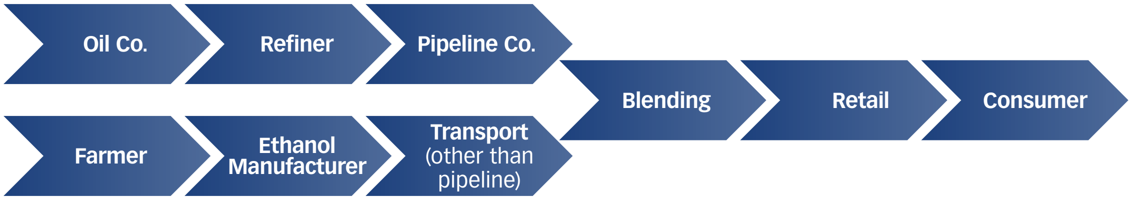
Figure 1

Feedstocks are shipped to a producer (refiner, blender or bio-refiner), where they are converted to a finished product, which is then cost-effectively shipped to market, and sold to the end user based on a specification that meets regulatory needs. Over time, as regulations have been introduced, the optimal value chain has remained intact.

With the advent of the Renewable Fuel Standard (RFS) and EISA, the value chain, using first-generation renewable products, has been changed; for example, ethanol enters the value chain at the terminal [Figure 1a], where it is either blended with a sub-octane gasoline product to produce the finished gasoline, or is added to a finished gasoline to produce a higher-octane product.

Figure 1a

Existing Gasoline Value Chain

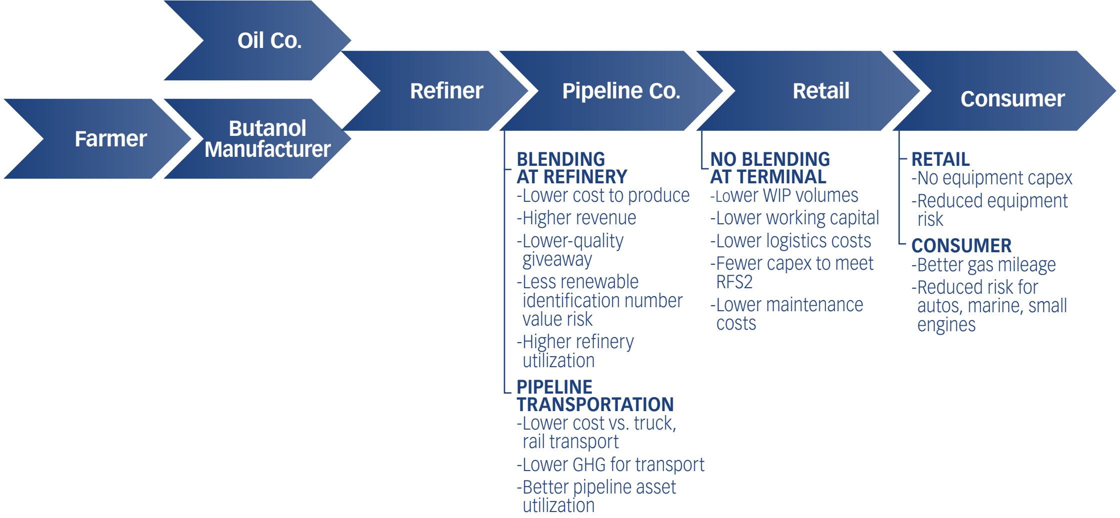


This inefficiency primarily stems from the inability of first-generation biofuels to be shipped in a pipeline, adding system cost(s) as additional capital is required at the terminals for blending these products. Additionally, giveaway costs increase as refiners no longer ship finished products but are held legally accountable for the finished-product specification. If the trend toward using first-generation biofuels grows, pipeline throughput volumes may decrease, giving rise to potential tariff increases on the remaining shippable products.

By analogy, isobutanol is today's "smartphone" to first-generation biofuels' "cell phone;" it can re-optimize the value chain with its ability to be shipped in pipelines, both inbound to and outbound from a refining/blending facility, as shown in Figure 1b. The versatility of isobutanol's properties as a blendstock for gasoline and its ability to be converted to other valuable products give the downstream industry great flexibility.

Figure 1b

Projected Isobutanol Gasoline Value Chain



BLENDING AT REFINERY
- Lower cost to produce
- Higher revenue
- Lower-quality giveaway
- Less renewable identification number value risk
- Higher refinery utilization

PIPELINE TRANSPORTATION
- Lower cost vs. truck, rail transport
- Lower GHG for transport
- Better pipeline asset utilization

NO BLENDING AT TERMINAL
- Lower WIP volumes
- Lower working capital
- Lower logistics costs
- Fewer capex to meet RFS2
- Lower maintenance costs

RETAIL
- No equipment capex
- Reduced equipment risk

CONSUMER
- Better gas mileage
- Reduced risk for autos, marine, small engines

Dynamic Molecule

ISOBUTANOL IS A DYNAMIC PLATFORM MOLECULE

Isobutanol is an ideal platform molecule, a more flexible and versatile renewable alternative to current biofuels. It can be used as a “drop in” gasoline blendstock; it converts readily to isobutylene, a precursor to a variety of transportation fuel products such as iso-octene (gasoline blendstock), iso-octane (alkylate—high-quality gasoline blendstock and/or avgas blendstock), iso-paraffinic kerosene (IPK, or renewable jet) and diesel. Isobutanol is not constrained to just the gasoline pool; hence, its value to a producer and/or purchaser is its flexibility.

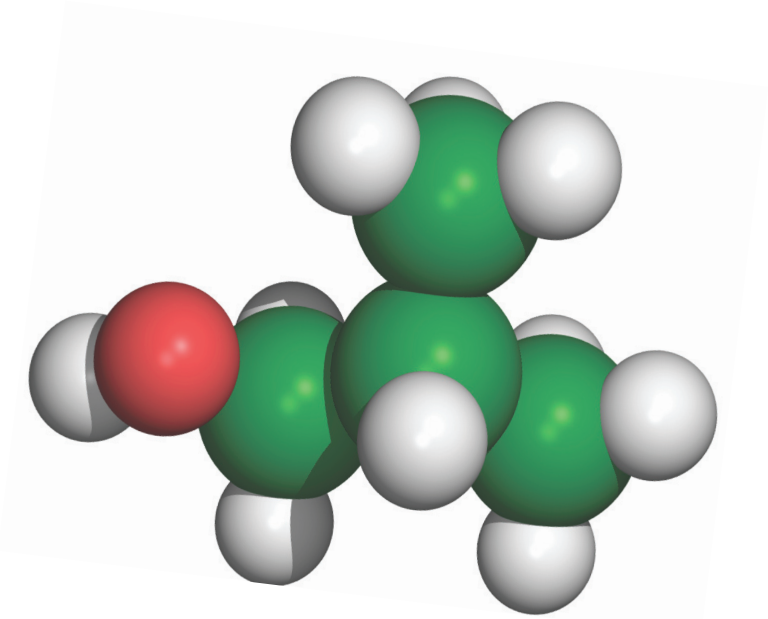
Gasoline and Renewables

The oil embargoes of the 1970s drove the introduction of alternative, renewable feedstocks for the oil-and-gas industry. At the time, the EPA granted various waivers allowing methanol, ethanol, butanols and other materials into gasoline. By the 1990s, the Clean Air Act required gasoline to have an oxygenate added to improve urban air quality. Until 2005, there were two primary options: MTBE (produced by the refinery and optimally blended into the finished product) and ethanol (produced locally and blended into gasoline, not always optimally, at various distribution terminals).

With the creation of the Renewable Fuel Standard (RFS) and the elimination of MTBE as a viable blendstock in 2004, ethanol became the prime renewable material. Production increased dramatically. As more ethanol entered the market, its price decreased relative to gasoline and its usage increased. The 2007 Energy Independence and Security Act (EISA), which requires different categories of renewable fuels (based on greenhouse gas emission reductions), has also increased the volume obligation of a refiner or blender to use renewable products. In addition, as sulfur and benzene concentrations in gasoline have been addressed, it is anticipated that there will be continued efforts to lower ozone levels, with gasoline volatility being a key driver.

The first-generation renewable products have provided a good start to improving air quality and increasing energy independence, but may not provide an optimal economic solution across the value chain. Isobutanol, as the next-generation product, builds on the foundation and provides additional solutions to various challenges not met by first-generation products. Some of these include:

» Blend properties in gasoline
» Volatility
» Phase separation
» Energy content
» Blend wall



Blend Properties in Gasoline

Isobutanol has several blend property advantages: low Reid Vapor Pressure (RVP), above-average octane, good energy content, low water solubility and low oxygen content [Figure 2].

Figure 2

	ETHANOL	ISOBUTANOL
Blend RVP	18–22 psi	4.5–5.5 psi
Blend Octane	112	102
Energy Content (% of gasoline)	65%	82%
Water Solubility	Fully Miscible (100%)	Limited Miscibility (8.5%)
Oxygen Content	35%	22%

Volatility

As sulfur and benzene content in gasoline is limited by legislation, it is likely that efforts to control ozone, which have already increased, will continue to increase in the future.

A key tool used by state regulatory agencies for reducing ozone precursors in the air is through reduced volatility of gasoline as measured by RVP. As ethanol's RVP blend value is high (~18 psi for E10 blends), the base blendstock for oxygenated blending (BOB) must be low to accommodate this high-RVP material. This problem will be exacerbated as any ethanol blends less than 9 percent or greater than 10 percent currently do not qualify for a 1-psi waiver.

Isobutanol's low-blend value RVP (~5.0 psi for 12.5 percent–volume blends) [Figure 3] allows refiners to decrease costs by optimally blending additional lower-cost blendstocks (butane, pentane, NGLs, naphtha) and/or reducing the purchases of more costly low-RVP alkylate. For example, by using Baker and O'Brien's proprietary PRISM™ model [Figure 4] , a refinery serving a low-RVP gasoline market was able to eliminate alkylate purchases and significantly increase butane purchases by using isobutanol instead of ethanol.

Figure 3

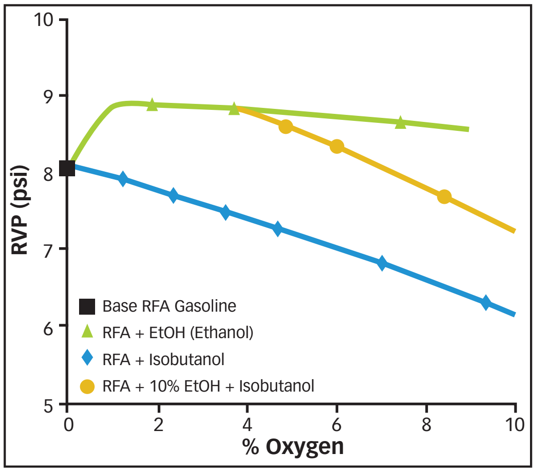
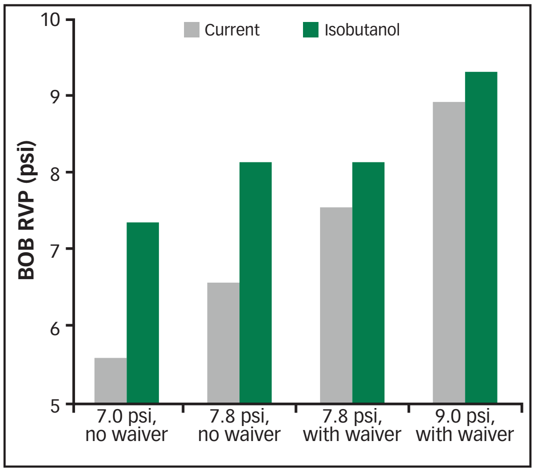


Figure 4



Phase Separation

Because gasoline may come in contact with water, it is important that the blendstocks remain in the hydrocarbon phase and not migrate into the water. Ethanol, a highly polar material, will separate from the gasoline phase into the water phase, degrading the gasoline's octane. Isobutanol is less polar than ethanol, and tends to act like a hydrocarbon with very limited amounts moving from the gasoline phase to the water phase [Figure 5]. As a result, there is no dilution of the gasoline's octane value, and operational issues related to water content are reduced or eliminated.

Figure 5

Gasoline with 10% Water

Isobutanol-Blended Gasoline with 10% Water

Ethanol-Blended Gasoline with 10% Water

Energy Content

Isobutanol has approximately 82 percent of the energy value of gasoline. Although every engine is different, higher energy content typically translates into greater fuel economy. In addition, per EISA, as isobutanol has 30 percent more energy than ethanol, its equivalence value (EV) is 1.3 [Figure 6], which translates into significantly more renewable identification numbers (RINs) being generated than ethanol.

Figure 6

BIOFUEL	EQUIVALENCE VALUE (EV)
Ethanol	1.0
Isobutanol	1.3
Biodiesel (FAME)	1.5
Renewable Jet (Biojet, IPK)	1.6*
Renewable Diesel	1.7

*Estimate based on EISA formula.

Blend Wall

Engine manufacturers are concerned about exceeding 3.5 percent–by-weight oxygen levels, and obligated parties need to generate even greater RINs. Isobutanol provides a solution to these needs. If isobutanol were used at E10 oxygen content levels (3.5 percent–by-weight oxygen), it would generate more than twice the RINs. Even at transitional "substantially similar" oxygen levels (2.7 percent– by-weight oxygen), isobutanol generates more RINs than either E10 or E15 [Figure 7].

Figure 7

	OXYGEN CONTENT (%)	EV	RINS GENERATED PER 100 GALLONS FINISHED PRODUCT
12.5% Isobutanol	2.7	1.3	16.25
10% Ethanol	3.5	1.0	10.00
16.1% Isobutanol	3.5	1.3	20.93
15% Ethanol	5.2	1.0	15.00

Converting to Jet Fuel

ISOBUTANOL CAN ALSO BE CONVERTED TO PRODUCE A RENEWABLE JET

According to the International Civil Aviation Organization (ICAO), environmental efficiency gains from technological and operational measures may not offset the overall emissions that are forecast to be generated by the expected growth in air traffic. As a result, the airline industry is evaluating sustainable alternative fuels to reduce its greenhouse gas (GHG) emissions profile, while improving local air quality. It is the ICAO's view that the development and use of sustainable alternative fuels may play an active role in improving the overall resource allocation and security of aviation fuels supply, perhaps by stabilizing fuel prices. A global framework has been established for sharing information on best practices and/or initiatives to allow sustainable alternative aviation fuels to be developed and brought to market.

IPK/KEROSENE

Isobutanol is an ideal platform molecule to produce renewable iso-paraffinic kerosene (IPK), a blendstock for jet fuel. Through known technology, isobutanol can be readily converted to a mix of predominantly C12/C16 hydrocarbons [Figure 8].

Figure 8

Bio-based IPK Jet

Gevo's IPK offers several benefits:

- **Blend Rate**—may be blended at up to a 1:1 ratio with petroleum jet.
- **Properties**—very low freeze point (–80°C), high thermal oxidation stability, and meets ASTM distillation curve requirements.
- **Regulatory**—using EISA's formula, the projected EV is approximately 1.6, which, at a blend rate of 50 percent, would generate 80 RINs per 100 gallons of finished product.
- **Tax Credit**—it qualifies for a $1.00/gallon tax credit under IRS Title 26, Subtitle A, Chapter 1, Subchapter A, Part IV, Subpart D, Article 40A.f.3.
- **GHG**—using renewable energy and/or improved feedstocks in the production process, it has the potential to significantly reduce GHG emissions.

Distribution Versatility

ISOBUTANOL CAN USE THE EXISTING PIPELINE DISTRIBUTION INFRASTRUCTURE

A key advantage for isobutanol to be adopted into the transportation fuels industry is its ability to be shipped in pipelines without negatively affecting the integrity, quality or operations of the pipeline system [Figure 9, below].

Pipelines are a key part of the value chain, and using the existing infrastructure to move product may provide significant advantages:

- There is value in blending at the refinery instead of at the terminal. According to a Solomon Associates presentation* finished fuel from a refinery appears to avoid giveaway costs estimated at $0.01 to $0.03 per gallon of finished gasoline.
- As ethanol volumes have grown, pipeline throughputs have fallen; with lower throughputs, tariffs on the remaining products may increase.
- Shipping material by pipeline is the most cost-effective manner to move liquid products compared to rail, barge and/or truck.

Isobutanol has the potential to be used in the existing pipeline system, both inbound and outbound, providing potential cost savings, flexibility and efficient access to end-user markets.

Figure 9

	ETHANOL		ISOBUTANOL	
Integrity				
Stress Corrosion Cracking	Yes		No	
Elastomeric Compatibility	Manageable		Highly Compatible	
Quality				
Oxygen Content in Gasoline	E10	3.5%	I12.5	2.7%
	E15	5.2%	I16.1	3.5%
Ship Neat Product	Qualified No		Qualified Yes	
Operations				
Blend Location	Terminal		Refinery/Terminal	
Segregated Storage	Yes		No	

---

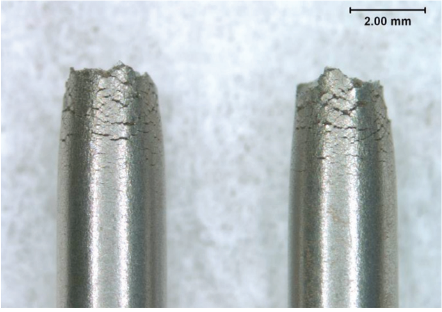
*_Use of Ethanol in Conventional Gasoline Blending—A Look at U.S. Refiner Trends_ by John Popielarczyk, October 2009, NPRA Q&A meeting.

Integrity

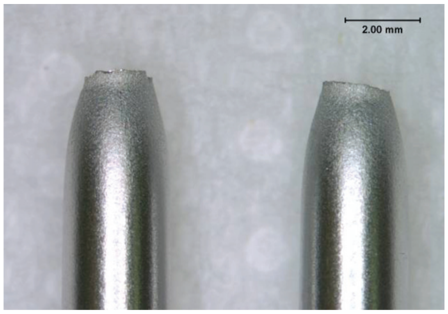
There are two key measures of integrity:

- » Stress corrosion cracking (SCC)
- » Elastomeric compatibility issues

Det Norske Veritas (DNV), a leading corrosion consultantcy that has done significant work on the distribution of ethanol-blended gasoline, has also evaluated isobutanol. Based on DNV's conclusions, carbon steel is susceptible to stress corrosion cracking (SCC) in fuel-grade ethanol; however, no SCC was noted in isobutanol-containing gasoline at concentrations of 12.5 percent and 50 percent, nor was any SCC found with neat isobutanol, as shown at right. In addition, several elastomeric materials were evaluated with respect to their compatibility with isobutanol and gasoline; the tested materials showed better performance in isobutanol than in gasoline.



Evidence of stress corrosion cracking



No stress corrosion cracking at 12.5% isobutanol

Quality

Today, regulatory pathways exist for isobutanol to be used in gasoline at two volume levels, 12.5 percent under the EPA "substantially similar" ruling (2.7 percent by-weight oxygen content) and 16.1 percent under previous EPA waivers (DuPont, Octamix waivers allowing 3.5 percent by-weight oxygen content). Discussions with pipeline distribution companies have revolved around the shipping, handling and storage of three possible products: 12.5 percent and 16.1 percent by-volume isobutanol-containing gasoline and 100 percent neat isobutanol.

Operations

In recent years, many terminals have increased capital spending to handle blending of ethanol. At the same time, the volume throughput of pipelines has been reduced by the amount of ethanol blended at the terminal. Isobutanol, shipped to a refinery, optimally blended to reduce giveaway cost(s), and then shipped as a finished product to end-user markets, would use the existing assets more cost-effectively.

Regulations and RIN

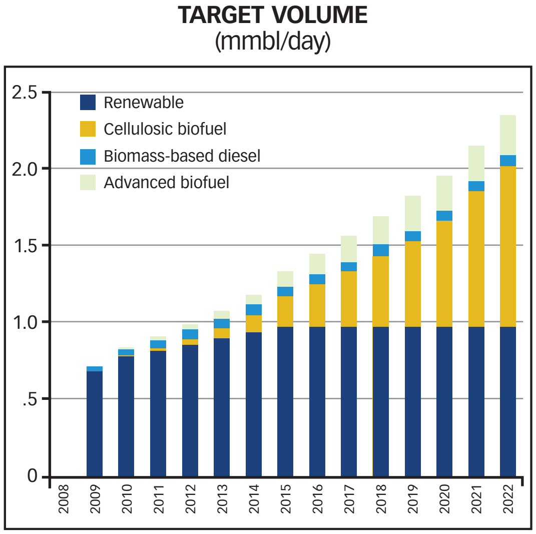
ISOBUTANOL CAN ADDRESS FUTURE REGULATORY ISSUES NOW

A key driver for isobutanol that will influence its adoption into the transportation fuels industry is the impact that existing and potential regulations may have on guiding which renewable fuels become prominent. Key issues include total RIN volume needed, RIN generation, type of RIN generated, 1 psi waiver and ozone control.

RIN Volume/Generation

EISA (or RFS2) set new volume targets for the industry; specifically, by 2022, 36 billion gallons per year (or about 2.4 million barrels per day) of renewable products are to be used [Figure 10]. To account for this volume, a renewable identification number (RIN) was established; using the concept of equivalence value (EV) [Figure 6, p. 5], which allows a multiplier based on energy content to be used, it is conceivable that the physical volume used by the transportation fuels industry is less than the EISA target volumes. For example, in Figure 11 (below), if 10 gallons of ethanol with an EV of 1.0 are used, 10 RINs are generated per 100 gallons of finished product. With isobutanol, if 12.5 gallons are used with an EV of 1.3, 16.25 RINs are generated per 100 gallons of finished product. The RINs generated are a function of the physical volume used multiplied by the EV of the renewable product.

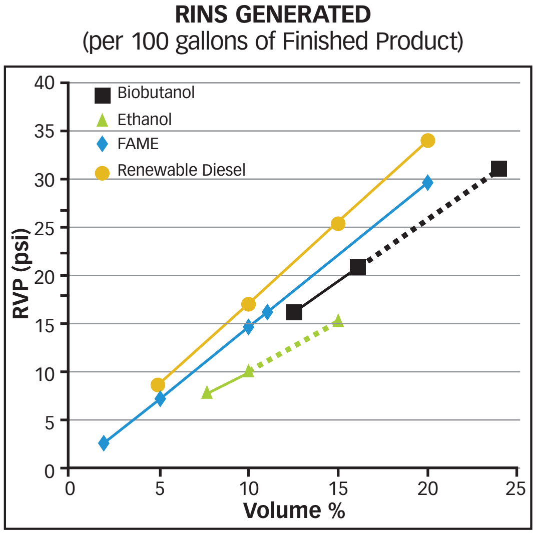
Figure 10



"Advanced" RIN Capable

A key component of the EISA legislation was the introduction of RIN types: renewable and advanced. The advanced category, with a minimum hurdle of reducing GHG emissions by 50 percent, has the subsets of cellulosic, biomass-based diesel and "advanced other." The ultimate volume requirement for the renewable type was set at 15 billion gallons per year (BGY), and for the advanced type at 21 BGY. Although target volumes were set for the cellulosic and biomass-based diesel categories, EPA has the authority to adjust these totals annually, based on availability, but it cannot reduce the total advanced requirement. As such, there may be a growing need [Figures 12, 13, p. 10] for products that meet the "advanced other" category, or products that have 50 percent lower greenhouse gas emissions compared to gasoline.

Figure 11



One psi Waiver

Another key driver of isobutanol adoption is a consistent standard with regard to volatility; for E10 blends, ethanol was granted a 1 psi waiver when the finished-product RVP was considered. If a state implementation plan (SIP) required a 9.0 psi RVP for conventionl gasoline, this specification would become 10 psi when using ethanol blends.

At present, only gasoline blends containing 9 percent to 10 percent ethanol are granted a 1 psi waiver. Hence, finished product with a 9.0 psi must have a base blendstock RVP substantially lower than 9.0 in order to accept higher ethanol blends, i.e., E15+.

With isobutanol, obligated parties have considerably greater formulation flexibility and might be able to go as high as 9.6 psi in their blendstock and still meet their Clean Air Act requirements without a waiver.

Figure 12

PROJECTED RIN (Gallons)
VERSUS EISA NEEDS (mmbl/day)

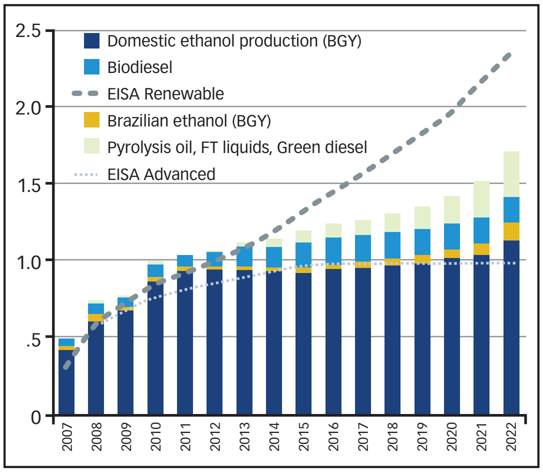
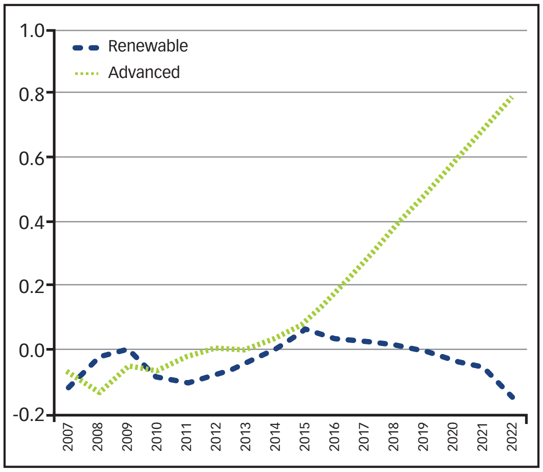


Figure 13

PROJECTED UNDER-SUPPLY
(mmbl/day)



NOTE: Per EISA, corn starch–derived ethanol plants are excluded from achieving an "advanced other" level. However, starch-derived isobutanol plants have the ability to achieve the advanced status. As the only currently available advanced products are FAME biodiesel (limited volumes) and Brazilian ethanol imports, isobutanol provides a secure alternative to meet this need.

Ozone Control

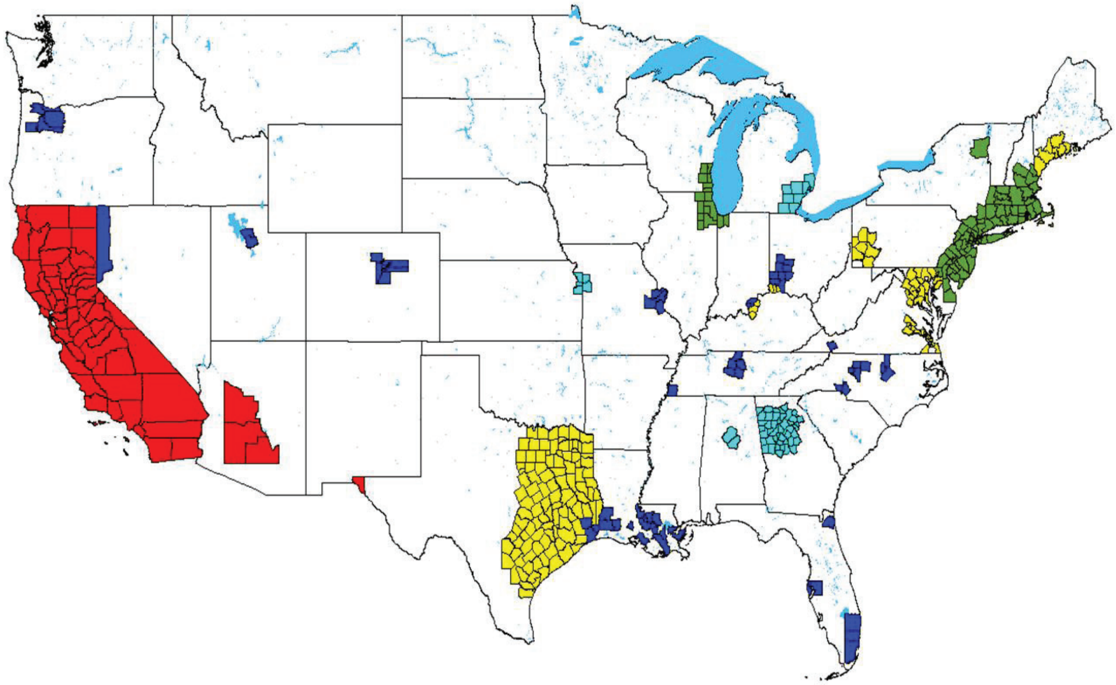
Ground-level ozone is harmful to breathe and damages crops, trees and other vegetation. Gasoline volatility is the key lever used by the states to control ozone precursors. There are already many markets requiring special RVP specifications [Figure 14]. If the EPA target for ozone is set at 75 ppb, it is estimated that over 300 counties nationwide will fall out of compliance. In addition, a U.S. EPA Scientific Advisory Board (SAB) has recommended that the ozone target be lowered (perhaps to 60–70 ppb), which would have a dramatic impact on most of the U.S. gasoline market. Isobutanol, with its low-blend volatility, provides obligated parties greater flexibility to meet both lower volatility (RVP) and renewable fuel obligations.

Figure 14

Increasing value ↑

Market RVP Specification	Gasoline Market Size	Isobutanol Market Opportunity
PSI	BGPY	BGPY
🔴 7.0 no waiver[1]	18	2.2
🟡 7.8 no waiver	16	1.9
🟢 9.0 no waiver	18	2.2
🔵 7.0 waiver	6	0.7
⚫ 7.8 waiver	11	1.3
○ 9.0 waiver	72	8.6

[1] Waiver = 1 psi RVP waiver given to ethanol in many markets.



Overcoming Concerns

ISOBUTANOL MITIGATES END-USER ISSUES

The concept of energy independence was established with the introduction of first-generation renewable fuels. However, in trying to increase the use of these products, several significant constraints must be addressed relative to the various end users: certification of storage tank/dispensing equipment, equipment operational concerns, product liability issues for convenience store operators, fuel mileage/maintenance issues and American pride/innovation. Isobutanol can address these concerns as the next step in the evolution of American-produced biofuels.

Fuel Dispenser Certification Concerns

Underwriters Laboratories (UL) establishes the safety requirements and testing procedures for automotive fuel dispenser systems (UL 87) and certifies new products to ensure they meet material compatibility, adhere to fire safety codes, and are consistent with related products. Although UL has certified certain dispensers for ethanol volumes greater than 10 percent, most existing dispensers used by convenience store operators were only tested and approved for 10 percent blends. The cost of replacing the dispensers is uneconomical for the operator. Isobutanol's initial use would be at EPA gasoline "substantially similar" levels eliminating the need to replace or certify fuel dispensers.

Consumer Labeling/Product Liability Concerns

EPA has given qualified approval for the sale of E15 blends for use in car model years 2001 and newer, and discussions are under way to determine an appropriate label to be displayed on the dispenser to ensure that the consumer uses the appropriate fuel for their car. Unfortunately, per EISA and its current legal framework, the liability to ensure that the consumer uses the right fuel is placed on the convenience store operator. Many operators find this risk to be too high to consider selling ethanol blends above 10 percent. Again, as isobutanol's initial use would be at EPA "substantially similar" levels, it would be considered the same as a conventional petroleum product.

Operational Concerns

The use of ethanol in gasoline has been encumbered by operational issues. In addition to its phase separation issues, it is a fairly strong solvent that tends to dislodge dirt/sludge from the dispensing equipment, causing dispenser filter problems and gasket leaking. Isobutanol is not as potent a solvent as ethanol, and based on preliminary discussions with dispenser equipment suppliers, is not expected to have the same issues as ethanol.

Price and Energy Content Concerns

Consumers tell us that although price remains a key driver of fuel purchase decisions, product performance as a reason for choosing a gasoline brand is increasing. Consumers are keeping their vehicles longer and taking better care of them; rethinking what goes in the tank is becoming more important. Any product that reduces fuel mileage and/or may increase maintenance costs will be avoided if there is a better alternative. Isobutanol has higher energy density than ethanol, and tests are being conducted to quantify this potential benefit to fleet operators and the general motoring public. Qualitatively, gasoline marketers are looking for ways to differentiate themselves, and having a fuel that is renewable but not ethanol is of high interest.

Marine and Small-Engine Concerns

For specialized uses, such as small-engine and/or marine fleet engines, it is paramount to have a fuel that does not cause operational safety issues and can meet EPA emission targets. As the amount of oxygen content in a fuel increases, the operating temperature of that engine increases, potentially causing undue wear and increased emissions. This is an issue with engines that do not have sophisticated instrumentation. In addition, safety issues have been highlighted, relative to higher idle speeds and unintentional clutch engagement.

The National Marine Manufacturers Association (NMMA), the Outdoor Power Equipment Institute (OPEI) and many of their member companies are evaluating isobutanol as a possible alternative to ethanol to help reduce emissions and eliminate phase separation issues. For example, BRP US Inc. recently conducted a study that found butanol-containing gasoline produced less greenhouse gas emissions and had less engine enleanment than ethanol-blended gasoline.

Summary

The petroleum industry needs to focus on innovation to meet future environmental regulations, achieve energy independence and mitigate end-user issues. Isobutanol is an ideal platform molecule to address these issues while benefiting the transportation fuels industry value chain.

Isobutanol may provide environmentally favorable options for the transportation fuels industry to position its products facilities and manufacturing processes to meet increasingly stringent regulatory policies and industry standards.

THE AUTHORS

Christopher Ryan, Ph.D.

Executive Vice President of Business Development

Dr. Christopher Ryan is the executive vice president of business development at Gevo. He started his tenure at Gevo in 2009 with more than 15 years of strategic leadership, business development, and research and product development in bio-based materials. Most recently, Dr. Ryan was chief operating officer and chief technology officer for NatureWorks, LLC, which he cofounded in 1997. While at NatureWorks, Dr. Ryan was involved in the development and commercialization of the company's new bio-based polymer from lab-scale production through the introduction and growth of PLA through its $300 million world-scale production facility. He also spent four years working in corporate R&D for HB Fuller, a specialty chemicals company.

Dr. Ryan completed the management of technology program at the University of Minnesota, Carlson School of Management, and holds a Ph.D. in organic chemistry from the University of Minnesota and a B.S. in chemistry from Gustavus Adolphus College.

Dave Munz, MBA

Business Development Manager, Transportation Fuels

Dave Munz joined Gevo in early 2008 and has been focused on placing isobutanol and/or its derivatives in the transportation fuels industry. His background includes business development, pricing, and/or sales and marketing positions with DuPont (U.S. and UK), Conoco (upstream and downstream, U.S. and UK) and CountryMark. Over the past several years, Mr. Munz's focus has been on renewable fuels and their efficient integration across the value chain within the oil-and-gas industry.

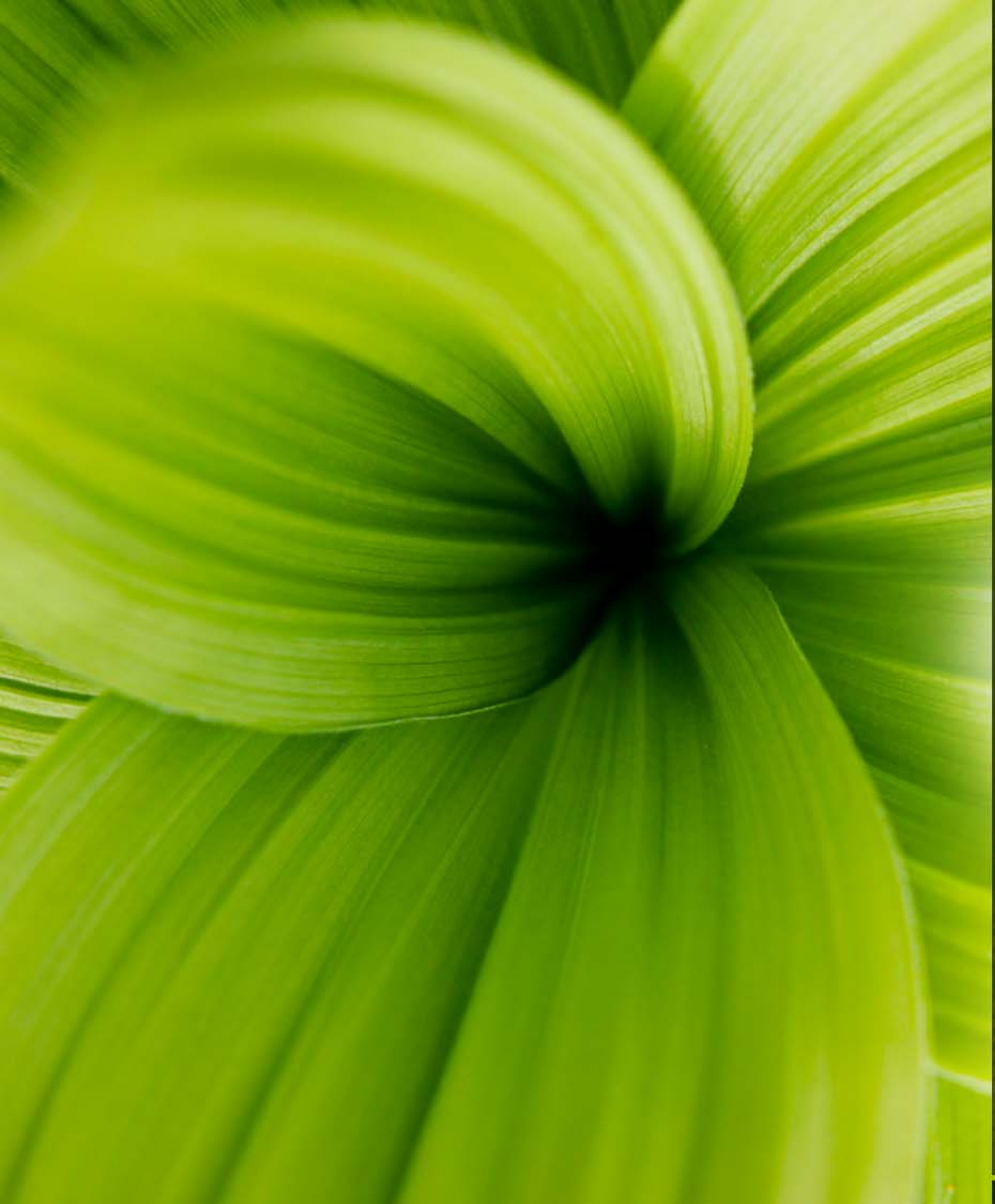
Mr. Munz has a BS degree in chemical engineering from the University of Wisconsin—Madison and an MBA from Warwick University in England.

Gary Bevers

Downstream Petroleum Consultant

Gary Bevers has 28 years' experience in product and market development for innovative eSupply Chain Management solutions designed to increase downstream petroleum distribution efficiencies. His firm focuses on systems and logistics support projects that help companies drive sales and operations more efficiently, especially online. He developed Internet-based e-business solutions for TETRA Technologies for oil and gas and handled product marketing for Exxon Chemical, where he received its "PRIME" Marketing Award of Excellence in 1996. He also published *NPN Magazine* and *Fuel Oil News*, covering every sector of the downstream wholesale, commercial, transportation and retail markets.

Mr. Bevers is a member of and actively participates on numerous industry organizations and committees: API/PIDX, SIGMA, NACS/PCATS, PMAA, ILTA, NPECA and MPGA.



gevo™

Renewable Hydrocarbons
for the Chemical and Fuel
Markets

Top 10
Reasons to use Isobutanol

SAFE HARBOR STATEMENT

Certain statements in this presentation, including, without limitation, statements related to Gevo's expected future production capacity, potential market demand, potential for increased margins, potential for reduced volatility, addressable markets, diversified and historically cost-competitive markets, lower carbon footprint, lower risk retrofit, lower cost, minimal downtime retrofit, intellectual property portfolio, feedstock flexibility potential and its ability to produce cellulosic isobutanol once biomass conversion technology is commercially available, may constitute "forward-looking statements" within the meaning of the Private Securities Litigation Reform Act of 1995. These forward-looking statements are made on the basis of the current beliefs, expectations and assumptions of the management of Gevo and are subject to significant risks and uncertainty. Investors are cautioned not to place undue reliance on any such forward-looking statements. All such forward-looking statements speak only as of the date they are made, and the Company undertakes no obligation to update or revise these statements, whether as a result of new information, future events or otherwise. For a further discussion of risks and uncertainties that could cause actual results to differ from those expressed in these forward-looking statements, as well as risks relating to the business of Gevo in general, see the risk disclosures under the section captioned "Risk Factors" in Gevo's final prospectus related to its initial public offering filed pursuant to Rule 424(b) under the Securities Act of 1933, as amended, on February 9, 2011.

1. A Bridge Between Two Industries

Two Industries: one established, one new

- **Downstream Petroleum industry - $500+ billion in transportation fuels assets**
- **Renewable Fuel industry - $50+ billion**

Goal is to better integrate them across the entire fuel value chain:

- **Reduce capex by retrofitting existing biochem facilities**
- **Use existing pipelines to access refineries**
- **Integrate “drop in” renewable materials into refinery**
- **Pipeline distribute finished refinery products**
- **Market products that the customer/consumer wants/needs**

Isobutanol has the potential to be that bridge that allows the two industries to become integrated

2. Evolving Beyond “Food for Fuel”

Feedstock Flexibility

Today

Corn

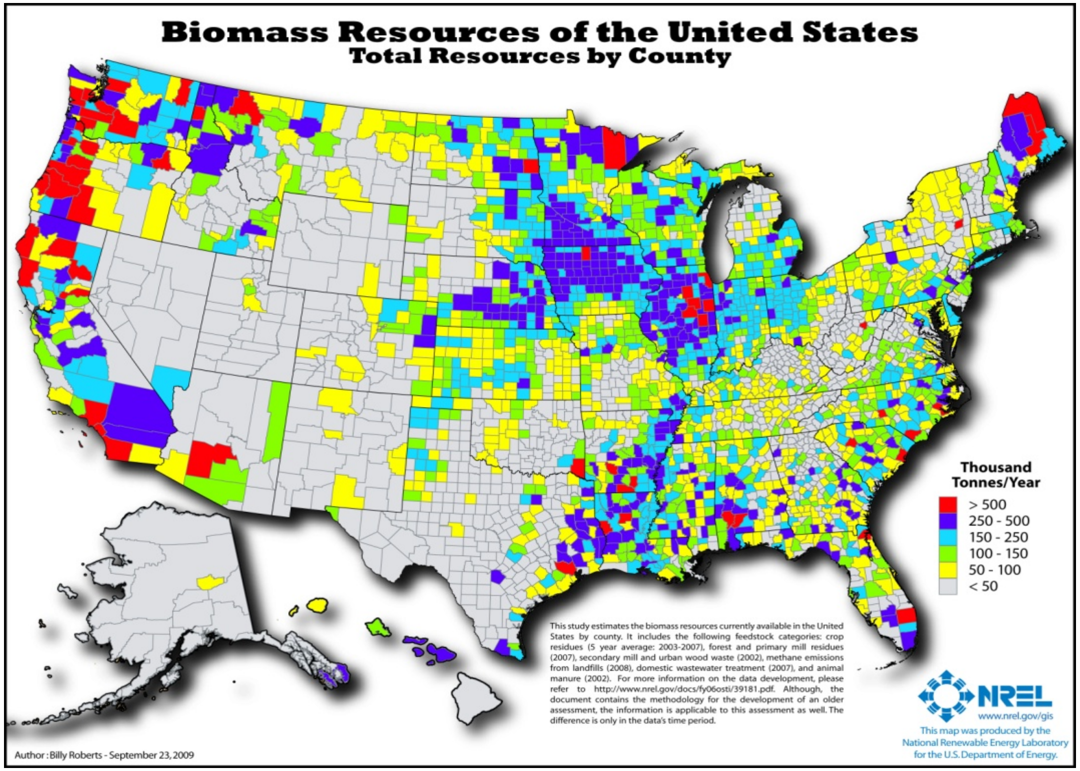
Sugar Cane

Future

Agricultural Residue

Wood

- **Initially, Gevo will use cost effective corn starch**
- **However, our technology can utilize cellulosic sugars**
- **Ongoing discussions with biomass conversion companies**
- **Purchase biomass sugar streams when they are ready**



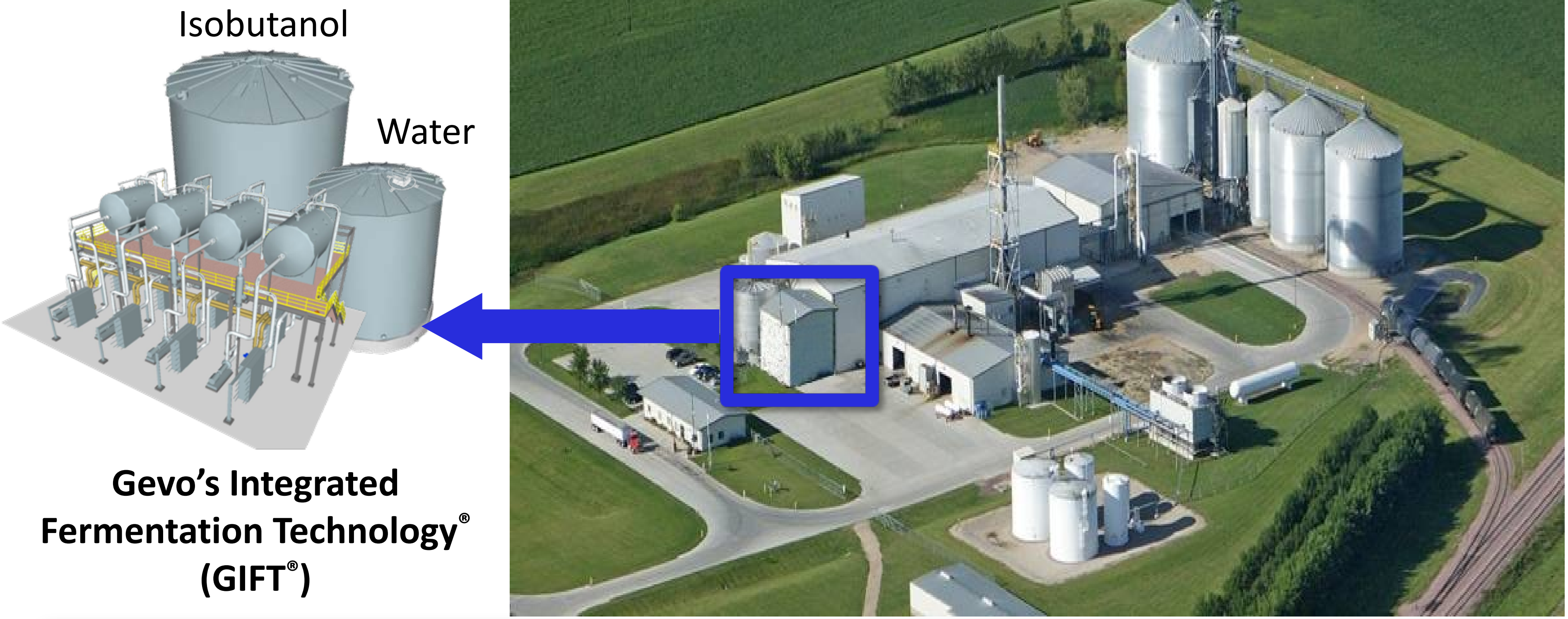
Biomass Resources of the United States
Total Resources by County

This study estimates the biomass resources currently available in the United States by county. It includes the following feedstock categories: crop residues (5 year average: 2003-2007), forest and primary mill residues (2007), secondary mill and urban wood waste (2002), methane emissions from landfills (2008), domestic wastewater treatment (2007), and animal manure (2002). For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf. Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Author : Billy Roberts - September 23, 2009

3. Upgrade Existing Biochemical Plants



Gevo's Integrated Fermentation Technology® (GIFT®)

Designed to be Capital Light, Fast Retrofit

Low retrofit costs

~ $0.40/gallon (100 Mgpy)

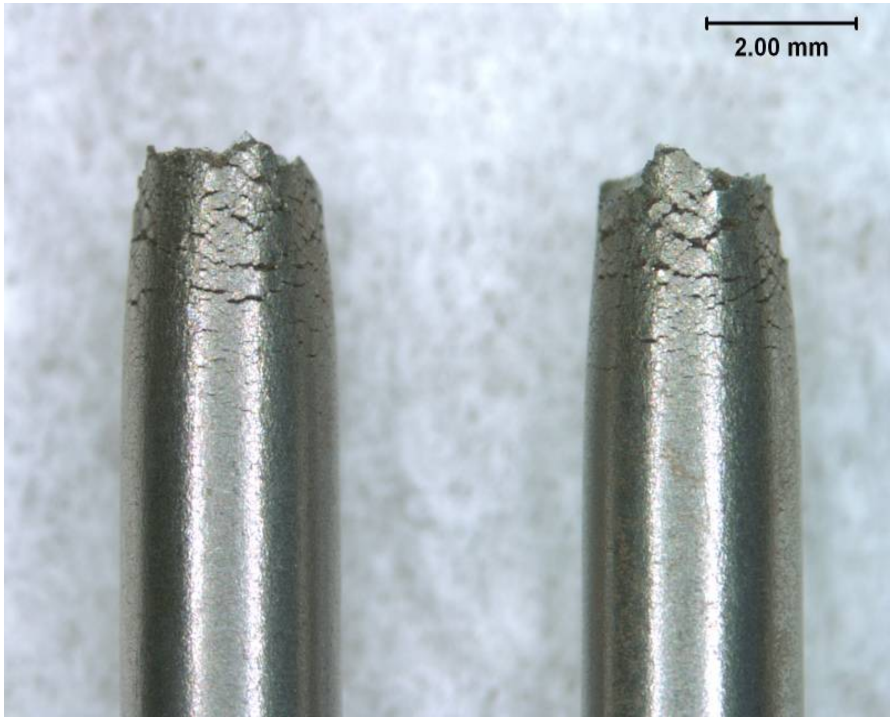
~ $0.60/gallon (50 Mgpy)

Short construction period

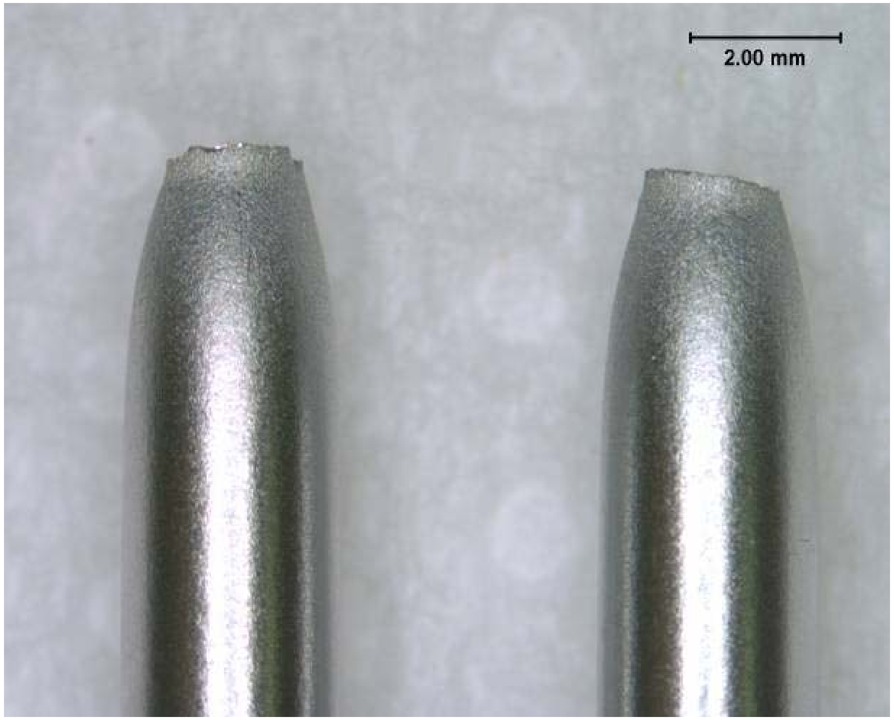
- 11-13 months
- Includes design and engineering

Gevo has not completed a commercial scale retrofit. All costs and construction periods are estimates based on engineering reports from ICM based on information provided by Gevo. We believe all estimates to be accurate.

4. Maximize Existing Pipeline Distribution Systems



Stress Corrosion Cracking (SCC)

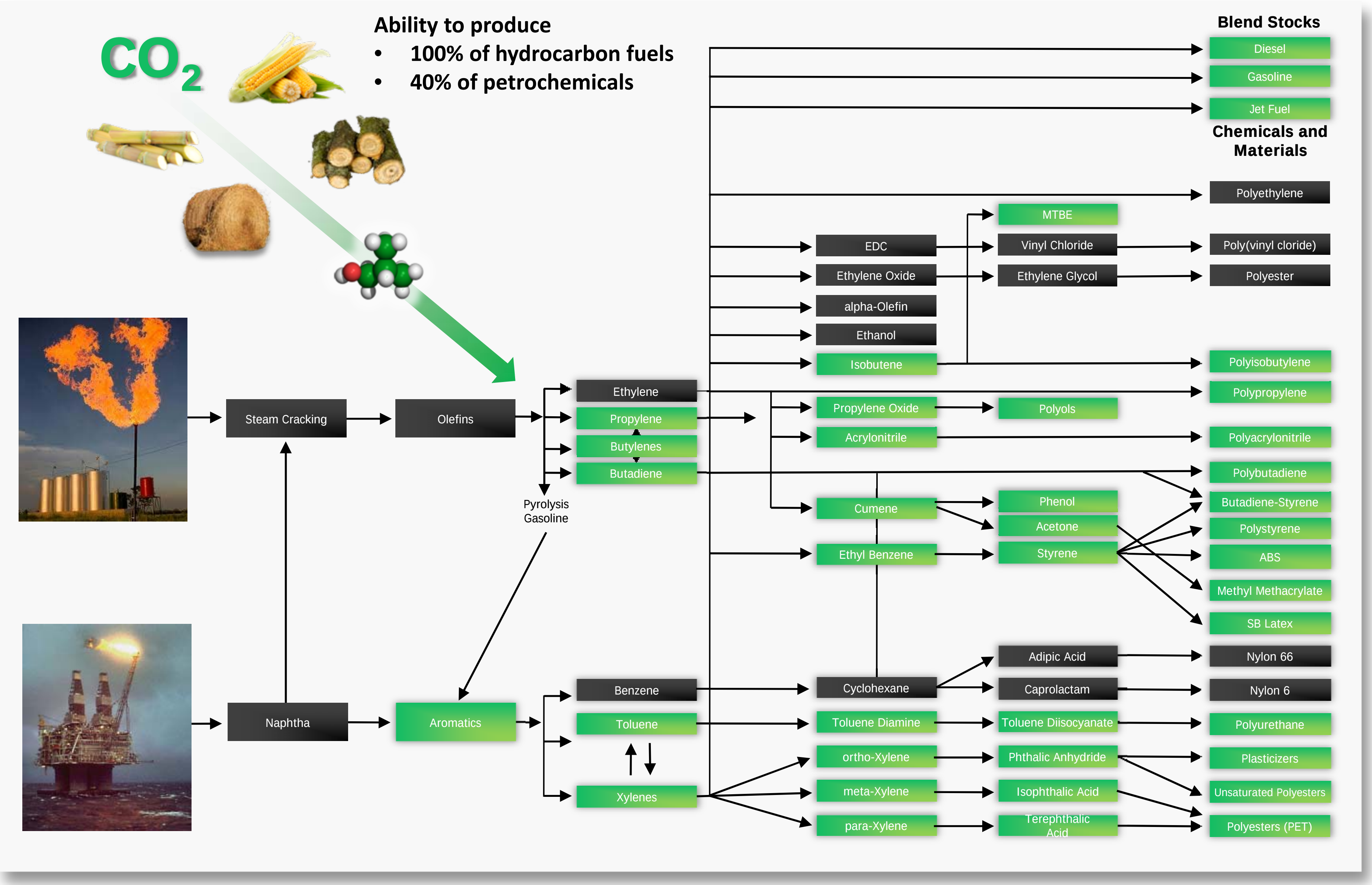


No Stress Corrosion Cracking (SCC)
(12.5% Isobutanol)

- **Integrity - No SCC or apparent elastomeric compatibility issues**
- **Quality - Ship neat isobutanol and/or isobutanol containing gasoline**
- **Operations – Use NGL and Finished Products pipeline systems**

Gevo has completed preliminary testing with DNV (Det Norske Veritas) on SCC and elastomeric compatibility

5. Not a "One Trick Pony"



CO_2

Ability to produce
- **100% of hydrocarbon fuels**
- **40% of petrochemicals**

Blend Stocks
- Diesel
- Gasoline
- Jet Fuel

Chemicals and Materials

Steam Cracking

Olefins

Ethylene

Propylene

Butylenes

Butadiene

Pyrolysis Gasoline

Naphtha

Aromatics

Benzene

Toluene

Xylenes

EDC

Ethylene Oxide

alpha-Olefin

Ethanol

Isobutene

Propylene Oxide

Acrylonitrile

Cumene

Ethyl Benzene

Cyclohexane

Toluene Diamine

ortho-Xylene

meta-Xylene

para-Xylene

MTBE

Vinyl Chloride

Ethylene Glycol

Polyols

Phenol

Acetone

Styrene

Adipic Acid

Caprolactam

Toluene Diisocyanate

Phthalic Anhydride

Isophthalic Acid

Terephthalic Acid

Polyethylene

Poly(vinyl cloride)

Polyester

Polyisobutylene

Polypropylene

Polyacrylonitrile

Polybutadiene

Butadiene-Styrene

Polystyrene

ABS

Methyl Methacrylate

SB Latex

Nylon 66

Nylon 6

Polyurethane

Plasticizers

Unsaturated Polyesters

Polyesters (PET)

Source: Adapted from Nexant

Note: Chemicals shaded green denote those which can be made from isobutanol-derived building blocks.

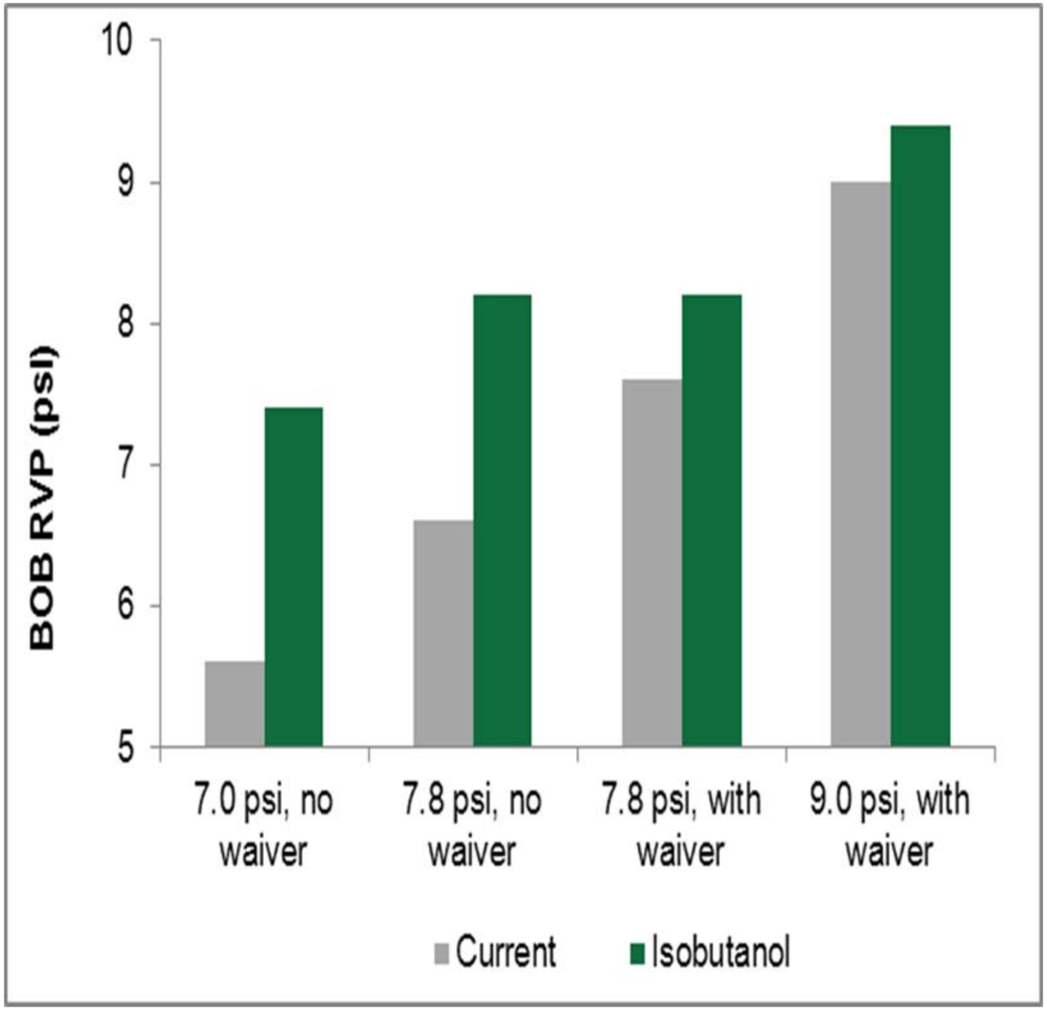
6. Exceptional Gasoline Blendstock

	Ethanol	Isobutanol
Blend RVP	18 - 22 psi (at 10% volume)	4.5 - 5.5 psi (at 12.5% volume)
Blend Octane	112	102
Energy content (% of gasoline)	65%	82%
Water Solubility	Miscible	8.5%
Lower Oxygen Content	35% oxygen	22% oxygen

Potential isobutanol benefits

- **Low volatility allows blending flexibility, optimization**
- **Octane, volatility mix gives better values than alkylate**
- **Higher energy content means higher EISA Equivalence Value and potentially, improved consumer benefits**
- **Limited solubility means the isobutanol stays in the gasoline**
- **Lower oxygen content enables higher renewable volume usage**

6a. Low volatility – a strategic advantage



Isobutanol benefits the blending of low cost feedstocks

Isobutanol's value to the refiner increases as RVP decreases

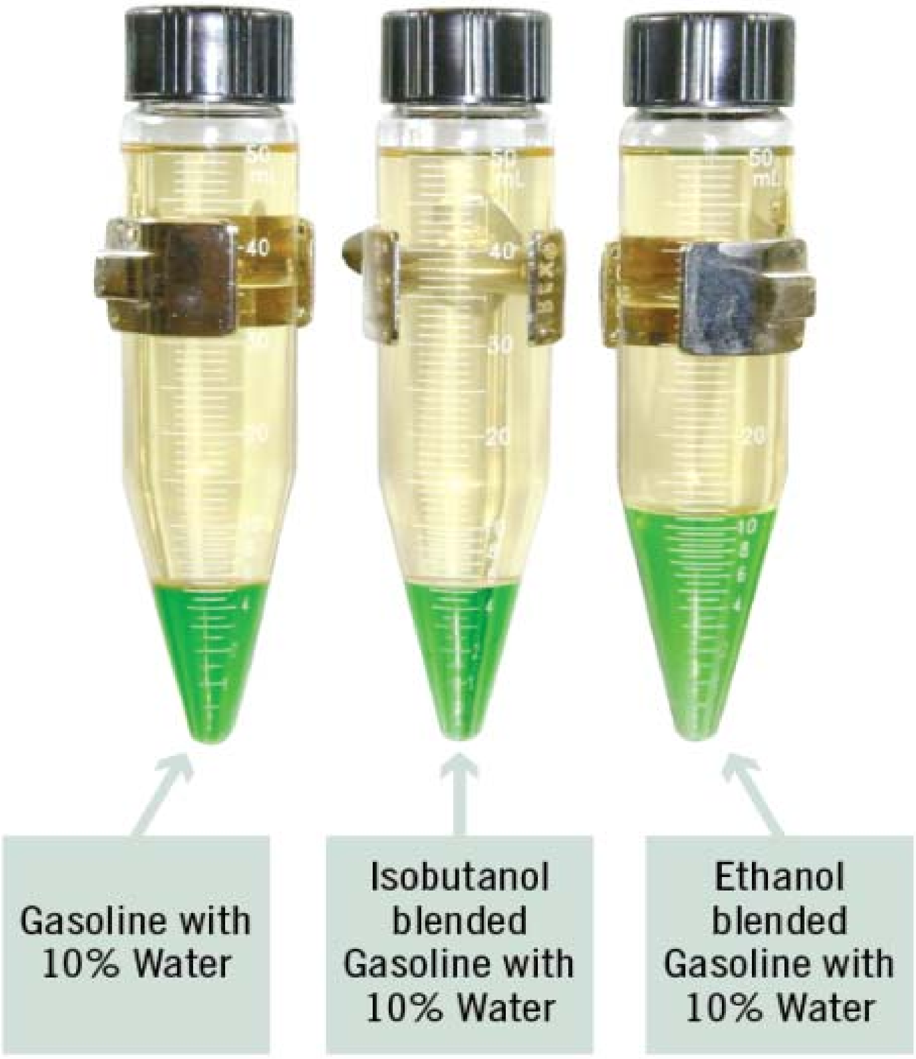
Currently, E15 does not have a 1 psi waiver

Future gasoline volatility may be lowered if the current 75 ppb ozone standard is reduced

Using isobutanol may mitigate expensive operational refinery upgrades

Source: Analysis via Baker & O'Brien's PRISM model

6b. Worried about water?



Isobutanol acts like a hydrocarbon; it stays in the gasoline

It has limited ability to attract, absorb, and hold moisture, maintaining the octane integrity of the gasoline

It is more tolerant to unintended contact with water, even if the volume levels are increased

There may be lower risk of phase separation in using isobutanol

6c. Lower Oxygen Content

	Volume in Gasoline	Oxygen Content	RIN-gallons per 100 gallons finished product
E10	10.0%	3.5%	10.00
E15	15.0%	5.2%	15.00
Isobutanol (Substantially similar gasoline)	12.5%	2.7%	16.25
Isobutanol (Octamix or DuPont Waiver)	16.1%	3.5%	20.93
Isobutanol (Waiver to match E15 oxygen content)	24.3%	5.2%	31.39

Refinery can produce finished products, with a renewable content, that helps them meet their RFS2 obligation

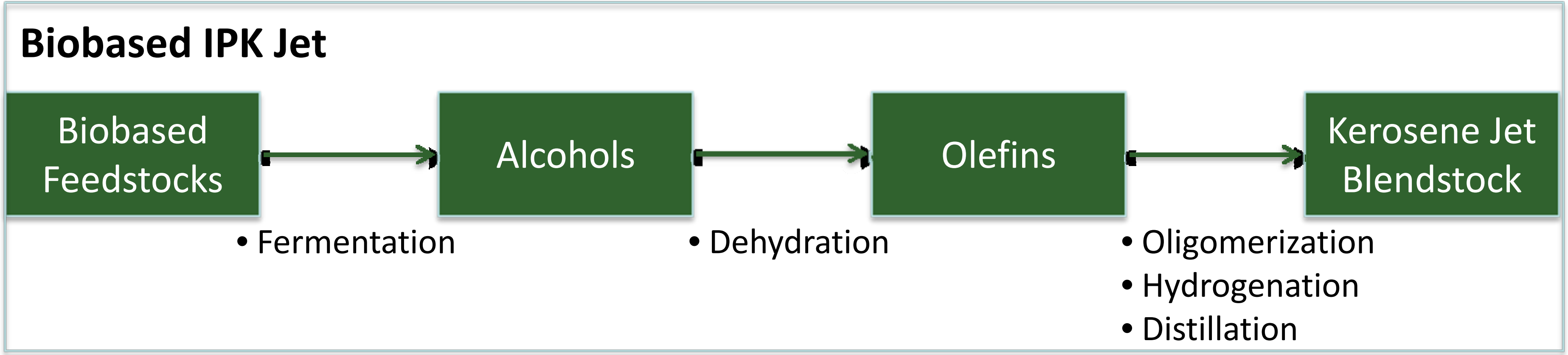
There may not be a "blend wall" issue with increased RIN-gallon generation rate

Non-closed loop engine manufacturers have more latitude to accept the gasoline produced

More time to evaluate and/or evolve engine design to accommodate higher levels of oxygen in gasoline blends

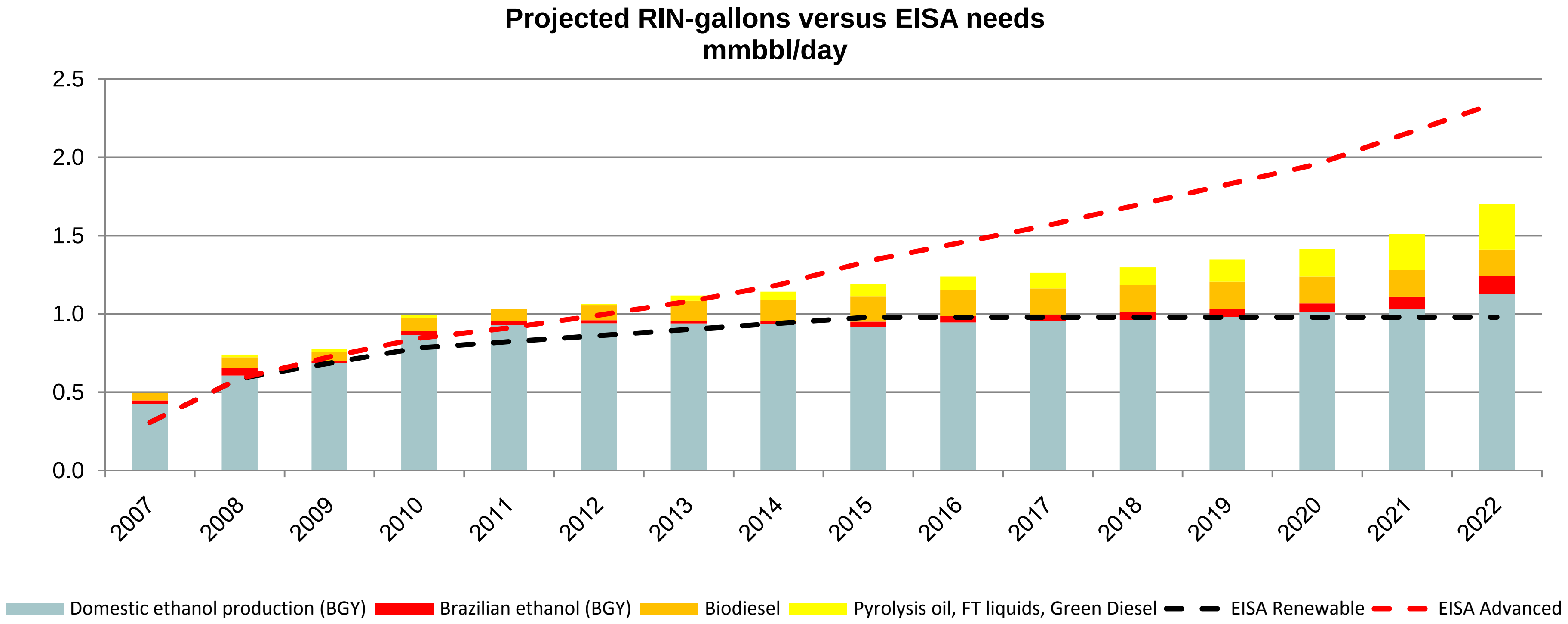
7. Outstanding Jet Blendstock

- Isobutanol to isoparaffinic kerosene (IPK)
  - known conversion unit operations
- IPK
  - may be blended at up to 50:50 mix with petroleum jet
  - has minus 80^{o}C freeze point property
- Relative to EISA, at a projected EV of 1.6, may generate up to 80 RIN-gallons per 100 gallons of finished product
- Airline interest: strategic fuel diversification, emissions reductions, sustainability



Biobased IPK Jet

8. EISA



Based on our knowledge of EISA today,

- **Advanced RINs may go significantly short**
- **Isobutanol provides an American made, price competitive “advanced” product, at a high RIN generation rate**

Source EIA AEO 2010 projected renewable volumes, EISA target volumes, Analysis by Gevo

9. Engaging End User Interest/Support

End User Group involvement

- UL – Isobutanol, at 12.5% by volume, meets ASTM 4814 requirements as a "substantially similar" gasoline
- Auto industry – Proposal for evaluating new fuels/fuel blends
- OPEI/members – discussing test program
- NMMA/members – BRP study, discussing additional test programs
- Retail equipment suppliers – discussing test programs
- ASTM – Sub-committees chartered for isobutanol, isoparaffinic kerosene

No apparent issues; in fact, positive preliminary findings imply isobutanol may address many of the concerns of first generation renewable products

10. Environmental

Naturally Occuring Material

Isobutanol is a naturally occurring substance, with a musky odor, that is found in many essential oils, foods and beverages (brandy, cider, gin, coffee, cherries, raspberries, blackberries, grapes, apples, hop oil, bread, and Cheddar cheese)

Biodegradability

Isobutanol readily biodegrades in water (360 hrs), soil (360 hrs), and sediment (1,440 hrs)

Toxicology

Isobutanol can be absorbed through the skin, lungs, and GI tract; acute effects are alcoholic intoxication

Compared to other transportation fuel blendstocks, isobutanol is a very good environmental alternative

OECD SIDS Isobutanol Assessment Report – 2004
Anaerobic Biodegradation of Known and Potential Gasoline Oxygenates, University of Oklahoma
US EPA HPV Challenge Robust Summaries and Test Plans (CAS 78-83-1).

Summary

In using isobutanol, the petroleum industry may be able to effectively roll back the clock 5-15 years to produce fungible, finished products, integrated with renewable materials, that may address regulatory, production, distribution, and marketing issues!

OECD SIDS Isobutanol Assessment Report – 2004
Anaerobic Biodegradation of Known and Potential Gasoline Oxygenates, University of Oklahoma
US EPA HPV Challenge Robust Summaries and Test Plans (CAS 78-83-1).

Thank You