NIGERIA FUEL ETHANOL COST-BENEFIT ANALYSIS STUDY

prepared for:

U.S. GRAINS COUNCIL

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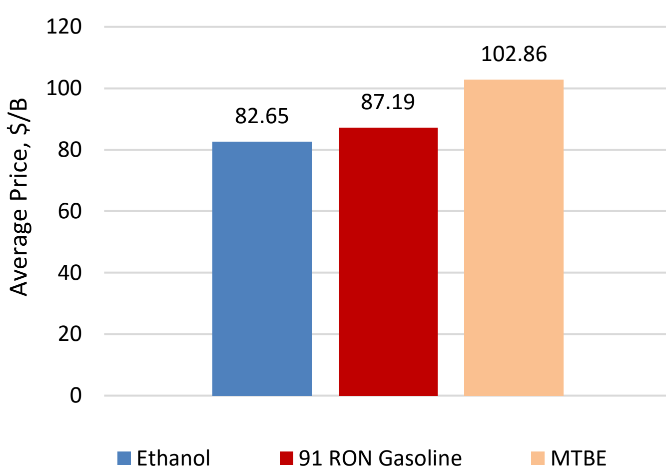
I. Executive Summary

There is only one grade of gasoline in Nigeria, a 91 RON regular. The gasoline is generally supplied from refineries in Western Europe and tankered to Nigeria. Nigeria has eight domestic refineries, four larger facilities with a combined capacity of 424 MBPD and four micro-refineries which have a total capacity of 24 MBPD. The larger refineries have run at low rates in recent years. The most promising outlook for the future rests with the startup of the Dangote refinery in Olokola in 2023. The massive 650 MBPD facility will be inaugurated this year, but substantial output is not expected until next year. The Olokola refinery will be the largest single train refinery in the world.

FIGURE I-1
Nigerian Gasoline Prices, 2012+



The role of oxygenates and biofuels in the global transportation fuel mix is steadily growing. While there are a number of fuels in these two categories, ethanol is the only fuel which is in both. As such, ethanol not only assists in the combustion process and reduces carbon monoxide emissions but is also a renewable biofuel which reduces the production of greenhouse gases. In addition to these benefits, the blending of ethanol in most years will reduce the cost of gasoline while the blending of other oxygenates will increase the cost. Figure I-1 is a comparison of the costs of ethanol delivered to Nigeria from the U.S. with spot Northwest European prices for gasoline[1]. These values are the average of prices from January 2012 through the first half of 2022. As can be seen from Figure I-1, delivered ethanol prices were lower than 91 RON gasoline by $4.54 per barrel.

In addition to the significant economic benefits, the use of ethanol also creates other operational and strategic gains. Ethanol is generally added to gasoline with a computerized in-line blending system which can reduce octane give-away and ensure proper octane requirements are met. The use of ethanol also reduces the concentration of contaminants, like sulfur, and undesired compounds, such as benzene and other aromatics. There are also strategic advantages with

[1] S&P Global Platts quotations, TM&C.

ethanol in the form of a diversification of the transportation fuel supply. This is accomplished by moving away from petroleum and by increasing the geographic sources of supply.

Economic Benefits

The direct economic benefits of ethanol come in three forms: 1) lower ethanol pricing which reduces the blended gasoline price, 2) higher ethanol octane which reduces the required subgrade octane, and 3) the use of ethanol creates dilution benefits. As seen in Figure I-1, ethanol is generally priced lower than regular gasoline with the result that the addition of ethanol will reduce the cost of the blended fuel. The higher the concentration of ethanol, the greater the price reduction. The value of these pricing reductions for each concentration of ethanol is seen in the first column of Table I-1.

The octane benefit is the result of the 130 RON for ethanol. This higher octane allows for a lower-octane subgrade to be blended with the ethanol, such that the blended fuel achieves its desired total RON requirement. The lower-octane subgrade is less expensive for a refinery to produce. Over the last ten years, octane in Europe has been valued at $2.20 per RON. The octane benefits shown in Table I-1 are greater than the pricing benefits.

The third economic improvement is derived from the dilution benefits of ethanol. Nigeria's fuel specifications are less stringent than most other countries, but the nation is working toward tightening these requirements. Ethanol contains no benzene or aromatics and essentially no sulfur. While ethanol will not achieve the desired improvements by itself, it does represent a highly economic first step and could substantially reduce refinery investments to achieve the balance of the objectives. Turner, Mason & Company (TM&C) has estimated the financial impact of these dilution benefits at $0.15 to $0.60 per barrel.

In addition to the scenario of blending ethanol into clear gasoline (E0), TM&C also calculated the economic benefits of

TABLE I-1

Cost Reductions from Adding Ethanol, $/B

	Vs. E0	Vs. MTBE
E5		
Pricing Benefits	0.23	1.79
Octane Benefits	4.29	-2.21
Dilution Benefits	0.15	-0.15
Total Reductions	**4.66**	**-0.57**
E10		
Pricing Benefits	0.45	2.02
Octane Benefits	8.57	2.42
Dilution Benefits	0.30	0.00
Total Reductions	**9.32**	**4.44**
E15		
Pricing Benefits	0.68	2.25
Octane Benefits	12.86	7.05
Dilution Benefits	0.45	0.15
Total Reductions	**13.99**	**9.44**
E20		
Pricing Benefits	0.91	2.47
Octane Benefits	17.14	11.67
Dilution Benefits	0.60	0.30
Total Reductions	**18.65**	**14.45**

transitioning from a 10% MTBE blend to the various ethanol grades. These benefits are shown in the second column of Table I-1. The pricing improvements are greater in this case due to the higher MTBE prices, but the octane contributions are lower as MTBE has a higher RON than the gasoline grades but less than that of ethanol[2]. In total, the MTBE to E5/E10/E15/E20 cases produce lower economic benefits than the E0 to the E5/E10/E15/E20 cases. This indicates there is value in utilizing MTBE but even a greater economic gain in utilizing ethanol. These two cases are described in greater detail in Sections IV and V.

Strategic Benefits

Not all of the benefits of ethanol blending can be quantified, but are real, nonetheless. The first of these is the ability to diversify the transportation fuel sources. Crude oil, and as a result gasoline prices, tend to be highly volatile. This volatility is generally much greater than that of ethanol prices. Transitioning 10% or more of the gasoline sourcing to ethanol will reduce the dependence on crude oil and its corresponding volatility. The second component of diversification is related to geography. Incremental global crude oil is often supplied by politically unstable countries: such as Iraq, Iran, and Venezuela. Sourcing transportation fuels from the U.S. helps to insulate against unexpected political disruptions.

A second strategic benefit results from aligning with global trends. In the last decade, many countries have seen an increase in octane requirements. The U.S. has experienced an octane consumption increase of 0.12 RON, Mexico has seen a 0.5 RON increase, while Indonesia has had a 2.0 RON gain. Many other countries are also increasing their octane requirements in line with the trend of producing higher Euro grade fuels (Table I-3). The higher Euro gasoline grades require higher RONs, and lower sulfur, benzene, and aromatic levels. Current Nigeria specifications are similar to Euro II or Euro III gasoline.

TABLE I-3

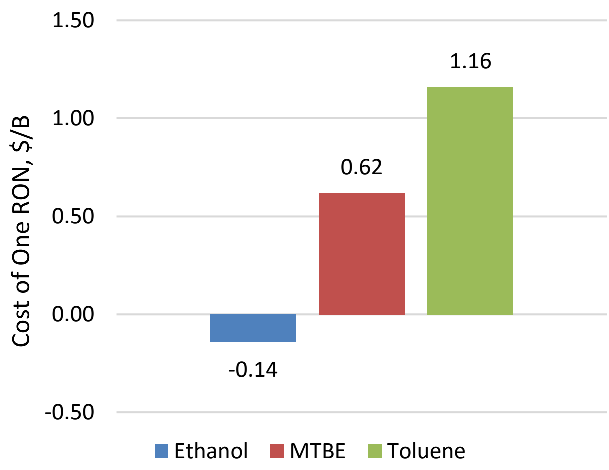
Nigeria and Euro Gasoline Specifications

		Euro Grades				Current
Property	Units	Euro II	Euro III	Euro IV	Euro V	Nigeria
Implementation Year		1996	2000	2005	2009	
RON	Minimum	92	93	94	95	91
Sulfur	Max. PPM	500	150	50	10	150
Benzene	Max. Vol. %	5	1	1	1	2

[2] *Cleaner Fuels for Latin America with MTBE and ETBE Advanced Gasoline Components*, LyondellBasell.

Other countries have also increased octane requirements in recent years and this trend is expected to continue into the near future. Ethanol and other additives are currently being used to enhance gasoline octanes around the world. For the last ten years, ethanol has proven to be the least costly method to increase octane. Figure I-2 compares the cost to increase regular gasoline by one RON using each of the three compounds[3]. While ethanol would reduce the cost of regular gasoline by approximately $0.14 per barrel per RON, the use of other additives would increase the cost between $0.62 and $1.16 per barrel.

FIGUR I-2
Relative Costs of Octane



Conclusions

Because of the uncertainty of global politics and the volatility of oil prices, diversifying the transportation fuel sources would seem to be a rational decision. The validity of this approach is further validated by a decade of recent history which concludes that not only will the blending of ethanol increase the octane pool and improve the quality of the gasoline by reducing sulfur and benzene levels, but it can accomplish all of these objectives while reducing the cost of the gasoline at the same time. This is a feat no other additive can achieve.

While this report has quantified many of the benefits of blending ethanol, the basis of this analysis is best described as preliminary. Actual savings will be related to a series of variables related to the actual refining and blending capabilities of Nigeria as well as the strategic objectives of the country. As such, a second analysis of the full ethanol blending potential is recommended which is tailored to the capabilities and objectives of Nigeria and conducted with the government of Nigeria or NNPC.

[3] TM&C Octane Cost Analysis.

II. INTRODUCTION

Because of the reliance on imports and the need for improved governance, the quality of Nigeria's gasoline supply has been erratic in recent years. The current specifications allow for a maximum sulfur level of 150 ppm and a benzene content of 2%. This is roughly equivalent to a Euro II or Euro III grade gasoline. TM&C has obtained laboratory results for four gasoline samples. All had sulfur levels in excess of the maximum level, and one was as high as 679 ppm. All four of the RONs were below the minimum 91 requirement. In the first half of 2022, Nigeria received up to four cargoes which had been contaminated with high concentrations of methanol. These practices point to either improper testing procedures or weak governmental controls which are not properly monitoring gasoline imports. For analysis purposes, we have assumed all gasoline meets the required specifications.

Our analysis of the additional cost advantages for ethanol blends compared to clear gasoline or MTBE blended gasoline is based on the following assumptions.

- All appropriate Nigerian laws have been modified permitting the blending of either 5%, 10%, 15%, or 20% ethanol into the gasoline supply.
- All other current gasoline specifications for Nigeria remain in effect.
- Infrastructure required for ethanol transportation, storage, and blending are in place. This would include terminal and retail facilities. Vehicle compatibility with ethanol is also assumed.
- The pricing of gasoline and components was based on historical European spot prices for 2012 through the first half of 2022 as reported by Platts. Ethanol prices are U.S. Gulf Coast (USGC) spot values with delivery costs to West Africa.

For the task of assessing the cost savings of converting from MTBE blends to ethanol blends, we reviewed the historical pricing differences between MTBE and ethanol and evaluated the octane contribution each makes to gasoline blends. For purposes of this analysis, we used an MTBE RON of 119 and ethanol RON of 130.

III. Background and Scope

TM&C was retained by the U.S. Grains Council to assess the economics of blending E5, E10, E15, and E20 ethanol grades in Nigeria. TM&C also assessed the economics of blending E5, E10, E15, and E20 compared to an alternate case of blending 10% MTBE. The basis for these economics was the use of European spot prices for gasoline and USGC spot prices for ethanol from S&P Global Platt's databases. TM&C evaluated a series of benefits of ethanol: including advantaged pricing, octane values, and the dilution effects on other gasoline specifications. The scope of work focused on the following:

1) The cost savings of producing an E5, E10, E15 and E20 versus no oxygenate blending;
2) The cost savings for producing an E5, E10, E15, and E20 compared to the use of MTBE;
3) The cost of producing octane in a global environment of increasing octane requirements; and
4) Gasoline Market Overview with a focus on supply, demand, and imports.

To assess the cost of ethanol, this study utilizes Platts pricing data for USGC quotations. These pricing assessments are predominantly utilized for domestic sales which are presumed to incorporate the value of a D6 RIN. When ethanol is exported, EPA regulations require the RIN which is attached to the ethanol to be retired. As such, no value of the RIN is received by either the buyer or the seller of the ethanol. Because of this, the Platts quotations for domestic sales of ethanol likely overstate the cost of ethanol when it is exported, resulting in the ethanol pricing benefits in this analysis being similarly understated.

IV. BENEFITS OF E5/E10/E15/E20 COMPARED TO E0

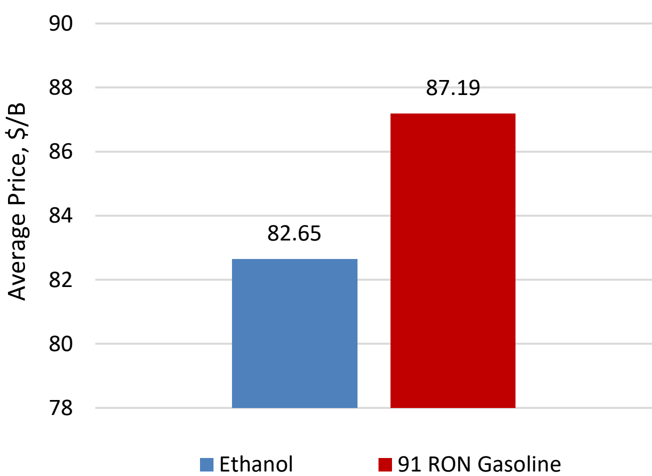
The assessment of production cost savings resulting from a transition from E0 to E5/E10/E15/E20 blends in Nigeria starts with the premise that the regulations have already been approved to blend ethanol and the benefits of various ethanol concentrations are being evaluated. Also, all of the infrastructure for the transportation, storage and blending of ethanol is assumed to be in place. As a result, the choice of the specific ethanol concentration would result in a seamless transition due to the computerized nature of the blending systems.

The advantages of ethanol blends over clear gasoline (E0) come in three distinct components. The first is that ethanol is generally priced lower than petroleum-based gasoline. Because of this, the cost of the blended fuel decreases as the ethanol concentration increases. The second advantage of ethanol blending is from an improvement in the octane of the fuel. Because of the higher ethanol octane, a lower octane of the petroleum gasoline subgrade is required to obtain the final desired octane of the blended mix. The third advantage is derived from the dilution effects of using greater concentrations of ethanol which contains no aromatic or benzene molecules and no sulfur.

Ethanol Pricing Effects

For the last decade, ethanol prices have been highly competitive with gasoline in most global markets. Since 2012, U.S. supplied ethanol has been priced well below the cost of 91 RON gasoline in Nigeria[4] (Figure IV-1). The ethanol prices are based on USGC values with transportation expenses to West Africa estimated at $1.83 per barrel. Nigeria does not currently sell a premium gasoline grade. This 10.5-year history indicates a pricing discount for ethanol at $4.54 per barrel. In four of these years, however, ethanol was priced above Nigerian gasoline. This was seen most dramatically during the COVID-19 pandemic of 2020 and 2021. When these two years are excluded, the ethanol discount increases to over $9 per barrel.

FIGURE IV-1
Historical Gasoline Prices, 2012-1H2022



[4] S&P Global Platt's quotations.

FIGURE IV-2
Historical Ethanol and 91 RON Gasoline Prices

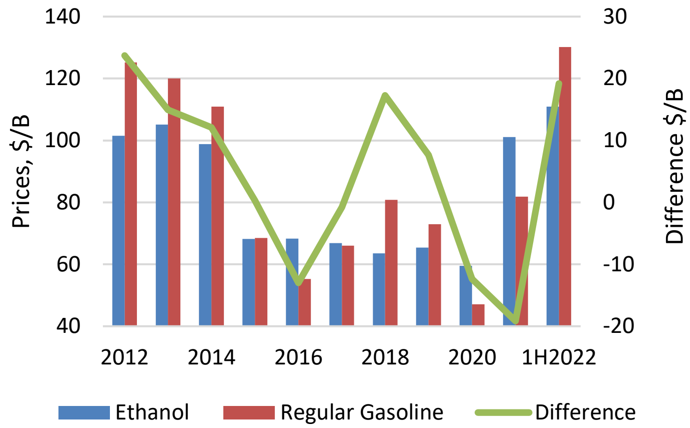


Figure IV-2 compares the yearly prices for delivered ethanol with 91 RON gasoline in Nigeria. As can be seen, the ethanol pricing discount is most pronounced when oil prices are high and lowest when oil prices are also low. Spot Nigerian gasoline prices were at a decade low in 2020 and 2021, as was the ethanol discount. Gasoline prices and the ethanol discount both rebounded in the first half of 2022. The ethanol/gasoline price also inverted in 2016 when gasoline prices were also low.

Because the delivered ethanol prices are generally lower than the gasoline prices, blending ethanol into the gasoline pool will lower the combined fuel price. Table IV-1 details these cost reductions. Blending an E10 to make 91 RON gasoline would have reduced the gasoline price by $0.45 per barrel while the price reduction for an E20 gasoline would have been $0.91 per barrel. The cost reductions increase as the ethanol concentration increases.

TABLE IV-1

Pricing Benefits, $/B	
	91 RON
E5	0.23
E10	0.45
E15	0.68
E20	0.91

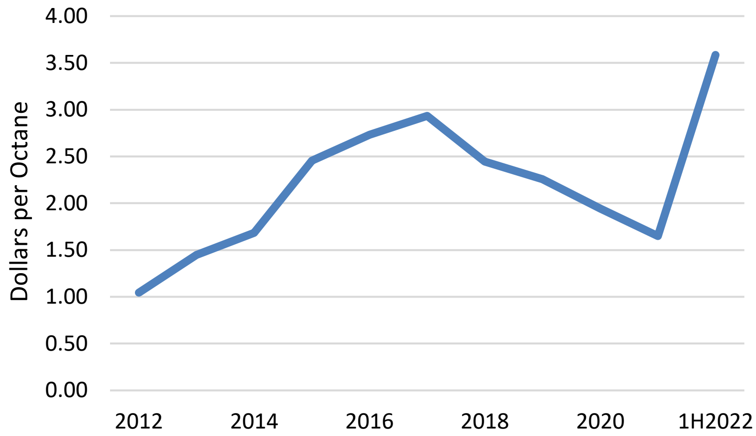
Octane Effects

In addition to the pricing benefits, the blending of ethanol also provides substantial octane benefits. The financial impact of these octane increases can be much greater than the pricing benefits. Because ethanol has a high octane (130 RON), a higher ethanol concentration in the gasoline allows for a lower octane in the gasoline subgrade, which when combined, will produce the desired RON for the final regular gasoline blend. Table IV - 2 illustrates this point. When the ethanol concentration is at 10% (E10), the octane of the 91 RON subgrade can be 86.7 RON, such that the RON of the total mixture will be the desired 91.0. If the ethanol concentration is increased to 20% (E20), the octane of the subgrade need only be 81.3 RON to achieve a 91.0 RON for the total blend.

TABLE IV-2

Subgrade Octane Requirements, RON	
	91 RON
E5	88.9
E10	86.7
E15	84.1
E20	81.3

FIGURE IV-3
Nigerian Octane Value



Decreasing the octane of the subgrade produces a financial benefit in that incremental octane has a defined cost. Using a Northwest Europe pricing spread between regular and premium gasoline, the cost of one incremental RON can be computed. Figure IV-3 displays the yearly variations with this calculation which varies from $1.04 per octane to $3.58 per octane. The adjusted average of the last decade was $2.20 per octane.

The combination of the octane savings in Table IV-2 with the historical cost of octane in Figure IV-3 will yield the total benefits of blending the various ethanol concentrations. These savings are seen in Table IV-3. The value of the octane benefits in Table IV-3 are significantly greater than the pricing benefits seen in Table IV-1.

TABLE IV-3

Historical Octane Benefits, $/B	
	91 RON
E5	4.29
E10	8.57
E15	12.86
E20	17.14

Dilution Effects

Because ethanol has no aromatic molecules (including benzene) and no or minimal sulfur, it is an excellent gasoline blendstock, particularly in regions where these contaminants are at high levels compared to their required specifications. The addition of ethanol would effectively reduce the levels of all of these contaminants while reducing the price of the fuel at the same time. While ethanol itself is devoid of sulfur, sulfur can be introduced by the addition of denaturants (generally gasoline) along with trace amounts from transportation, handling, and storage facilities. The U.S. EPA mandates using a nominal value of 5 ppm sulfur for Reformulated Gasoline reporting purposes when the sulfur content of the ethanol is not actually tested. This is the value which has been used for this study.

TABLEIV-4

Nigeria and Euro Gasoline Specifications

		Euro Grades				Current
Property	Units	Euro II	Euro III	Euro IV	Euro V	Nigeria
Implementation Year		1996	2000	2005	2009	
RON	Minimum	92	93	94	95	91
Sulfur	Max. PPM	500	150	50	10	150
Benzene	Max. Vol. %	5	1	1	1	2
Aromatics	Max. Vol. %	---	42	35	35	---

Europe has been on a multi-decade path to improve the fuel specifications of the gasoline consumed in the region (Table IV-4). The current specifications are for Euro V which was implemented in 2009 and requires a maximum sulfur level of 10 ppm and a benzene level of less than 1%. West African nations have implemented their own program with the current AFRI-4 requirement being 150 ppm sulfur. This is the existing specification for Nigeria. The current schedule is to advance to an AFRI-5 standard by 2030 which would limit the sulfur level to 50 ppm.

TABLE IV-5

Dilution Effects for Ethanol Blending

	Typical	Blended Values			
Specification	E0	E5	E10	E15	E20
Sulfur	150 ppm	143	136	128	121
Benzene	2.0 vol. %	1.9	1.8	1.7	1.6

Reducing the sulfur and benzene levels in Nigerian gasoline will require considerable effort and capital. The blending of ethanol will not achieve a higher Euro grade by itself, but it could provide an easy and economic first step in this process. While the percent reduction in sulfur, aromatics, and benzene levels is dependent on the levels present in the gasoline subgrade, Table IV-5 details the linear reductions in a typical subgrade which is fully compliant with each of the specifications. For subgrades which are noncompliant, the ethanol blending benefits would be greater than those shown in Table IV-5. These reductions could become a critical component in the success of Nigeria's efforts to upgrade its gasoline specifications to a Euro V standard.

The total of the dilution effects is difficult to calculate and is highly country specific and refinery specific. TM&C estimates the total impact of the quality improvements related to ethanol dilution effects to be $0.15 per barrel for E5 and $0.60 per barrel for E20. These savings are achieved by reducing the environmental burdens on the domestic refineries which can improve the ability to produce higher Euro Grade gasolines.

Total Cost Reduction Benefits

The total cost reductions for transitioning from an E0 to the various ethanol blends are shown in Table IV-6. For an E10 regular, the total reduction in costs averaged approximately $9.30 per barrel for the last decade while an E20 would have yielded a reduction in costs of approximately $18.60 per barrel. As can be seen, the bulk of the savings is related to the octane benefits of blending ethanol.

TABLE IV-6

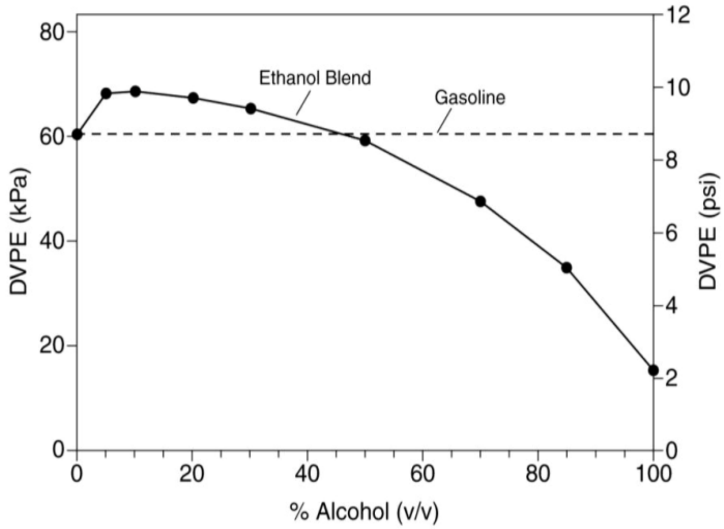
Cost Reductions from Adding Ethanol, $/B

	91 RON
E5	
Pricing Benefits	0.23
Octane Benefits	4.29
Dilution Benefits	0.15
Total Reductions	**4.66**
E10	
Pricing Benefits	0.45
Octane Benefits	8.57
Dilution Benefits	0.30
Total Reductions	**9.32**
E15	
Pricing Benefits	0.68
Octane Benefits	12.86
Dilution Benefits	0.45
Total Reductions	**13.99**
E20	
Pricing Benefits	0.91
Octane Benefits	17.14
Dilution Benefits	0.60
Total Reductions	**18.65**

While the decade-long average of cost reductions was related to the ethanol concentration, there was considerable volatility in the yearly averages. For E10 regular, the yearly cost reductions were as low as $4.82 per barrel but were as high as $16.20 per barrel. The E20 regular cost reductions were as high as $32.40 per barrel.

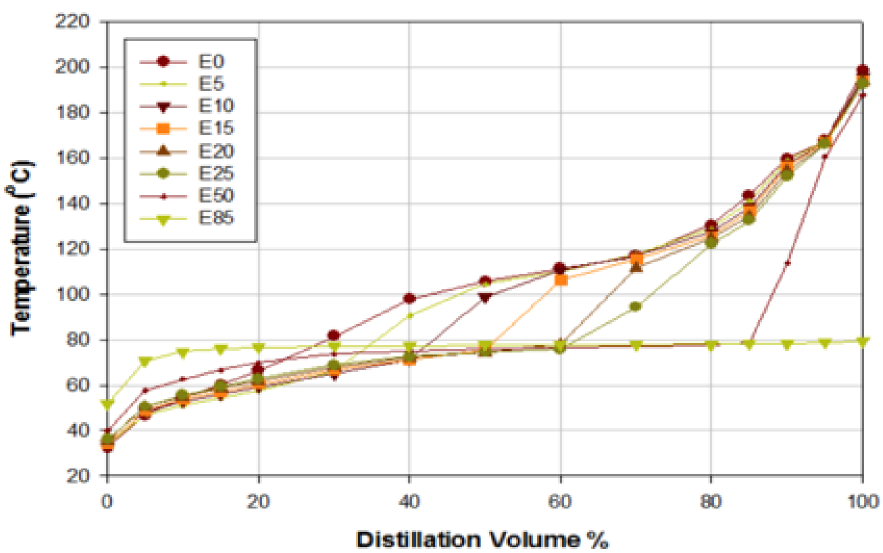
Gasoline Volatility

FIGURE IV–4
Effect of Ethanol Blending on Gasoline Vapor Pressure



Because of air quality issues, the vapor pressure of gasoline is always of paramount importance. A reasonable concern which could arise in the conversion to various ethanol blends is the potential of a decrease in air quality due to an increase in the vapor pressure. While ethanol itself has a low RVP (around 2 psi), it is well established that ethanol/gasoline blends with low concentrations of ethanol (up to 10%) tend to increase the RVP of the blend. As the concentration of the ethanol increases above 10%, however, the vapor pressure of the blend decreases. This effect is shown in Figure IV-4 and was produced by the National Renewable Energy Laboratory[5] which validates that the vapor pressure of ethanol blends between 5% and 20% are essentially flat. As a result, while a 1 psi waiver would likely be necessary, no additional cost impacts relating to vapor pressure have been assumed for conversions to E5, E10, E15, or E20.

Figure IV-5
Ethanol Impacts on T50 Point



Another specification in which ethanol impacts

[5] "Discussion Document – Effect of Ethanol Blending on Gasoline RVP", letter to the Renewable Fuels Association, March 26, 2012, National Renewable Energy Laboratory.

gasoline volatility is the T50 point. This is the temperature at which 50% of the gasoline would be vaporized. Ethanol tends to lower the 50% point as illustrated in Figure IV-5[6] which depicts a typical E10 and E20 distillation curve compared to E0. This impact is relatively minor for E10 and would not be a concern for most gasolines which are not light, i.e., highly volatile. Light gasoline, with a low pre-existing T50 point, could yield a blended T50 below desired levels or specification limits and will need additional evaluation.

[6] "Distillation Curves for Alcohol-Gasoline Blends", Energy Fuels. V F Anderson, J E Anderson, T J Wallington, and S A Mueller.

V. Benefits of Ethanol Blends versus MTBE

While MTBE can also be considered as an oxygenate and octane enhancer for use in Nigerian gasoline, ethanol is more advantageous in every respect. Ethanol is less expensive than MTBE, it has a higher octane than MTBE, and it can be used in higher concentrations than MTBE, resulting in greater dilution benefits. These total benefits serve not only to lower transportation costs for Nigerian consumers but will also reduce the refining upgrades necessary to produce higher Euro grades of gasolines in the future.

The most obvious benefit of ethanol is its lower price. Since 2012, the average price of ethanol delivered to Nigeria was over $20 per barrel less than the price of MTBE (Figure V-1) using Northwest Europe pricing[7]. When the COVID-19 years of 2020 and 2021 are taken out of this comparison, the ethanol pricing advantage rises to over $26 per barrel. For over 10 years, ethanol has been priced below regular gasoline while MTBE has been priced substantively over gasoline.

FIGURE V-1
Nigerian Gasoline Prices, 2012-2022

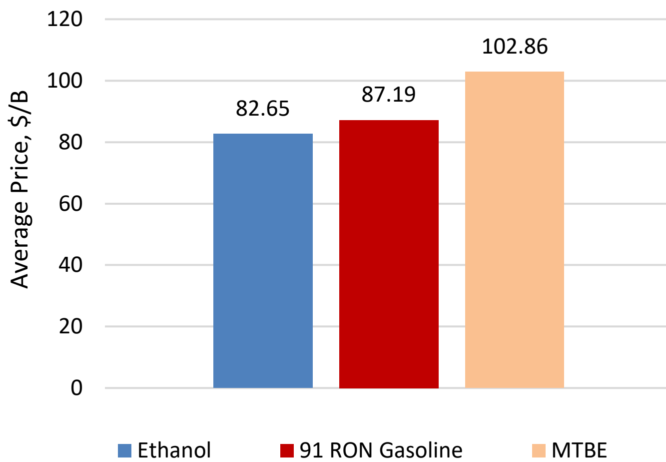
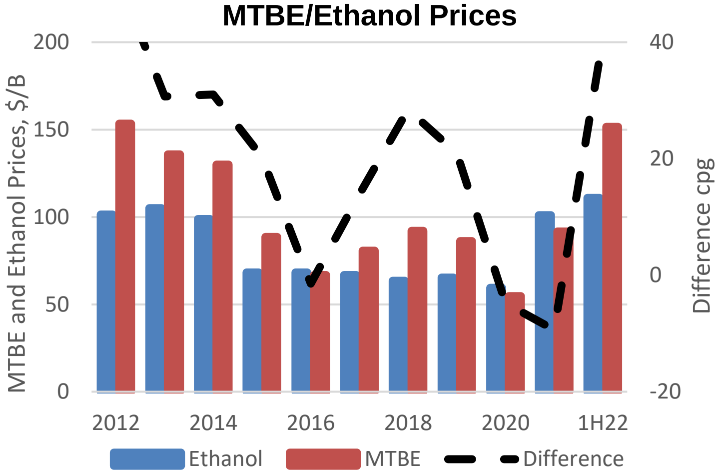


FIGURE V-2
MTBE/Ethanol Prices



In general, higher priced petroleum markets provide for greater discounts in ethanol pricing. Figure V-2 compares the yearly differences in ethanol and MTBE prices. In 2020, demand for MTBE plummeted, causing prices to fall below ethanol values. This condition carried into 2021. By 2H2021, however, global demand for MTBE recovered, pushing the 2022 price well above that of ethanol. MTBE prices were also

[7] S&P Global Platt's quotations.

below ethanol in 2016, but only by $1.45 per barrel. The pricing inversion in 2016 was also related to weak petroleum prices.

The degree of savings generated by the blending of ethanol is related to the concentrations of the ethanol and MTBE. In countries where MTBE is utilized, concentrations are generally up to 10%. TM&C has compared the historical prices of blending 10% MTBE with ethanol grades of E5, E10, E15, and E20. The lower pricing of ethanol compared to MTBE would have reduced blended gasoline prices between $1.79 per barrel and $2.47 per barrel depending on the ethanol concentration and the grade of gasoline produced (Table V-1).

TABLE V-1

Reduction in Gasoline Costs - Ethanol vs. 10% MTBE, $/B

Ethanol Grades	91 RON
E5	1.79
E10	2.02
E15	2.25
E20	2.47

Because ethanol has a higher octane (130 RON) compared to MTBE (119 RON)[8], the gasoline subgrade which would be blended with each would have a lower required RON for ethanol than the subgrade for MTBE, except for E5. The value of the octane reduction can be measured by the difference in regular and premium Northwest European prices. The average price difference for each year divided by the octane difference would yield the historical value of one octane, as previously shown in Figure IV-3.

TABLE V-2

Reduction in Subgrade Octanes - Ethanol vs. 10% MTBE, RON

Ethanol Grades	91 RON
E5	-1.1
E10	1.2
E15	3.8
E20	6.6

The octane reductions shown in Table V-2 multiplied by the cost of octane displayed in Figure IV-3 will calculate the value of the savings in usage of ethanol compared to a 10% MTBE blend. These values are shown in Table V-3 for the last 10.5 years. Depending on the ethanol concentration and the grade of gasoline, the value of the improved octane ranges between -$2.21 per barrel and $11.67 per barrel.

TABLE V-3

Historical Octane Benefit - Ethanol vs. 10% MTBE, $/B

Ethanol Grades	92 RON
E5	-2.21
E10	2.42
E15	7.05
E20	11.67

As described in the previous section, Nigeria could derive substantial environmental benefits in blending ethanol. Ethanol blends would reduce sulfur, benzene, and aromatic levels while simultaneously reducing the cost of the gasoline. While ethanol blends would not reach Euro III gasoline qualities, they could provide a substantive step in that direction. By comparing these dilution benefits with that of 10% MTBE, TM&C assesses the financial savings at -$0.15 per barrel for E0, $0.00 per barrel for E10, $0.15 per barrel for E15 and $0.30 per barrel for E20. The E10

[8] *Cleaner Fuels for Latin America with MTBE and ETBE Advanced Gasoline Components*, LyondellBasell.

TABLE V-4

Cost Reductions of Ethanol vs. MTBE, $/B	
	Regular
E5	
Pricing Benefits	1.79
Octane Benefits	-2.21
Dilution Benefits	-0.15
Total Reductions	**-0.57**
E10	
Pricing Benefits	2.02
Octane Benefits	2.42
Dilution Benefits	0.00
Total Reductions	**4.44**
E15	
Pricing Benefits	2.25
Octane Benefits	7.05
Dilution Benefits	0.15
Total Reductions	**9.44**
E20	
Pricing Benefits	2.47
Octane Benefits	11.67
Dilution Benefits	0.30
Total Reductions	**14.45**

is assumed to have no improved dilution benefits as it is compared with a comparable 10% MTBE blend.

The total economic value of blending the various ethanol grades with 10% MTBE for the last 10.5 years are shown in Table V-4. The level of benefits ranges from -$0.57 per barrel to $14.45 per barrel.

VI. GLOBAL OCTANE REQUIREMENTS

As global efforts to reduce the production of greenhouse gases increase, one of the dominant pathways has been the improvement of fuel economies in the transportation fleet. If automobiles can travel farther on a gallon of fuel, then they will emit less greenhouse gases per mile traveled. As a result, government actions around the world have stimulated increased mileage requirements in new vehicle sales.

Auto manufacturers have adopted numerous methods to improve vehicle fuel efficiencies: such as lighter and more streamlined designs, more gear ratios, and engines which cut off when idling. One of the more significant methods of improving fuel mileage is the use of turbochargers. Automobile turbochargers have been around for decades but have only recently become mainstream. It represents one of the only methods to increase vehicle fuel economy and driving performance simultaneously, but at a higher vehicle cost.

When gasoline is combusted inside the engine cylinders, two actions occur. First, the hydrocarbon molecules are converted primarily to carbon dioxide and water vapor. Secondly, heat is generated by the combustion process. Much of this heat is transferred to the gases inside the cylinder which causes the gases to expand. The expansion of the gases causes the piston to move inside the cylinder which provides motion for the vehicle. One of the shortcomings of this process, however, is that only about half of the heat generated by combustion is absorbed by the gases and used to propel the vehicle. The remaining heat radiates out of the engine and is lost. The turbocharger is designed to capture part of this waste heat and improve the vehicle efficiency.

A turbocharger is simply a fan which routes a portion of the already combusted gases which otherwise would exit the vehicle through the tail pipe back into the engine. These exhaust gases enter the cylinders along with fresh air but are forced in at a higher pressure by the fan. The result is that there are more molecules of gases in the cylinder immediately before the spark plug fires than otherwise would be without the turbocharger. The greater number of gas molecules mean more heat will be absorbed during combustion and less heat will radiate out from the engine.

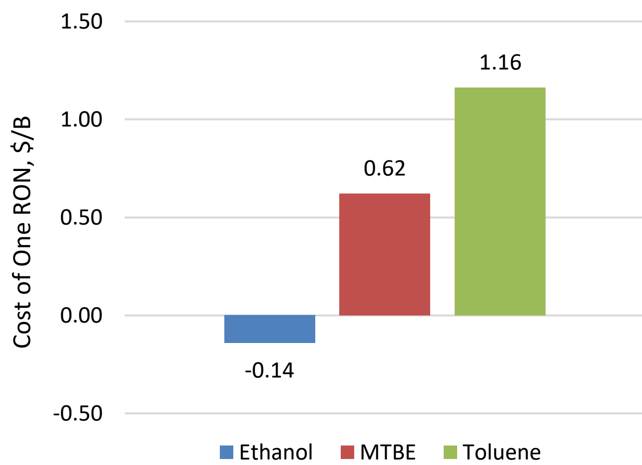
Because the engine operates at a slightly higher pressure due to the turbocharger, the engine will tend to knock easier. The solution to this issue is to provide a higher octane fuel which will resist the premature ignition. As turbocharged engines become more widespread around the world, global octane requirements are likely to increase. Most countries are already seeing this process occur.

Superchargers are the next step in the process and produce even greater efficiency gains. Instead of a fan, a supercharger utilizes a compressor to force more exhaust gases into the cylinder, causing the engine to operate at a higher pressure than a turbocharged engine. As a result, supercharged vehicles require even higher octane fuels.

In the last ten years, octane consumption has increased in many countries. In the U.S., the average octane in the gasoline pool has risen by 0.12 RON while Mexico has seen an increase of 0.5 RON. Indonesia has experienced a much larger increase of 2.0 RON due to the phaseout of its dominant regular gasoline of 88 RON being replaced by a new 90 RON fuel. While many factors are contributing to this process, it is clear that fuel efficiency gains are impacting global octane requirements.

One of the benefits of ethanol is that it represents the least expensive path to increase gasoline octane. In fact, during most years of the last decade, the addition of ethanol would have decreased gasoline production costs. Figure VI-1 is a comparison of the cost to increase a regular gasoline (90 RON) by one octane using ethanol, MTBE, and toluene based on average prices for the last 10.5 years[9]. The use of ethanol would have reduced the cost of the gasoline by $0.14 per barrel while MTBE would have increased the cost by $0.62 per barrel and toluene by $1.16 per barrel.

FIGURE VI-1
Relative Costs of Octane



[9] TM&C Octane Cost Analysis.

VII. GASOLINE MARKET OVERVIEW

Gasoline Market

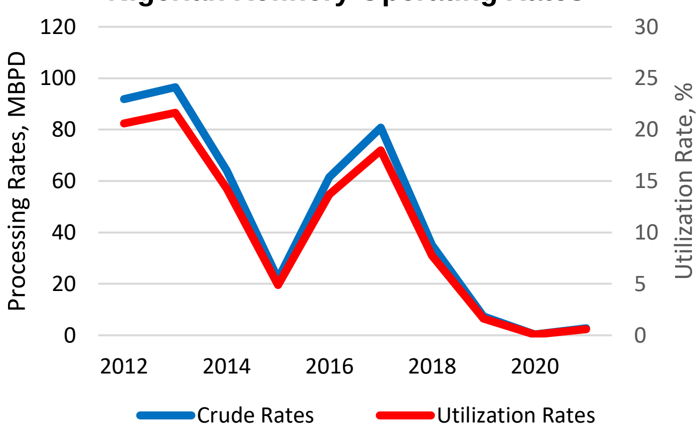
The refining history in Nigeria has had a troubled past. There are currently four larger facilities which have a combined capacity of 424 MBPD and four micro-refineries with a total capacity of 24 MBPD (Table VII-1). Unfortunately for the country, none of the larger plants are currently operating. As a result, virtually all the gasoline consumed in Nigeria is imported, primarily from Europe. The four larger refineries are owned and operated by the Nigerian government. These plants have moderate levels of catalytic cracking and hydrocracking capabilities but no coking capacities[10]. By African standards, these plants are of average size but have slightly higher than average processing complexities.

TABLE VII-1
Capacities of Nigerian Refineries

	MBPD
Kaduna	105
Port Harcourt 1	143
Port Harcourt 2	57
Warri	119
Micro-Refineries	
Ogbele	6
Edo	6
Ibigwe	5
Kwale	7
Total	**448**

The micro-refineries have been recently constructed and are privately owned and operated. It is likely that these facilities will experience significantly higher utilization rates than the larger, government-owned plants. All the refineries process indigenous Nigerian crude grades.

FIGURE VII-1
Nigerian Refinery Operating Rates



Despite the significant processing capacities, actual crude rates in Nigeria have been steadily declining (Figure VII-1)[11]. In 2001, crude processing rates were at 221 MBPD but have plunged in the last decade. The only crude oil being processed in recent years has been in the micro-refineries.

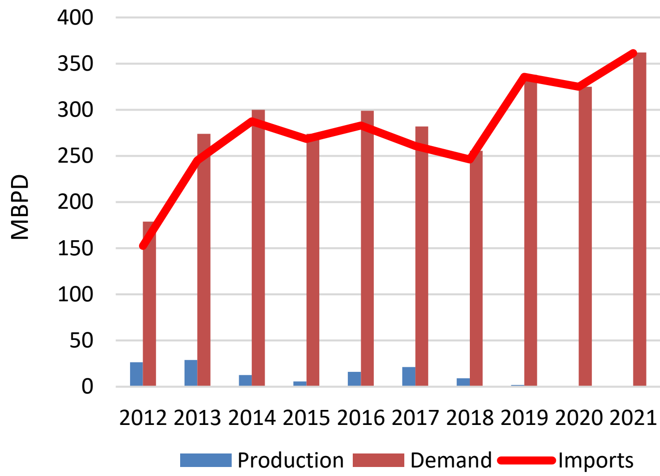
While the history of the Nigerian refining industry has been bleak, the future is much brighter. In 2023 the 650 MBPD Dangote refinery in

[10] Oil & Gas Journal, *Worldwide Total Refining Survey*
[11] *BP Statistical Review of World Energy.* June 2022.

Olokola is expected to start up which will dramatically alter the supply and demand balance for the country. The refinery will be the largest single-train refinery in the world and the largest facility in Africa by far. Being privately owned, the plant should experience a significantly higher utilization rate than the other large refineries in the country.

Gasoline demand in Nigeria has been increasing at a robust rate of 8.1% per year in the last decade (Figure VII-2)[12]. Because of the low level of domestic refining, gasoline imports have generally tracked consumption growth. While most countries experienced a pronounced decline in gasoline demand in 2020 because of the COVID-19 pandemic, the decline in Nigeria was more modest along with stronger growth in 2021.

FIGURE VII-2
Nigerian Gasoline Supply and Demand Balance



The reliance on imports will mostly end in 2023 with the start-up of the Dangote facility. This refinery should be able to produce around 300 MBPD of gasoline when it achieves maximum processing rates. This level of operations could supply approximately 75% of Nigeria's gasoline requirements.

Gasoline Specifications

The current year has been a tumultous period for Nigeria's gasoline supply with the Russia-Ukraine war causing gasoline prices to rise sharply. The Nigerian government has set limits on retail prices, however, which at times are below global spot prices. This has created periodic gasoline shortages which have led to reports of consumers waiting in lines up to eight hours at retail sites. When gasoline was unavailable, consumers often turned to black market sources which offered sales at market prices.

Compounding the supply problems, four gasoline cargos were received in the first half of 2022 which contained up to 20% methanol. There were numerous reports of engine issues, and the government is currently seeking damages from the fuel suppliers. Testing and governmental oversight of gasoline quallity is likely an ongoing issue for the country. TM&C has received four analyses of gasoline samples, all with sulfur levels in excess of the stated maximum of 150 ppm and all with octanes below the required minimums.

There is only one grade of gasoline available in Nigeria. This is a 91 RON regular. There are no premium gasoline sales in the country. The introduction of ethanol into Nigeria could present an

[12] Energy Information Agency, Nigeria.

economic opportunity to produce premium gasoline, although the current retail infrastructure is generally limited to only one underground tank per site.

The current gasoline specifications for the 91 regular gasoline are shown in Table VII-2.

TABLE VII-2

Nigerian Gasoline Specifications	
Grade	RON 91
Effective Date	Jul, 2017
RON, min	91
MON, min	81
Antiknock index (MON+RON)/2, calculated, min	86
Sulfur, ppm, max	150 (1)
Lead, g/l	(2)
Benzene, vol%, max	2.0
RVP @ 37.8°C (100°F), kPa, max	62.0
Density @ 15°C (60°F), kg/m3, max	780
Density @ 15°C (60°F), kg/m3, min	720
Distillations	
T50, °C, max	125
E70, vol%, max	10
E180, vol%, max	90
FBP, °C, max	210
Residue, vol%, max	2
Oxygen, wt%, max	0.2
Oxygenates	
Oxygenates, vol%	(3)
Methanol, vol%, max	Nil
Ethanol, vol%, max	Nil
Iso-butyl alcohol, vol%, max	0.2
Iso-propyl alcohol, vol%, max	0.2
Tert-butyl alcohol, vol%, max	0.2
Ethers (5 or more C atoms), vol%, max	0.2
Other oxygenates, vol%, max	0.2
Oxidation stability (Induction period), minutes, min	360
Sediment, wt%	Nil (4)
Water, vol%	Nil
Existent gum (solvent washed), mg/100ml, max	4
Copper corrosion, 3hr @ 50°C, merit (class), max	1b
Color	Ox blood red (5)
Appearance	Clear and Bright
Particulate contamination, size distribution	Nil
(1) 300 ppm sulfur gasoline will be imported from July 2018, followed by 150 ppm sulfur gasoline starting October 1, 2019. Local refineries have until 2021 to meet the new sulfur limit.	
(2) Max 0.0005 wt%	
(3) Every source of supply shall declare all oxygenates used in the Certificate of Quality	
(4) Suspended matter	
(5) Before distribution	

VIII. Glossary of Terms

AKI	Anti-Knock Index. The measure of a fuel's ability to resist premature ignition. The average of the fuel's Motor Octane Number (MON) and its Research Octane Number (RON).
Aromatic	Hydrocarbon molecule in a ring formation and a specified hydrogen to carbon ratio.
Barrel	42 U.S. gallons. Approxately 159 liters.
BPD	Barrels per day.
CBOB	Conventional gasoline before the addition of an oxygenate.
Cpg	U.S. Cents per gallon.
E0	Gasoline without ethanol.
E5	Gasoline which contains 5% ethanol.
E10	Gasoline which contains 10% ethanol.
E15	Gasoline which contains 15% ethanol.
E20	Gasoline which contains 20% ethanol.
Gallon	Approximately 3.79 liters.
G20	19 large, industrialized nations along with the European Union.
MBPD	Thousand barrels per day.
MON	Motor Octane Number. The gasoline octane when the engine is at a full throttle or high speed.
MTBE	Methyl tertiary-butyl ether. A common gasoline oxygenate.
Olefin	Hydrocarbon molecule in a chain formations deficient in hydrogen.
RBOB	Reformulated gasoline before the addition of an oxygenate.
RON	Research Octane Number. The gasoline octane when the engine is at a low speed.
RVP	Reid Vapor Pressure. A measurement of the volatility of gasoline.
TM&C	Turner, Mason & Company.
USGC	U.S. Gulf Coast

IX. TM&C QUALIFICATIONS

Founded in 1971, TM&C provides technical, commercial, and strategic consulting services to worldwide clients in the crude oil, midstream, refining, refined products, and biofuels industries. For nearly 50 years, we have undertaken various single and multi-client consulting engagements along with research products covering crude oil, feedstocks, refining, and refined products outlooks. Our core competencies include individual refinery, company and refining industry studies, technical and commercial support in mergers and acquisitions, transaction due diligence, economic, feasibility and market analyses, expert witness as well as attestations and fuels regulatory support.

TM&C has had an active involvement in fuels studies in the U.S. and international markets for almost five decades. Such studies have included engagements with industry associations, governmental agencies and with individual companies and multi-client subscribers. The following is a summary of relevant past studies and engagements.

<u>Representative Past Study Team Fuels Engagements</u>

Mexico Fuel Ethanol Cost-Benefit Analysis Study
U.S. Grains Council, May 2020

Mexico Downstream Refining, Midstream, and Retail Offering
Multi-Client Study, October 2019

Energy Reform under AMLO
Mexico Energy Intelligence, June 2018

Outlook for Gasoline Pricing in Mexico
Industry Forum Presentation, April 2017

Mexico Export Market Opportunities for US Gulf Coast Refiners
Multi-Client Study, October 2016

Reformulated Gasoline Survey Association, 2000-Present
TM&C provides QA/QC Oversight to the National Program at Retail Stations & Labs

95 RON Gasoline Study
American Fuel & Petrochemical Manufacturers, 2016-Present

Independent Engineer Reviews of International Biofuels Facilities – Ongoing since 2010
Provide IE Reviews of Facilities for Registration with US EPA

Gasoline Octane Screening Study
American Fuel & Petrochemical Manufacturers, February 2014

Impact of the Energy Reform on Mexico's Refining Industry
Presented at Oil & Gas conference, May 2014

Economic and Supply Impacts of a Reduced Cap on Gasoline Sulfur Content
American Petroleum Institute, February 2013

Potential Tier III Gasoline/Lower Aromatics and Increased Octane – An Analysis of Economic and Supply Implications
American Petroleum Institute, 2011/ 2012

Ultra-Low Sulfur Diesel Planning Study/Survey
Multi-Client Study in conjunction with Colonial Pipeline, 2004/2005

Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel
American Petroleum Institute, February 2000

Initial Ballpark Assessment: CARB 3 RFG Potential Regulations and MTBE Ban
Western States Petroleum Association, November 1999

Costs of Potential Ban of MTBE in Gasoline
Lyondell Chemical Company, April 1999
Presented to EPA Blue Ribbon Panel on MTBE

Saudi Aramco, Two Major Studies, 1990s
Optimization of Fuels Distribution in The Kingdom

Review and Critique of the Economics Portion of "Health and Environmental Assessment of MTBE" University of California at Davis – November 1998
Oxygenated Fuels Association, December 1998

Reformulated Gasoline Study
New York State Energy Research and Development Authority, October 1994

U.S. Petroleum Refining: Meeting Requirements for Cleaner Fuels and Refineries
National Petroleum Council, August 1993
Modeling performed by TM&C

Alternate Gasoline Formulation Costs: Results of U.S. Refining Study
Economics Committee of the Auto/Oil Air Quality Improvement Research Program, April 1992

Cost Impacts of Potential CARB Phase 2 Gasoline Regulations

Western States Petroleum Association, November 1991

Reformulated Gasoline: The Impacts on Related Industries
Multi-Client Study, August 1991

Future Reformulated Gasolines, WSPA/CARB/GM, RVP/Drivability Index Emissions Testing Program
Western States Petroleum Association, August 1991
Developed the gasoline blends used in the test
U.S. Gasoline Outlook 1989-1994: Changing Demands, Values and Regulations
Demands, Modeling and Values – TM&C
Multi-Client Study, 1989

API Screening Study of Reformulated Gasoline
American Petroleum Institute, December 1989

U.S. Gasoline RVP Reduction Capabilities and Costs
American Petroleum Institute, November 1987

U.S. Gasoline Production Capabilities and costs
Multi-Client Study, November 1986

U.S. Petroleum Refining Capabilities
National Petroleum Council, October 1986
Modeling performed by TM&C