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Refinery Modeling for Argonne National Laboratory

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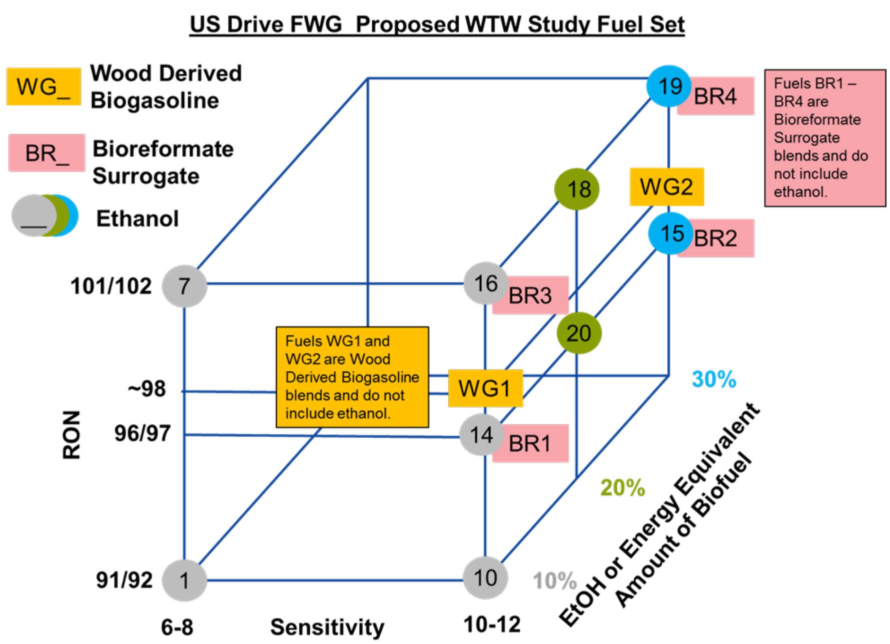
Contents

Executive Summary

With support of the U.S. Department of Energy, Argonne National Laboratory is conducting a comprehensive well-to-wheels (WTW) analysis for the Fuels Working Group (FWG) of US DRIVE — a partnership between the US government and auto and energy industries — to examine energy and GHG effects of producing fuels with higher octane ratings produced with various gasoline blending stocks and renewable blending components for use in vehicle engines developed for the new fuel properties. Understanding changes to petroleum refining activities to produce such fuels is key to this WTW analysis. Linear programming (LP) modeling is an appropriate technique for simulating these activities. Jacobs Consultancy was retained to design and conduct various LP modeling cases with its proprietary LP model.

Figure 1 depicts the cases analyzed, with each dot representing a case (from the Fuels Working Group of the US DRIVE).

Figure 1. Case Matrix

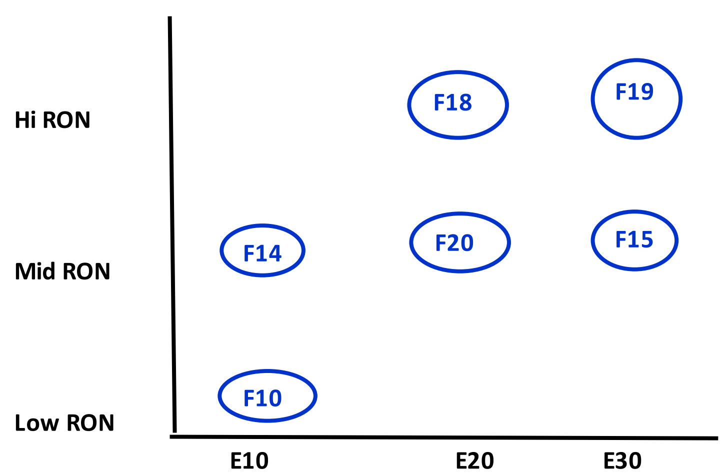


Gray dots assume 10% ethanol by volume, green dots represent 20%, and blue dots represent 30%. The squares indicate the specification for the three Biofuel blends.

The X axis, as drawn above, indicates two sensitivity levels — that is, the difference between RON and MON. As the LP modeling work progressed, it was decided that having a "hard" specification for MON with low sensitivity cannot be achieved in a practical way. In some cases, the model showed significant RON giveaway. Other cases were infeasible as a result of the “hard” MON specification. The FWG decided that MON was not as important as RON and the “hard” MON portion of the study was relaxed. The MON spec for all cases was today’s minimum specification of 82. This decision does impact the results. Ethanol has a very high research octane — between 130 and 150 RON depending on the blend — but a much lower MON, circa 99. Thus, minimizing the impact of MON makes ethanol even more valuable as a high octane fuels (HOF) blend component.

If we rotate the above figure and eliminate the biofuel blends and low sensitivity cases for now, a portion of the study reduces to an ethanol/octane evaluation.

Figure 2. Study Cases for Ethanol



All other gasoline specifications such as RVP, distillation, and driveability adhere to the incumbent regulations. All LP cases were “summer only” specifications, with RVP being the major difference between summer and winter. In the winter, the addition of butane (which has high octane) makes formulation of high octane fuels easier and would not test the ability of the industry to make HOF.

Overall Results

At a high level, there are three octane cases:

- Current, circa 91/92 RON
- Mid HOF, 96/97 RON
- High HOF, 101/102 RON.

There are likewise three ethanol levels: 10, 20, and 30%. Clearly, higher levels of ethanol are only needed for higher HOF production – that is, there is no low RON, E20 case. Cases were developed for 2022, in which 50% of gasoline met the higher octane specification, and 2040, in which 100% HOF is produced. We find:

- At the current 10% ethanol requirement and gasoline specifications, the refining industry, on average, does not appear to be significantly octane constrained. In most refineries, the unit with the highest ability to vary octane is the catalytic reformer, either by adjusting throughput or severity. Our modeling shows a higher cost of octane production for California versus the other regions analyzed.
- Gasoline sold in California must meet CARB specifications and formulations, which are generally more rigorous than the rest of the country. Aromatics content is limited and the gasoline is lower boiling (i.e., lighter). As a result, California refiners have less flexibility than the rest of the United States and would find production of HOF more challenging
- Some refineries will struggle when raising octane to mid HOF with 10% ethanol. California refiners, in particular, would be challenged more than PADD 3 as a result of tighter specifications. Obviously, 2040 is more difficult than 2022.
- Increasing ethanol to 20% makes mid octane HOF production relatively achievable. In these cases, the refinery sourced octane requirement is about the same as the E10 low octane case. This is because the incremental octane from additional ethanol tends to reduce the requirement from refinery sourced octane
- The internal refinery sourced octane requirements for E10 mid octane and E20 high octane are similar. Reformer severity increases by about 5 numbers. This is feasible in some refineries, while other will struggle.
- Adding 30% ethanol makes the high octane HOF feasible with reasonable operations, although high exports are expected under the US demand assumptions. Adding 30% ethanol to the mid HOF cases results in octane giveaway for RON, so 30% is more than needed for mid-RON.

Ethanol is a good blendstock for high octane, especially RON. Even using the low end of ethanol's RON blend range, the material is 40 numbers higher than the current gasoline sold, illustrating that the addition of ethanol clearly increases the overall gasoline RON. The fact that we are keeping volume constant for domestic sales provides even more capability. Not only does the ethanol material add octane, it adds volume, making it possible to reject low octane stocks into other markets (e.g., gasoline exports). One of the negative attributes of ethanol is high RVP. At 10% ethanol, there is a 1 psi RVP "waiver" to manage the E10 blending. However, in this Study any blends above E10 do not have a 1 psi waiver.

Two "biofuel" products (i.e., bio-reformate and woody gasoline) were evaluated as possible gasoline additives in lieu of ethanol. (That is, these cases assumed no ethanol.) After developing and analyzing six cases, both biofuel blending stocks were found to be poor candidates as additives.

- Bio-reformate has excellent octane blending quality and low RVP, both valuable to the gasoline pool. However, Bio-reformate is essentially 100% aromatics, which have high boiling points, negatively impacting distillation specifications and Drivability Index (DI). The DI blending impact from bio-reformate is approximate 1,670 compared to a gasoline specification of 1,250. The distillation specification in California is even more rigorous than the rest of the United States.
- Woody gasoline has low RON blending quality at 87.3 and poor RVP at 12.2 psi. These poor blending qualities negatively impact the gasoline pool and limits its inclusion in a HOF scenario.

Regarding US Gasoline Demand

The assumption that gasoline demand will fall in the United States, which is based on a recent EIA forecast, is an important parameter in our Study.

Table 1 shows the barrels of petroleum derived hydrocarbon (i.e., not ethanol) required in gasoline pool for 2015, 2022, and 2040.

Table 1. Hydrocarbon Barrels Required, MMBPD

Ethanol	2015	2022	2040
10%	6.38	5.99	4.75
	Delta vs 2015	(0.39)	(1.63)
20%		5.66	4.23
	Delta vs 2015	(0.72)	(2.16)
30%		5.33	3.70
	Delta vs 2015	(1.05)	(2.68)

In 2015, total domestic gasoline production in the areas of the country that were modelled (which represent 85% of US refinery capacity) was 7.09 MMBPD. The 6.38 MM barrel figure is 90% of the total. In the 10% ethanol case, demand for gasoline falls 25% over the period of interest. Adding ethanol to 20% and 30% of the blend further reduces the petroleum-derived requirement by 40% (or over 2.5 million barrels) in 2040. The drop in total demand makes it easier to produce high levels of HOF since lower octane blend stocks (e.g., light straight run) can be eliminated from the pool for US gasoline blending.

Aggregated versus Configuration Models

As discussed in detail in this report, Jacobs Consultancy used two modelling approaches in our work: Aggregated PADD (Petroleum Administration for Defense Districts) models and configuration models. *Aggregated models* effectively assume that the refinery is one big system with the capability to transfer streams between refineries within the PADD. This ability can lead to over optimization and generate solutions that may not be viable. *Configuration models* assume a single refinery with a “typical” configuration. There are 3 configurations with varying degrees of complexity and capability incorporated in this analysis. The configuration models do not portray any specific refinery, but the set of configuration models does portray the range of refineries in each PADD.

From a modeling standpoint, the intent is for the PADD models and configuration models to provide reasonably consistent answers and to determine whether policies may impact one class of refinery much more than another. As would be expected, the configuration models became infeasible more frequently than the PADD models, indicating that some refineries may be challenged in meeting the specifications.

Capital Analysis

Capital analysis was performed on E10 mid RON and E20 high RON, which were chosen because these runs are challenging in terms of compliance. The analysis is performed on the PADD 3 model, and is not intended to represent the range of capital, reconfiguration, or operational alternatives available to all refiners.

Generally speaking, we find that C4 alkylation is a preferred method to boost refinery-sourced octane. Incremental reformate will improve the refinery octane position, but the heavy aromatic characteristic tends to ultimately challenge distillation blending specifications. C4 alkylation requires incremental C4 olefins and Isobutane feed, which could be sourced through operational adjustments or capital spending.

The range of operational and capital scenarios will vary by location, including but not limited to:

- Improved fractionation and segregation of intermediate streams
- Access to pipelines and infrastructure (ex: Isobutane feed)
- Access to export markets (ex: naphtha sales)
- Summer/Winter operations (ex: inventory summer naphtha, blend off in winter)
- Reformer Operations (ex: design and severity range)

1. Introduction

Driven by the global effort and domestic regulations to curb greenhouse gas (GHG) emissions, automakers, energy companies, and policymakers are making concerted efforts to identify and produce appropriate transportation fuels to power vehicles more efficiently and thereby reduce petroleum use, GHG emissions, and other air pollutant emissions. One approach is to blend renewable fuel components to increase gasoline octane ratings to gain engine fuel efficiency. These changes, along with the crude supply and production slate changes, can lead to significant changes and/or pose challenges for petroleum refinery operations.

With support of US Department of Energy, Argonne National Laboratory is conducting a comprehensive well-to-wheels (WTW) analysis for the Fuels Working Group (FWG) of US DRIVE — a partnership between the US government and auto and energy industries — to examine energy and GHG effects of producing fuels with higher octane ratings produced with various gasoline blending stocks and renewable blending components for use in vehicle engines developed for the new fuel properties. Understanding changes to petroleum refining activities to produce such fuels is key to this analysis. Linear programming (LP) modeling is an appropriate technique for simulating these activities. Jacobs Consultancy was retained to design and conduct various LP modeling cases with its proprietary LP model. Modeling results include changes in energy balance and mass balance for several US refinery configurations. Argonne will incorporate the simulated petroleum refinery impacts from Jacobs Consultancy into WTW Analysis for the fuels under consideration.

2. Project Assumptions

2.1 Refinery LP Modeling Approach

A wide variation exists among different refinery operations in the world. Some operations are designed to process heavy crude and have high complexity to achieve the conversion of heavy crudes into light products (LPG, gasoline and diesel). Other refineries have lower complexity and tend to process lighter crudes to achieve the production of light products and may have significant production of heavy products (fuel-oil and bunker fuels). The types and combinations of different operations in a refinery is often called the refinery configuration. Additionally, there are other considerations that affect the product distribution from a refinery other than configuration. Some of these factors include the prices of feeds and products, supply and quality of feeds (primarily crude oils).

Refinery products such as gasoline are a mixture of intermediate streams of varying volume and quality blended to produce the desired amounts with target specifications. The volumes and qualities of these intermediate streams are a function of the configuration, type of feedstock and operating conditions of the process units. Optimization of the refinery operations is a major challenge due to the multiple combinations of feedstocks, product requirements and flexibility of the operating units, and complex interactions between all of these factors.

In the refining industry, the most common tool for establishing the operating conditions is the Linear Program or LP model. The LP model represents the complex operations and interactions within the refinery in a mathematical model, it calculates the production costs and associated revenues and provides a solution that maximizes (optimizes) profit for a given set of inputs and constraints. The LP model establishes the operating conditions for the facility or maximum profit by using input feed and product prices, feedstock qualities, product specification blending requirements, and unit operating limits, among other factors. Outputs from the model include the overall margin and the estimated production, utility requirements (fuel gas, electricity, stream, and natural gas), product blending recipes, operational strategies, and a complete feed and product material balance of the system.

Specific to the production of gasoline; there are many parameters to optimize the refinery to meet octane specification. The refinery has flexibility to produce more or less of an intermediate product, and the intermediate product can have higher or lower octane depending on the operation. For example, a refinery can reduce reforming severity to produce lower octane reformate for blending and run a fluid catalytic cracking (FCC) unit at higher severity to produce a higher octane FCC naphtha for blending. Each of these strategies has an associated cost (or savings). The LP model will determine the optimal response for octane while taking all the other refinery operating parameters into consideration.

In this study we use the LP as the tool of choice to predict refinery performance for different scenarios, because it represents what the industry will most likely do to look for the operations that will yield the maximum economic margin.

2.1.1 Representation of the US Refining Industry in the Model

Representation of the refining industry in a model is a challenge. There are generally three types of modeling strategies incorporated:

Specific Refinery Location. This approach includes developing a specific LP model for each refinery in the region under consideration. In the United States, this would require the development of over 100 unique refinery LP models. This strategy can isolate unique operations at the refinery level since publicly available data would be used to develop the LP models. In reality, at the refinery level, there are many operating details that will not be captured due to confidential business operations. The resource requirement to develop individual models is significant. This study did not incorporate modeling of individual refineries.

Configuration Modeling. With this approach generic configurations are developed that represent the types of operations within the region under consideration. These are generally characterized as Cracking (CRK) and Coking (COK). This distinction is made because of wide differences in operations. Cracking refers to the Fluid Catalytic Cracking (FCC) and does not have a Delayed Coker. Consequently, there is no bottoms upgrading and the configuration tends to process lighter crudes and produces residual fuel oil. Coking (COK) — which also has an FCC in the configuration — processes heavier crude and has minimal production of residual fuel. A further delineation can be made to the COK configuration based on the type of crude to the refinery [either light (LT) or heavy (HVY) crude], establishing two different coking configurations: LTCOK and HVYCOK.

Two other configurations include Topping and Hydroskimming, but the number of these configurations and the volume of crude processed by these in the United States are very small compared to the CRK and COK. Topping and Hydroskimming refineries have no conversion capabilities such as FCC cracking or coking The throughput capacity of Topping and Hydroskimming refineries is less than 5% of the total US capacity.

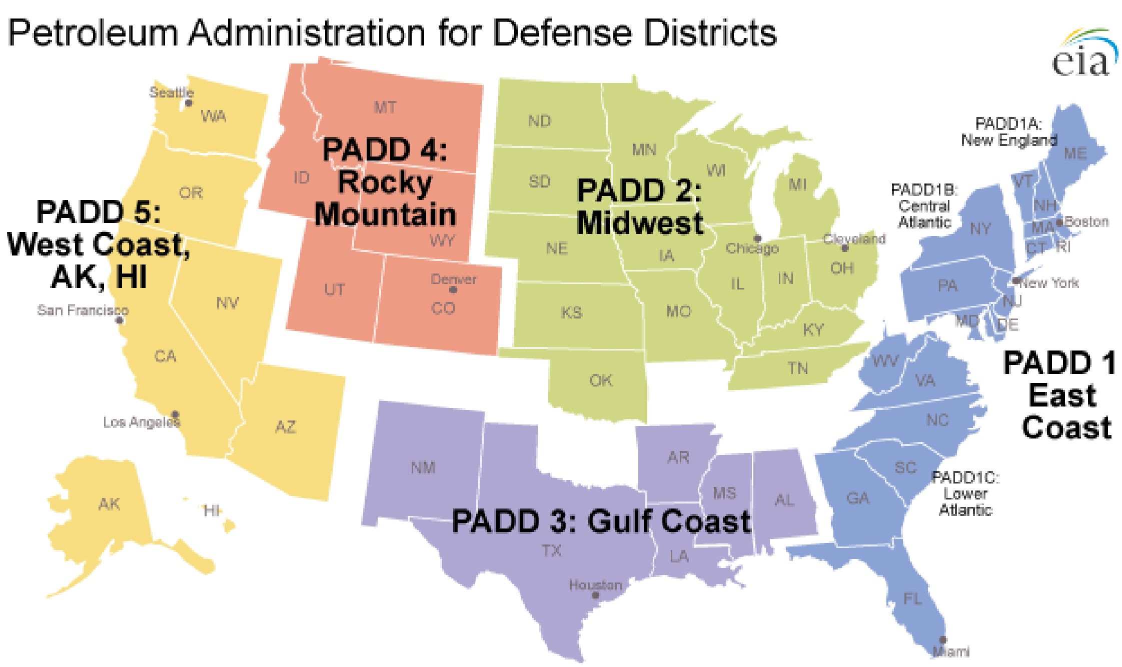
Each of the configurations represents a different set of crude feed, quantity and quality of intermediates, and operations. As such, each HOF scenario has different responses for each configuration. Some refineries purchase and sell intermediate streams which could potentially impact operations, but would be very specific to a location. For example, while it is well known that some refineries purchase FCC feeds or sell naphtha products, the configuration models intentionally do not adopt this structure because of the uncertainty of these strategies for specific locations.

Aggregate Modeling. Also called *regional modeling*, this is a methodology representing the total refining operations of a region in aggregate. This is done by combining the individual refineries of the region into a single "aggregate" model. The capacities of all the process operations for the region are volumetrically summed to create the aggregate refinery. For example, if the crude capacities of three refineries A, B, and C are 100, 150, and 200 MBPD, the crude capacity for the aggregate (A+B+C) is 450 MBPD.

One advantage of aggregate modeling is the model can be calibrated to reported data. For this US-based study, the reported basis for refinery operations and refined products production is publicly available, provided by the Energy Information Agency (EIA). The EIA data is provided at the PADD level.

The PADDs are geographic aggregations of the 50 states and the District of Columbia into five districts, as depicted below.

Figure 2-1. Petroleum Administration for Defense Districts (US EIA 2014b)



2.2 Project Assumptions

2.2.1 Modeling Basis for the Study

There are benefits to each type of modeling strategy, and each provides unique insight to the analysis. This study incorporates a combination of configuration and regional modeling. The regional modeling effort includes: PADD 2, PADD 3, and the State of California. The combination of these regional models represents 85% of US refining capacity. PADD 3 is the largest PADD in the U.S. at 53% of the United States, followed by PADD 2 at 22% (2015 Oil and Gas Journal data)

Table 2-1. US Crude Throughput (2015)

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 Exclude Cal	California	Total
Crude	1,121	3,561	8,531	602	695	1,696	16,207
Pct of USA	7%	22%	53%	4%	4%	10%	100%
PD2+PD3+CAL	85%						

For this Study, four generic refinery configurations were developed in addition to the PADD models to represent the different US operations. As such, we utilized the following seven models (three regional and four configuration) in different combinations for the various scenarios of the Study:

- PADD 2: P2
- PADD 3: P3
- California: CA
- Fluid catalytic cracking (FCC) no coking refinery configuration: CRK
- Coking refinery processing light crude configuration: LTCOK
- Coking refinery processing heavy crude configuration: HVYCOK
- California Configuration: CAL FIG

2.2.2 Years for Representation

The years for the study are 2022 and 2040. Each year has a base case, which produces E10 gasoline with no HOF. Each Year then has the HOF scenarios. With a base case and scenario case, the results can be analyzed on a differential basis by comparing the scenario to the base.

In 2022, HOF production is 50% of the total US gasoline production (by volume); in 2040, 100%.

Prior to the development of the future 2022 and 2040 models, there was a calibration step for the regional models, developed and based on EIA refinery production data for 2015. California production data was provided by the California Energy Commission. The calibration ensures that the LP model is a reasonable representation of the aggregate PADD production and operations.

2.2.3 Crude Basis for the Study

The crude slate basis initiates with a company-level analysis of 2015 crude imports, which includes crude API, sulfur, country of origin, destination to United States, and volume. We characterize each crude shipment according to its density (light, medium, or heavy) and its sulfur content (sweet or sour). The designations are Light Sweet (LTSWT), Light Sour (LTSWR), Medium Sweet (MDSWT), Medium Sour (MDSWR), Heavy Sweet (HVYSWT), or Heavy Sour (HVYSWR). Within these groupings we assign representative crude for the category (e.g., a HVYSWR designation from Mexico is characterized as Maya).

The EIA crude import data, combined with our domestic crude allocation, provides a realistic characterization to the overall crude API and Sulfur reported by the EIA.

We assess the imports and domestic crudes in specific types and normalize the volumes to match the actual reported crude characterization. The number of individual crudes run in the models for this study ranges from 5–9. In this report and in the table below, we provide the crude characterization by category, but the actual modeling includes specific crudes.

Going to the future years, crude characterization is assessed primarily by our estimates across data sources, as we are not aware of actual crude characterization forecasts reported to the fidelity of PADDs. Table 2-2 shows the crude characterization for the regions.

Table 2-2. Crude Characterization by Region

	PADD 2			PADD 3			CALIFORNIA		
	2015	2022	2040	2015	2022	2040	2015	2022	2040
LTSWT	53.6%	34.9%	33.2%	27.8%	30.6%	30.0%	0.0%	0.0%	0.0%
LTSWR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	21.6%	23.2%	21.1%
MDSWT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	28.5%	20.2%	15.9%
MDSWR	8.0%	2.4%	2.3%	26.8%	26.4%	16.0%	7.6%	9.1%	10.0%
HVYSWT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HVYSWR	38.4%	62.7%	64.5%	45.4%	43.0%	54.0%	42.3%	47.5%	53.1%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
API	33.2	28.8	28.4	31.6	32.3	30.7	26.9	26.3	25.5
SUL	1.6	2.2	2.2	1.9	1.8	1.9	1.5	1.6	1.6

Table 2-3 shows the crude characterization for the configuration models, for which the crude slate is held constant across the years.

Table 2-3. Crude Characterization by Configuration Model

	CONFIGURATION MODELS			
	CRK	LTCOK	HVYCOK	CALIF
LTSWT	85.0%	34.0%	15.0%	0.0%
LTSWR	0.0%	0.0%	0.0%	20.0%
MDSWT	0.0%	0.0%	0.0%	40.0%
MDSWR	15.0%	9.0%	20.0%	0.0%
HVYSWT	0.0%	0.0%	0.0%	0.0%
HVYSWR	0.0%	57.0%	65.0%	40.0%
TOTAL	100.0%	100.0%	100.0%	100.0%
API	42.6	31.3	26.2	27.1
SUL	0.4	2.0	2.8	1.3

Once the crude slate is established, a ratio (of crude mix) is developed for each year and each model. These ratios must be maintained, and while a model can optimize with more or less crude throughput, the ratios do not change. This is intentional, as we do not intend the study results to be based on crude slate re-optimization under different HOF scenarios.

2.2.4 Product Specifications

The models are developed to produce "clean" fuels, with the following specifications:

- All diesel is ultra-low-sulfur diesel (USLD) with 15 ppm sulfur content
- All gasoline sulfur content conforms to Tier 3 specification of 10 ppm
- All gasoline benzene is Mobile Source Air Toxics (MSAT) compliant (0.62 volume pct)
- Reformulated gasoline (RFG) summer RVP of 7.0 psi
- E10 RVP has 1 psi waiver
    - Summer: PADD3 = 9.0 psi and PADD2 = 10.0 psi (includes waiver)
- Future E20 and E30 do not have waiver
    - Summer: PADD3 = 8.0 psi and PADD2 = 9.0 psi

- California gasoline is regulated by CARB specifications and formulations, which are generally more rigorous versus the rest of the country. For example, California gasoline has lighter distillation than the rest of the country which impacts the amount of heavy components such as reformate to the pool

Regional specifications are developed for each model, so that a distinction is made on gasoline specifications for PADD 2 vs. PADD 3 vs. California.

The configuration models have the following additional representations that reflect typical refinery operations:

- Jet fuel production can range from 8%–12% of crude
- Premium gasoline production set to 11%
- RFG production at approximately 20%
- G/D Ratios consistent with EIA projections

Export gasoline production is allowed for HOF scenarios. Once the base case production is determined, all future incremental gasoline production is limited to the base case. Exported gasoline is specified as "typical" quality for Latin America (Mexico) with 30 ppm sulfur, 1.0% benzene, 35% aromatics, 12.5% olefins, 87 (R+M)/2 and summer RVP of 8.0. When exported gasoline is produced, the price is discounted compared to conventional gasoline. It should be noted that this study is not an economic supply/demand analysis on the impact of incremental gasoline, or HOF scenarios, on the World market. EIA prices are held constant throughout the study for the specific years of the study. Exported diesel quality is consistent with US ULSD specifications.

The LP models calculate Driveability Index (DI), defined as:

$$1.5*T10 + 3*T50 + T90 + 2.4*Alcohol\%.$$

This is standard for grades of gasoline at 10% ethanol. At higher blends of ethanol, there are terms (higher than the 2.4*Alcohol in the above equation which have been developed and published, but not ASTM specification. It was decided to use the 2.4 term for all ethanol blends.

2.2.5 Pricing Assumptions

The study's pricing basis was derived from EIA's Long-Term Outlook. The study results are relatively independent of price because the material balance from the refinery operations is held to forecasted production levels with allowable tolerances. That is, if the production requirement of a product is "100 BPD," the models have to produce the "100 BPD" regardless of the price. Tolerances are generally held to approximately +/- 3%.

If EIA data was not provided, empirical estimates were used to provide reasonable price data. Table 2-4 below highlights key refined product prices and basis. The price set is deemed a US average price set, which is used for all models.

Table 2-4. Key Product Prices and Basis

	UNITS	Basis	2015	2022	2040
Marker Crudes					
WTI (USGC)	$/Bbl	**EIA**	48.7	78.7	129.1
Brent (USGC)	$/Bbl	**EIA**	54.3	86.7	138.2
Refined Products					
Natural Gas	$/MMBtu	**EIA**	2.6	4.4	4.9
Normal Butane	¢/gal	Empirical	100.3	119.5	170.6
Isobutane	¢/gal	Empirical	105.2	125.3	178.9
Propane	¢/gal	**EIA**	111.8	148.8	192.9
Propylene	¢/gal	Empirical	170.0	202.5	289.1
Naphtha	¢/gal	Empirical	183.4	218.4	311.9
CG Reg	¢/gal	**EIA**	187.9	223.8	319.6
CG Prem	¢/gal	Empirical	205.8	245.0	349.9
RBOB Reg	¢/gal	Empirical	192.0	228.6	326.5
RBOB Prem	¢/gal	Empirical	209.8	249.8	356.8
Jet Kerosene	¢/gal	**EIA**	146.7	224.9	360.6
Low S Diesel	¢/gal	Empirical	165.1	232.8	368.3
No. 2 Oil	¢/gal	Empirical	162.1	228.5	361.5
Ultra-Low Sulfur Diesel	¢/gal	**EIA**	167.2	235.8	373.0
1.0%S Resid	$/Bbl	Empirical	42.4	82.4	129.3
3.0%S Resid	$/Bbl	Empirical	39.5	76.8	120.5
Technical Indicators					
3-2-1 Brent (USGC)			23.1	10.7	5.9
3-2-1 WTI (USGC)			26.8	16.7	13.0
5-3-2 Brent (USGC)			22.4	10.9	7.2
5-3-2 WTI (USGC)			26.1	16.8	14.3

2.2.6 Production Assumptions

The models are initially calibrated to actual reported 2015 operations in the United States. For regional modeling, this includes reported data for PADD 2 and PADD 3. EIA reports PADD 5, but our requirement is for California. California Energy Commission reports California data, although in less detail than the EIA.

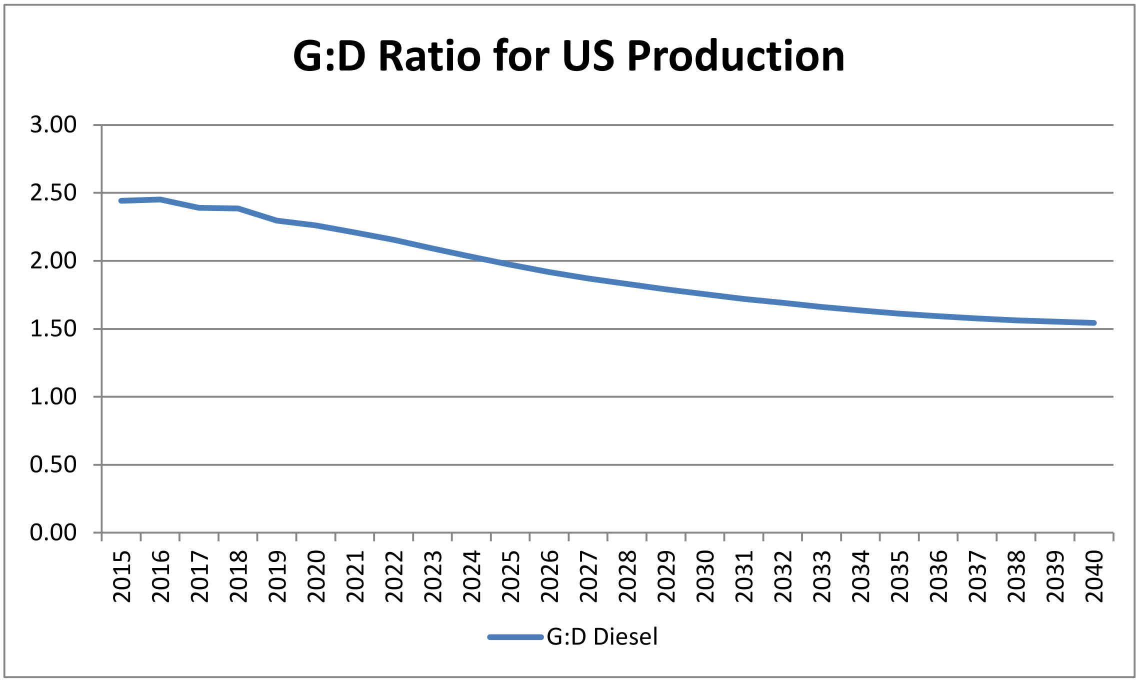
The EIA Long-Term Outlook reports US demand for major refined products supplied, from which growth rates can be calculated, as shown below:

Table 2-5. Product Grown Rates

Products Supplied	2015-2022	2022-2040
	Annual Growth Rate	
Crude	0.14%	0.34%
Natural Gas Plant Liquids	3.11%	1.23%
Unfinished Oil Imports	-0.82%	-1.61%
Motor Gasoline	-0.89%	-1.28%
Jet Fuel	0.47%	0.87%
Distillate Fuel	1.24%	0.43%
Residual Fuel	-0.40%	0.48%
Other Products	1.13%	1.20%

Critical to this study is the change in motor gasoline and distillate fuel demand. For the years under study, US motor gasoline demand is projected to drop while diesel fuel grows. This translates to a steady reduction in the G:D ratio shown below. Keep in mind that this is for US demand. The models are developed to produce “US” gasoline and diesel, and have an export production. This applies primarily to PADD 3, which is a significant exporter.

Figure 2-2. USA G:D Ratio



Once the 2015 models are calibrated, the EIA annual growth rates are applied to these calibrated results. The same production growth rates are applied to all of the models. For example, if 100 BPD is a calibrated data point in a 2015 model, and the EIA growth is 10% from 2015 to 2022, the base point for 2022 becomes 110 BPD.

2.2.7 Configuration and Operating Assumptions

The refinery configuration basis for regional models is the aggregate of *Oil & Gas Journal's* refinery configuration database for the region. The term “capacity creep” reflects that the refining industry capacity steadily increases in throughput. Going into the future, a 0.5% capacity creep is applied to the configurations, reflecting that new construction, reconfigurations, and upgrades have expanded US refining throughput without the construction of a new “grass-roots” refinery. From 2000 to 2016, annual refinery crude throughput has “crept” at approximately 0.7%, supporting our creep assumption.

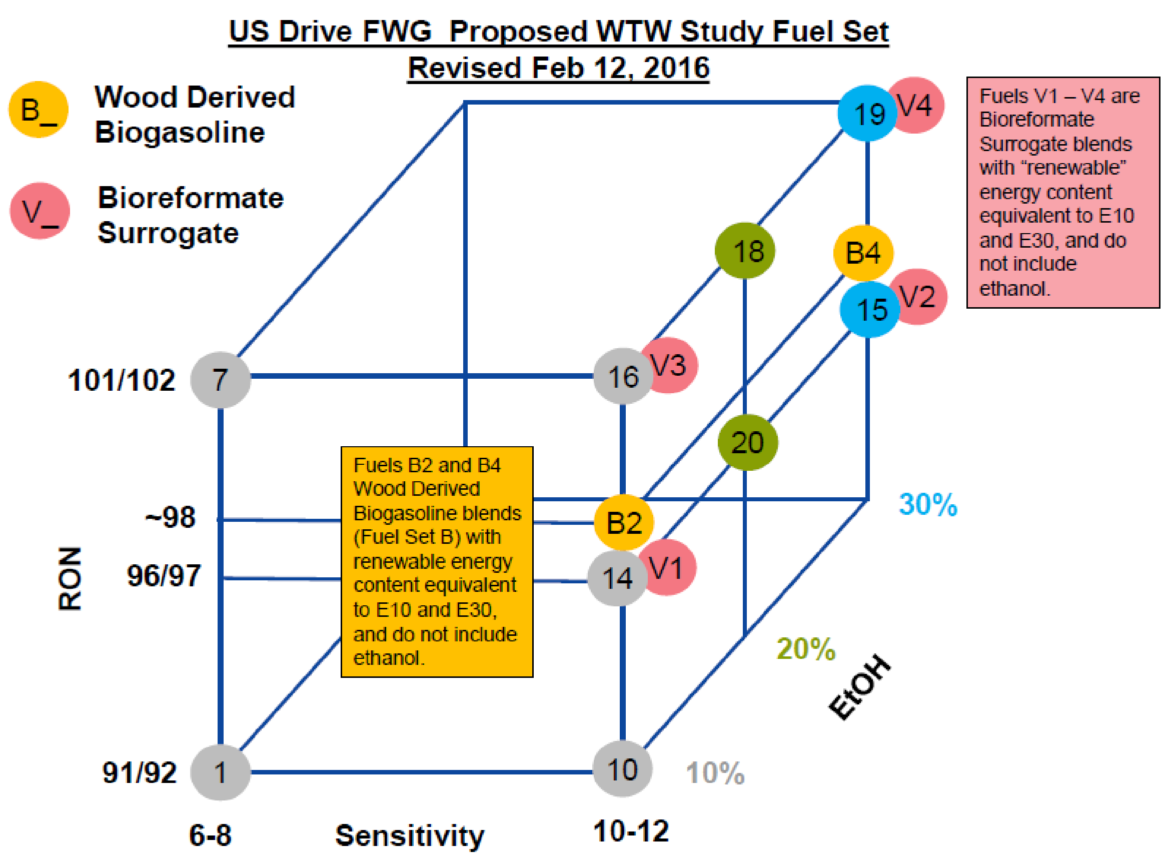
For the configuration models, representative models are developed with process units consistent with a typical configuration to process the crude slate applied to each model. The key distinction by far is whether the model has a coker (A delayed coker is used in this study, consistent with U.S. majority refineries). CRK models do not have a coker. The LTCOK, HVYCOK, and CALFIG all have cokers. Additionally, the HVYCOK and CALFIG have hydrocracking.

For each case, the LP model is allowed to optimize the refinery system operation while maintaining the refinery production material balance for each region and year. Critical to the study is the optimization of intermediate stream volumes and qualities to the various grades of gasoline to produce on-specification product. The model has operational flexibility in the process units to change critical volumes and qualities of gasoline blending components. Some of the more robust alternatives include changing FCC conversion, endpoint on FCC naphtha, as well as the throughput and severity of the reformer. The model has capability to change butane purchases for all cases.

2.2.8 HOF Scenarios

A generalized visual of the HOF scenarios is presented in Figure 2-3.

Figure 2-3. Fuels Matrix



There are fifteen HOF fuel scenarios: 9 for ethanol, 4 for bio-reformate (BR), and 2 for woody gasoline (WG). Fuels Working Group (FWG) provided the lab data for the finished baseline and the Blendstock for Oxygenated Blending(BOB) for each HOF scenario. The BOB data represents what the refinery produces before ethanol blending, and with respect to this study represents the refinery sourced octane production. With this data, the blending value for ethanol for each HOF can be calculated. The blending data for BR and WG components are the same for each of their scenarios. Two of the ETH cases (i.e., Fuel 01 and Fuel 07) have low sensitivity on octane numbers, defined as the difference between RON and MON.

Table 2-6. Lab Data

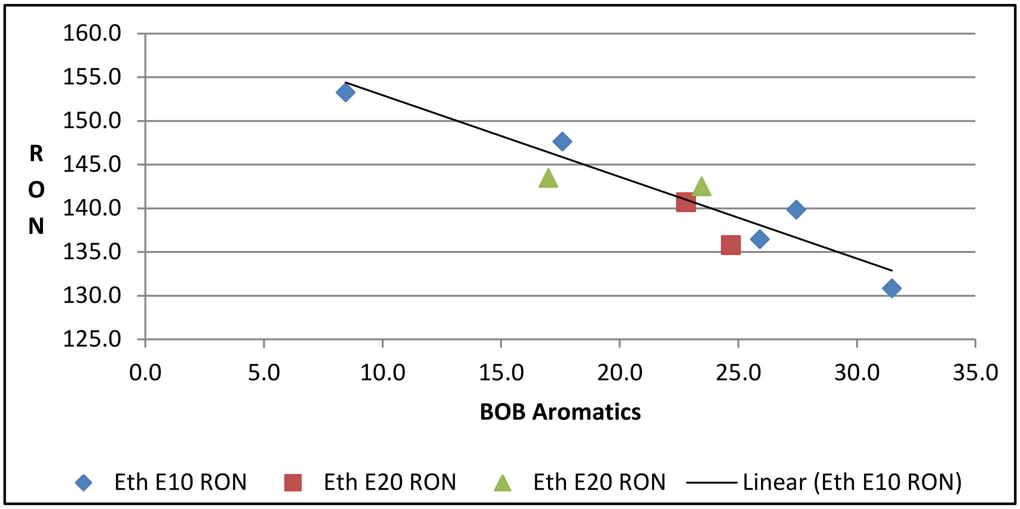
		Lab Data for BOB			Lab Dat for Finished				Derived Data for ETH, BR, WG		
FUEL	VOL%	RON	MON	RVP	RON	MON	RVP	Sensitivity	RON	MON	RVP
Fuel 01 E10	10.0	85.6	81.2	7.0	91.8	84.5	8.3	7.3	147.6	114.2	20.3
Fuel 10 E10	10.0	86.4	79.3	6.6	91.4	81.0	7.7	10.4	136.4	96.3	18.1
Fuel 14 E10	10.0	91.8	83.8	7.1	96.6	85.5	8.3	11.1	139.8	100.8	18.8
Fuel 07 E10	10.0	94.2	90.3	7.0	100.1	92.5	7.7	7.6	153.2	112.3	13.5
Fuel 16 E10	10.0	97.8	87.6	6.4	101.1	89.3	7.8	11.8	130.8	104.6	19.5
Fuel 20 E20	20.0	86.4	82.2	6.4	97.3	86.6	7.3	10.7	140.7	104.1	10.9
Fuel 18 E20	20.0	92.3	86.1	6.9	101.0	89.0	7.7	12.0	135.8	100.6	10.9
Fuel 15 E30	30.0	76.8	71.0	6.9	96.5	84.9	7.7	11.6	142.5	117.3	9.4
Fuel 19 E30	30.0	83.1	80.7	6.4	101.2	89.2	7.2	12.0	143.4	109.0	8.9
Fuel BR V1	9.0	96.4	86.0	8.3	97.6	87.2	7.6	10.4	109.4	99.5	0.2
Fuel BR V2	27.0	92.8	82.4	10.0	97.3	87.0	7.4	10.3	109.4	99.5	0.2
Fuel BR V3	9.0	100.3	89.1	8.3	101.1	90.0	7.6	11.1	109.4	99.5	0.2
Fuel BR V4	27.0	97.9	86.9	9.9	101.0	90.3	7.3	10.7	109.4	99.5	0.2
Fuel WG B2	9.0	98.7	88.1	10.0	97.7	87.5	10.2	10.2	87.3	81.3	12.2
Fuel WG B4	27.0	101.0	89.3	8.4	97.3	87.1	9.4	10.2	87.3	81.3	12.2

The HOF scenarios in the model produce a finished gasoline per regional specifications. The lab data above for finished gasoline is only used to set the RON specification for each grade in the model, by region (and to calculate a derived blending value for ETH, WG, and BR). For example, if the regional RVP specification is 8.0 psi, and the RVP of the finished lab data for Fuel 01 is 8.3 RVP, the models must produce Fuel 01 with the regional specification of 8.0, not 8.3 psi. However, the RON specification for Fuel 01 is 91.8, which is the target RON for the models.

2.2.9 Ethanol Blending

Above, the data of ethanol blending RON values is scattered. This is a blending phenomenon associated with the chemical properties of ethanol when combined with hydrocarbons. It is understood that the ethanol blending RON is a function of the composition of the BOB. When we correlate the BOB aromatics with the lab blending RON values of ethanol, the relationship is clear: higher aromatics (low saturates) in the blend result in a lower ethanol RON blending value.

Figure 2-4. Lab Ethanol RON Data vs. BOB Aromatics



The linear relationship above is programmed into the LP model. With this technique, the LP can optimize on the solution which includes the optimization of aromatics production and blending with ethanol RON blending value as a function of BOB aromatics, to produce the HOF gasoline. This is described in more detail in the results section of this report.

The correlation of MON with BOB aromatics (or any other BOB quality) is not as clear statistically. After reviewing the data with FWG and Argonne, it was decided to use the derived lab data for the MON blending values, not a statistical relationship. In the models, the minimum MON for finished gasoline was set at 82.0.

2.2.10 HOF Shares

Today's E10 gasoline premium grade sales are about 11% of the pool. Production by region is unclear. For this study, we assigned 10% premium production on "today" E10 grades.

Reformulated gasoline (RFG) production is about 15% and 20% for PD2 and PD3, respectively. California CARB gasoline (also referred to as RFG in this report) is approximately 88%. For the RFG volumes currently produced in the regions, under the HOF scenarios there is the same percentage of HOF RFG shares in addition to the HOF CG. Restated, the HOF scenarios have both HOF CG and HOF RFG

For the base cases, the following distributions are used. Note there is a base case, non-HOF production, for 2022 and 2040 which use the same ratios below: (ULR = Conventional Unleaded Regular, ULP = Conventional Unleaded Premium, RFG = Reformulated Gasoline)

Table 2-7 Gasoline Grade Ratios 2015

2015	Notes	PD2	PD3	CAL
ULR	Current Specifications	76%	71%	11%
ULP	Current Specifications	9%	9%	1%
RFG PREM	Current Specifications	2%	2%	10%
RFG REG	Current Specifications	13%	18%	78%
TOTAL		100%	100%	100%

In 2022, 50% of the pool is converted to HOF; in 2040, 100%. In 2022, however, FWG provided the assumption that 50% of today's premium would remain, and not go to zero under the assumption that all premium becomes HOF, rationalizing that any grade of today's gasoline could not go to zero in the short term. In the 2040 long term there is a 100% conversion to HOF. These distributions are shown below.

Table 2-8. Gasoline Grade Ratios 2022, 2040

2022 Breakdown	Notes	PD2	PD3	CAL
ULP	50% stays	**5%**	**4%**	**1%**
RFG PRE	50% stays	**1%**	**1%**	**5%**
HOF RFG	HOF/Bio Blends	8%	10%	44%
HOF CG	HOF/Bio Blends	43%	40%	6%
RFG REG	Current Specifications	7%	9%	39%
CG REG	Current Specifications	38%	36%	5%
TOTAL		100%	100%	100%

2040 Breakdown	Notes	PD2	PD3	CAL
ULP	Zero, becomes HOF	**0%**	**0%**	**0%**
RFG PRE	Zero, becomes HOF	**0%**	**0%**	**0%**
HOF RFG	HOF/Bio Blends	15%	20%	88%
HOF CG	HOF/Bio Blends	85%	80%	12%
RFG REG	Current Specifications	0%	0%	0%
CG REG	Current Specifications	0%	0%	0%
TOTAL		100%	100%	100%

3. Refinery Modeling Results and Discussion

3.1 Background for Analysis of Results

From the LP results there are different analysis techniques. Each model has different focus areas, such as:

- Identification of feasible or infeasible cases from LP modeling
- RON and MON for HOF Blend
- Refinery operational changes
- Blending composition changes
- Other limiting specifications
- Other Interpretative Analysis

LP Modeling concepts. The LP is a tool that simulates the full range of refinery operations, including feedstock purchases, transformation of feeds into products using refinery operations, and the sale of products. A primary goal of refinery operations is to maximize margin, which is the same goal of the LP model. The results from an LP run represent the "optimal" solution to maximize variable margin, given the constraints and operations in the model. An infeasible solution from an LP indicates that there is no solution set which satisfies the conditions and constraints in the model.

RON and MON specifications. While there are numerous specifications which are modeled and must be satisfied for gasoline blending, RON and MON are critical to this study. With respect to specifications, "giveaway" represents a condition where the operation not only meets but exceeds the minimal requirements of the specification. For example, if RON specification is 100 and the model produces 101, that represents a 1 RON giveaway. Quality giveaway is common, but for a variety of reasons, we do not typically see octane giveaway — which could be RON, MON or (R+M)/2. This study focus is RON which is presented in this report. When a gasoline has multiple specifications such as MON and RON (e.g., all the HOF gasoline), we often expect to see one of these octane specifications with giveaway, because the other specification is constraining (or bounded).

Operational changes. A key process unit to produce incremental octane is the reformer. In most refinery operations there is a cost associated with producing octane. Operationally, one production cost is associated with the liquid recovery percentage across a process unit. For example, in the naphtha reformer — which is the major producer of high octane products in most refineries — the liquid reformate yield at low severity is approximately 90 volume percent of the input feed, but reduces to about 80% at high severity. The "lost" liquid production appears in the higher light ends production, which generally have less value than reformate.

A refinery can increase octane by a combination of increasing volume of reformate, increasing octane of reformate with changes in severity, or a combination of both. This report will reference Severity*BBLS: the throughput (BPD) of the reformer times the severity of the reformer, which is a useful technical indicator refinery-sourced octane analysis.

Another key process unit in the refinery is the Fluid Catalytic Cracker (FCC) because the produced FCC naphtha presents the highest volume among gasoline blending components in most refinery operations. The FCC also produces C3 and C4 olefins that can feed an alkylation unit to produce alkylate. Alkylate is a valuable blending component because it has low RVP, high octane (although generally less than reformate), and a light distillation compared to reformate. If there are operational pressures to reduce the FCC throughput under a HOF scenario, this often translates into less alkylate to produce and blend.

Blending Composition Changes. Incremental reformate can increase the pool octane but brings incremental aromatics to the blend composition. For this Study, the change in aromatics is important because the ethanol blending RON has a linear relationship in the model as a function of aromatics.

Other Specification Impacts. Reformate is a "heavy" distillation component, and the volume of reformate that can blend to gasoline is often limited by the heavy distillation specifications such as T90 and DI. Additionally, RVP is a critical blending specification that can be challenging for current gasoline blends and HOF scenarios, particularly in the summer.

Other Analytical Methods

Liquid recovery reflects the volume gain (or shrinkage) of the liquid products divided by the feeds, across the refinery. This can be expressed differently, and often a C3+ recovery is referenced. A drop in liquid recovery directly translates to a drop in margin, and relatively "small" drops of less than 0.5% are quickly noticed at the refinery level. Liquid recovery can change for a variety of reasons, but for this study the emphasis is on the reformer operations. As the reformer severity increases, the liquid recovery decreases.

Marginal Values (MV) are reported in an LP output. A marginal value is only reported when a constraint is being met, such as the purchase of feeds, sale of products, unit capacities, and specification blending. The use of marginal values must be done with caution because the value literally reflects the "next" or "marginal" impact, and does not reflect the average impact. A useful use of MVs is a differential method where an MV on Case X constraint is compared to the MV on the same constraint for Case Y.

Trends. For any given scenario, there could be up to seven different LP cases. The report focus is on general trends. We do not attempt to dissect these results to explain why an anomaly might exist between the cases. Every case has thousands of different operating conditions and constraints, and the responses will change and in some cases might deviate from the general trend.

3.1.1 "Feasible but Unreasonable"

When reviewing these cases, the phrase "feasible but unreasonable" might be applied. We need to make a distinction between an LP model being feasible versus the actual operations of a refinery. The LP, for example, has "perfect" fractionation and can blend components to an accuracy of ten-thousandths of a percent. We review the magnitude of marginal value changes, component values, and limiting conditions and constraints to form an opinion; while the LP is feasible, we need to be reasonable, in a practical operation sense, to distinguish between modeling results and how these results translate to an industry.

Reasonableness can take on different meanings; the simplest requires that a case is feasible under the HOF scenarios. Beyond that, other "gauges" for reasonableness include:

- Minimal capital costs. Costs may include fractionation, storage, piping, and blending systems to manage and "cherry pick" streams for more accurate blending. Process expansions could be in this category, but could extend to new process units.
- No or limited RON giveaway
- No remarkable changes in marginal octane production costs (marginal values)
- Reformer severity increases approximately 5 numbers or less versus base
- Reasonably consistent component blend values versus base
- No significant drops in production, crude runs, or operations
- No excess gasoline exports to "dump" bad quality into non-US gasoline

3.2 Cost Implications

The emphasis of the modeling effort is not a cost analysis for the HOF scenarios. That being said, the LP is, in fact, driven by economics to maximize margin. Comparisons can be made on the solutions for the change in objective value (variable margin) to get a sense of the economic impact between cases.

The margin results are based on the unique price set for the case. The LP is not a price equilibrium tool; for example, if gasoline exports increase significantly for a given case, we generally expect downward price pressure in the markets. The LP results, however, are based on a single price for exported gasoline, regardless of the volume exported.

Another example specific to this study is the ethanol price assumption. Ethanol prices do not impact the material balance, operations, or blending because the gasoline volumes are fixed. For example, an E10 case for 100 BPD of gasoline is 90 BPD of BOB and 10 BPD of ethanol, regardless of price. The same assumption was used for woody biomass gasoline and bioreformate blended gasoline as well, as the blending was fixed on volume ratio not by price differentials.

With these caveats, we do screen and analyze the margin changes for directional impacts. In simple terms, we look for relatively “large or small” changes in the margin between cases to identify which cases are relatively “easy or difficult” for the refinery.

Detailed analysis of the economic impacts for the HOF scenarios is outside the scope of this study; consequently, economic results are not provided in this report.

3.3 Base Cases

There are three base cases: 1) Calibration to 2015, 2) Future 2022, and 3) Future 2040.

The calibration is to match actual EIA 2015 reported data. California is not reported separately in the EIA data; as stated previously, we relied on California Energy Commission data coupled with EIA data. To be clear, there are no HOF scenarios for 2015. Additionally, there is less certainty with the California data because of lack of fidelity compared to the EIA.

Going into the future, we do not have regional projections, only the United States in total. While we applied these growth assumptions to all locations, it is unlikely that growth across all regions would be the same.

Future years are estimated using the EIA growth projections applied to the base 2015 data, as explained in the methodology. The gasoline and diesel projections are based on the US demand rates which exclude exports. The LP has the flexibility to produce exports to maintain the forecasted US demand requirements; this becomes significant when higher ethanol blends are studied.

PADDs 1, 4, and 5–excluding California were not simulated for this Study. The regions used in various HOF scenarios (PADDS 2, 3, and CAL) account for about 85% of all crude throughput in the United States.

The table below shows the relative differences between all the regions from the LP modeling results versus the target volumes. This study's key data points are US gasoline and diesel in years 2022 and 2040 (highlighted). Targeted volumes are generally held in +/- 2%, although allowed additional float when data uncertainty or lesser significant products (other than gasoline or diesel) are involved.

Table 3-1. Comparisons of LP results to Targets

CALIBRATION 2015 (LP vs Target)				
	PADD 2	PADD 3	CAL	TOTAL
Crude	1%	1%	2%	1%
USA Mogas	0%	0%	5%	1%
US Diesel	2%	-2%	3%	0%
Total Jet	1%	-2%	3%	0%
Heavies	-3%	-3%	-11%	-4%

YEAR 2022 (LP vs Target)				
	PADD 2	PADD 3	CAL	TOTAL
Crude	3%	3%	3%	3%
USA Mogas	0%	2%	2%	1%
US Diesel	2%	2%	2%	2%
Total Jet	2%	2%	2%	2%
Heavies	0%	-3%	7%	-1%

YEAR 2040 (LP vs Target)				
	PADD 2	PADD 3	CAL	TOTAL
Crude	-4%	3%	0%	1%
USA Mogas	2%	2%	2%	2%
US Diesel	2%	2%	2%	2%
Total Jet	2%	-2%	-2%	-1%
Heavies	1%	-2%	-2%	-1%

In absolute terms, the regions are broken out in the following table represented in 000BPD (MBPD). Table 3-2 includes gasoline and diesel exports. The G/D ratio shows a steady decline in gasoline production, and these ratios are production for US demand.

Table 3-2. Summary Material Balances

000 BPD	Base 2015				Base 2022				Base 2040			
	PD2	PD3	CAL	Total	PD2	PD3	CAL	Total	PD2	PD3	CAL	Total
Crude	3,597	8,617	1,735	13,948	3,703	8,871	1,763	14,337	3,652	9,432	1,818	14,903
Net LPG prod	95	385	53	533	94	368	35	496	46	264	-6	304
Finished Mogas	2,149	4,259	966	7,374	2,017	4,254	1,006	7,276	1,633	3,977	756	6,366
Total Distillate	1,313	3,617	669	5,599	1,507	4,280	705	6,492	1,819	5,069	1,066	7,953
Total Diesel	1,070	2,773	367	4,209	1,255	3,373	396	5,023	1,525	4,056	718	6,299
Total Jet	243	844	302	1,390	252	907	309	1,469	294	1,013	347	1,655
Heavies	213	459	87	759	222	460	106	788	236	497	104	836
Other	31	519	70	621	29	527	34	590	31	536	25	592
G/D - USA Prd'n	**2.0**	**2.2**	**2.6**	**2.2**	**1.7**	**1.9**	**2.2**	**1.9**	**1.3**	**1.4**	**1.6**	**1.4**

3.3.1 Results: HOF Scenarios

Table 3-3 is repeated for reference for the 15 HOF scenarios to be presented next. This is referred to as the "Lab Data" representing actual blends produced in the Laboratory. Our modeling focus is to meet RON for the lab data below with the volume percent of oxygenate or renewable.

Table 3-3. Laboratory RON Data

LAB DATA FUEL	VOL%	RON
Fuel 01 E10	10.0	91.8
Fuel 10 E10	10.0	91.4
Fuel 14 E10	10.0	96.6
Fuel 07 E10	10.0	100.1
Fuel 16 E10	10.0	101.1
Fuel 20 E20	20.0	97.3
Fuel 18 E20	20.0	101.0
Fuel 15 E30	30.0	96.5
Fuel 19 E30	30.0	101.2
Fuel BR V1	9.0	97.6
Fuel BR V2	27.0	97.3
Fuel BR V3	9.0	101.1
Fuel BR V4	27.0	101.0
Fuel WG B2	9.0	97.7
Fuel WG B4	27.0	97.3

3.4 Fuel 01: E10, Low RON, Low Sensitivity

Fuel 01 is a Low RON, Low Sensitivity, E10 HOF scenario. As explained in the methodology section, all HOF scenarios are simulated in the LP model using a minimum 82 MON, which is the specification for today's regular grade. The RON specifications are equal to the lab data shown above.

Fuel 01 is only simulated using the regional models; no configuration models are utilized. This fuel is similar to current gasoline specifications. Today's octane gasoline specification for regular grade is (R+M)/2, and the study uses only RON; as such, differences do exist.

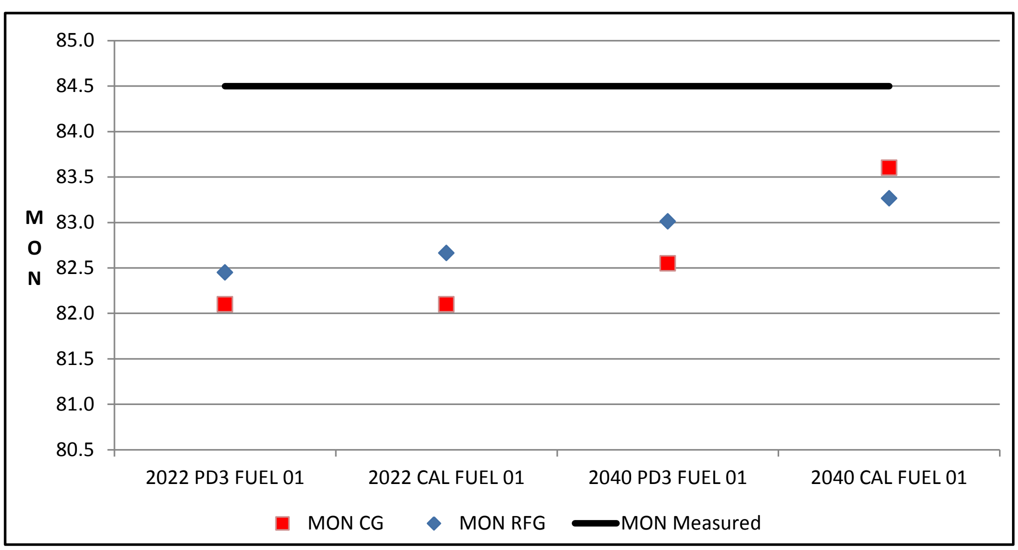
Table 3-4. Fuel 01 Summary

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 01 E10	n/a	n/a	n/a	n/a	n/a	Feasible	Feasible	n/a	n/a	n/a	n/a	n/a	Feasible	Feasible

Lab Data	RON Lab	MON Lab
FUEL 01	91.8	84.5

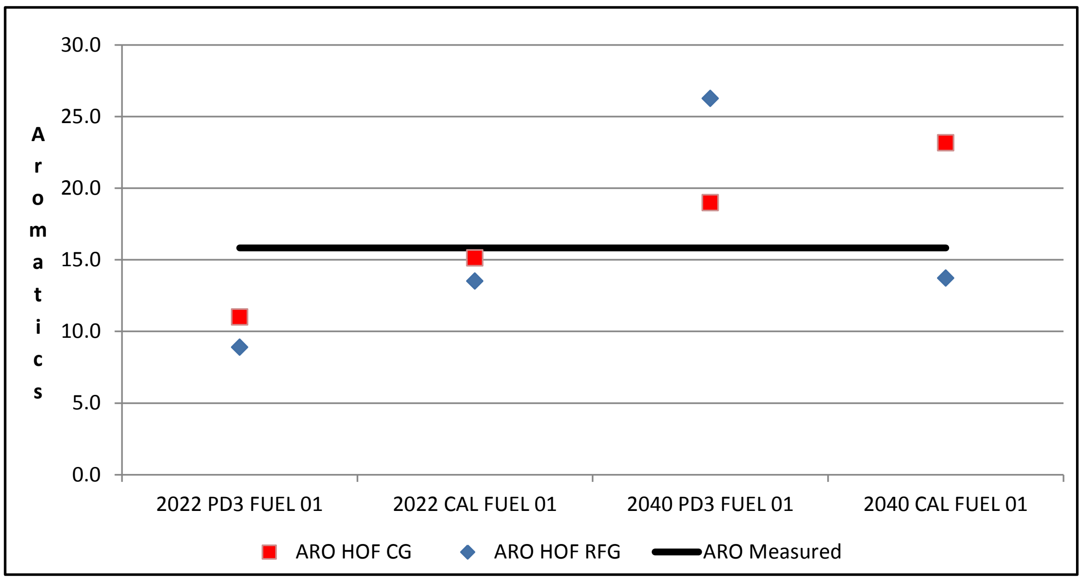
All cases are constrained to the 91.8 RON specification, and no RON giveaway is present. The cases exceed the 82 MON but are below the 84.5 MON that was measured in the lab. This was originally envisioned as a low sensitivity case, but ultimately the modeling was done at 82 MON minimum. These results range from 1 – 2 MON below the lab data.

Figure 3-1. Fuel 01: Finished MON for CG & RFG



The aromatics response is typical of many scenarios. Remember, a low aromatic BOB provides a high ethanol RON blend value. In 2022, only 50% of the pool is converted to HOF so there is lower requirement for refinery-sourced octane versus a 2040 scenario when 100% of the pool is converted to HOF. In 2022, a high ethanol RON blend value is obtained with a low aromatic BOB pool. However, at 100% HOF conversion in 2040 there is a greater need for refinery-sourced octane, and ethanol blending alone is not sufficient to meet the high octane demand. Consequently, we see the production of incremental reformate resulting in a higher aromatic blend.

Figure 3-2. Fuel 01: HOF Aromatics for CG & RFG



It is worth noting that these cases are not limited by the DI constraint.

Consistent with the scenario cases, California is more challenged to produce HOF compared to the rest of the country. Today's CARB gasoline is more difficult to produce with stricter blending specifications, resulting in less operation leeway. At a fundamental level, going from a more difficult starting point in California to a higher HOF position is more difficult compared to non-California gasoline.

In summary, there are few identified challenges associated with producing Fuel 01. The octane requirement for this fuel is similar to today's octane.

3.5 Fuel 10: E10, Low RON, Hi Sensitivity

Fuel 10 is a Low RON, High sensitivity, E10 scenario that was performed on PD2, PD3, PD Cal, and all four configuration models. Similar to Fuel 01, the gasoline specifications are reasonably consistent with current specifications gasoline.

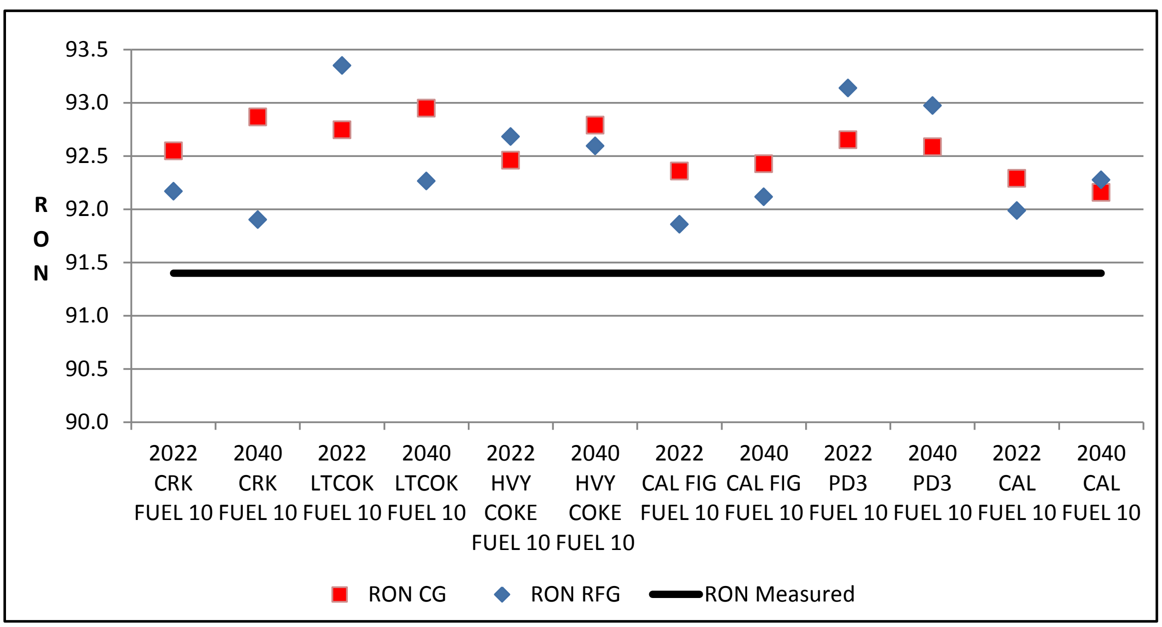
Table 3-5. Fuel 10 Summary

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 10 E10	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible

Lab Data	RON Lab	MON Lab
FUEL 10	91.4	81.0

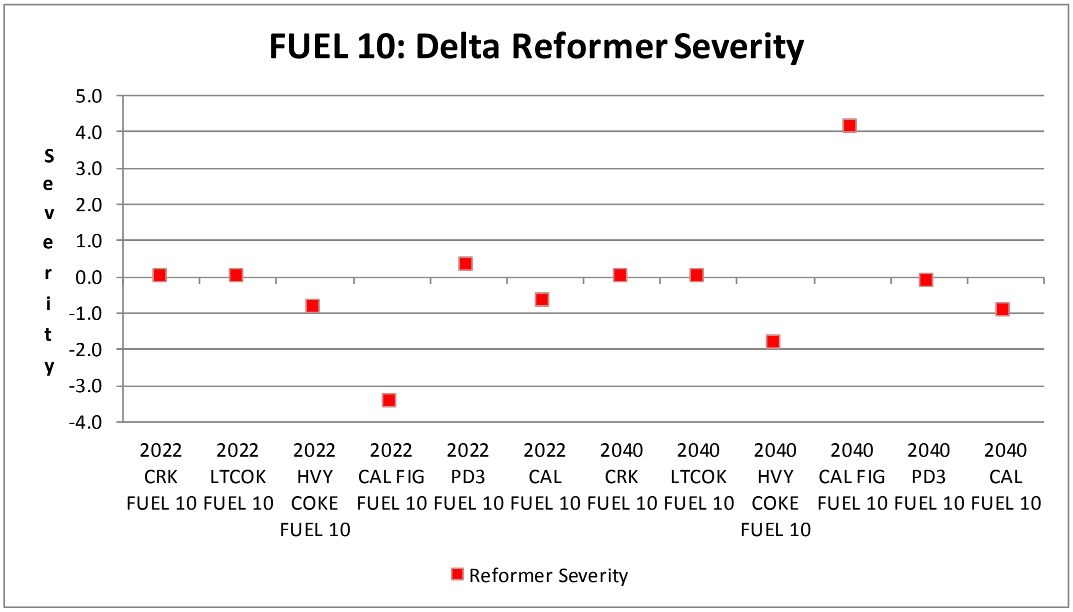
Fuel 10 is constrained by the 82 minimum MON in all cases. This specification is actually more rigorous than the measured 81 lab data. All of these cases are constrained by the 82 MON specification, and there is RON giveaway, shown below. The RON is similar to today's gasoline production.

Figure 3-3. Fuel 10: Finished RON for CG & RFG



The operational and blending changes in this case are unremarkable, stemming from the fact that the incremental octane requirement for this low RON is minimal. The changes in reformer severity are generally less than one number, California being the exception.

Figure 3-4. Delta Reformer Severity



In summary, Fuel 10 has a low incremental octane requirement and the operational and blending changes are minimal versus today's operation. Both Fuel 01 (above 91.8 RON) and Fuel 10 (91.4 RON) are low RON E10 cases with a difference of 0.4 RON. While the 0.4 RON difference is relatively small, we observe that Fuel 01 is constrained at 91.8 RON, and Fuel 10 is constrained by 82 MON.

3.6 Fuel 14: E10, Mid RON, Hi Sensitivity

Fuel 14 is E10, Mid RON, Hi Sensitivity where scenarios were performed for PADDs 3 and California, and all configuration models. The configuration model for California is infeasible for both 2022 and 2040. The regional California model is feasible. The regional model is an aggregate of the total California refining system, and has more operational flexibility than the configuration model.

The Mid RON lab data and specification of 96.6 is approximately 5 numbers higher than today's currently produced E10. Clearly the challenge of producing 100% of this HOF gasoline pool in 2040 is significant compared to 50% of the pool in 2022, and requires substantially more refinery-sourced octane. This is reflected in 2040, where the average reforming severity increase of over 5 numbers across the cases results in a negative impact of refinery liquid yield.

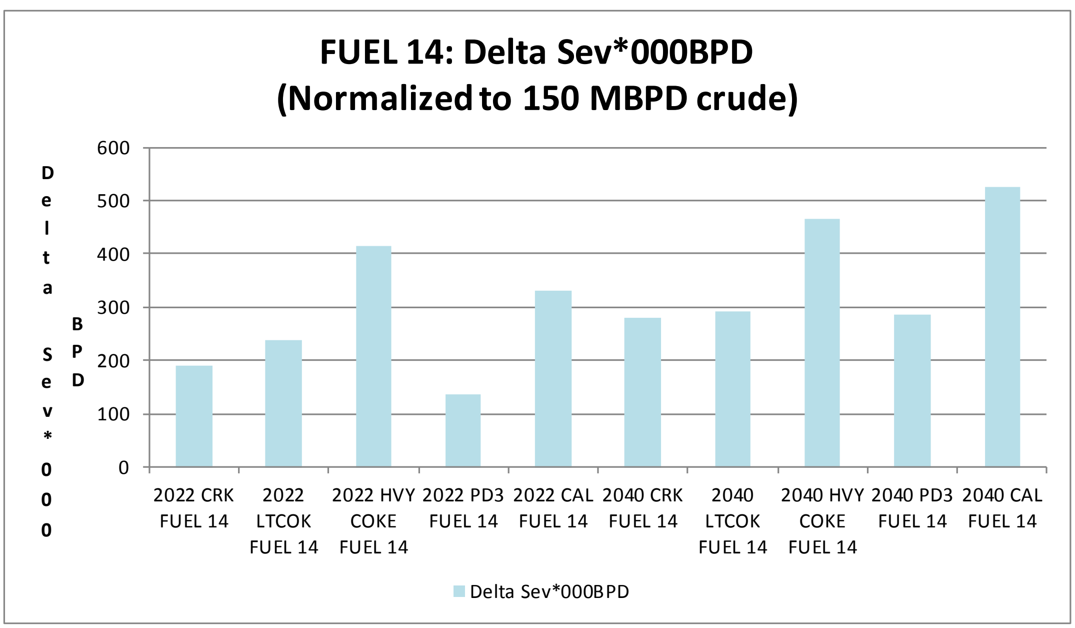
Table 3-6. Fuel 14 Summary

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 14 E10	Feasible	Feasible	Feasible	INF	n/a	Feasible	Feasible	Feasible	Feasible	Feasible	INF	n/a	Feasible	Feasible

Lab Data	RON Lab	MON Lab
FUEL 14	96.6	85.5

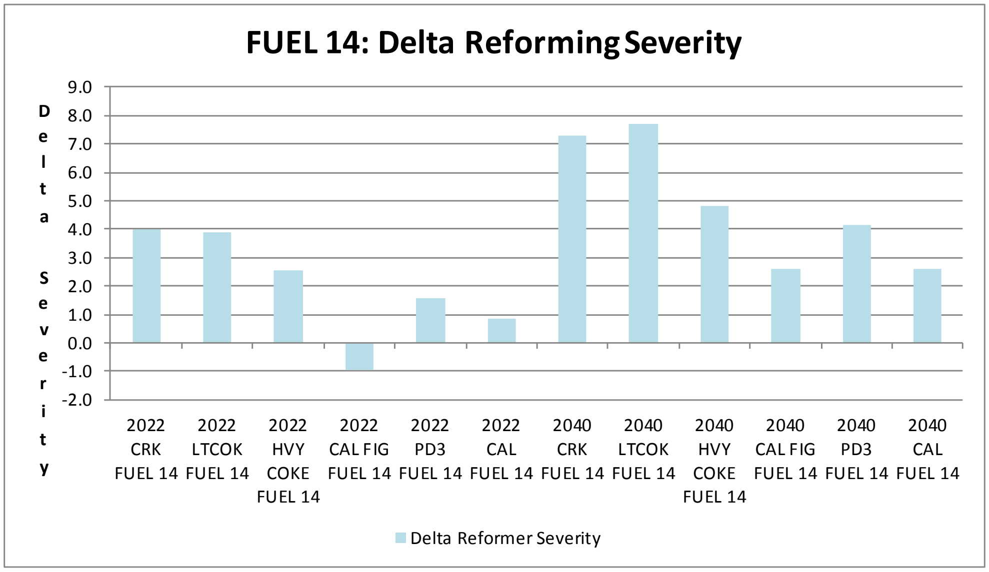
All of Fuel 14 is RON constrained at the 96.6 specification. Reforming operations increase to produce incremental octane, shown below in the deltas for reforming severity*BPD. Recall, the severity represents the RON of the reformate, so that a 100 severity (RON) for 1,000 BPD of throughput results in 100 Sev*000BPD Note: the regional models have been normalized below to a 150 MBPD crude basis. Also shown is that reformer severity*BPD increases from 2022 to 2040 for all cases.

Figure 3-5. Fuel 14: Delta Sev*000BDP (Normalized to 150 MBPD Crude)



To highlight the increase in reformer operations, Figure 3-6 shows the severity increases for the cases. The 2022 gains are generally below 4 numbers, averaging 2. The average 2040 gain is 5, with a couple noteworthy increases exceeding 7.

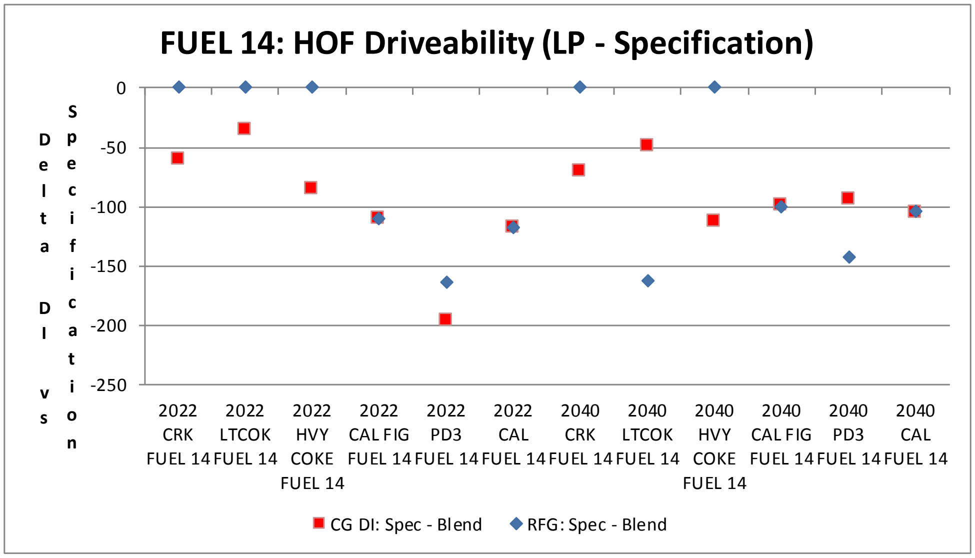
Figure 3-6. Fuel 14: Delta Reforming Severity



Alkylation increases are more pronounced in 2040 versus 2022.

While reforming severity increases, there is not significant blending pressure on DI from the heavy distillation of reformate. We often expect to see DI blending constraints on RFG before CG blends. This is primarily from the lower RVP RFG constraint, and reformate has low RVP, making it a preferential blending component to RFG. Figure 3-7 shows the difference between the gasoline specification and the blend. Any points below zero indicate the specification is not being constrained. Other than a few RFG blends hitting the DI constraint, there are no limiting CG HOF DI blends for either 2022 or 2040.

Figure 3-7. Fuel 14: HOF Drivability Delta to Specification



With the higher reformer severity operations, we expect the liquid volume recovery to be reduced. The average C5+ reduction for all 2022 cases is 0.4% drop; this increases to a 0.7% drop for 2040. Liquid recover decreases typically result in economic margin loss.

This mid RON scenario requires a significant incremental octane increase to be sourced at the refinery. Versus the E10 BOB produced today, this case requires the BOB pool to increase almost 5 RON numbers, which is substantial. The refinery will utilize all available resources to achieve this scenario, including reforming, alkylation, isomerization or disposal of light naphtha through sales or summer/winter inventory management controls.

In summary, Fuel 14 is challenged in 2022, and becomes critically challenged in 2040. Later in this report, capital analysis is performed on Fuel 14.

3.7 Fuel 07: E10, Hi RON, Low Sensitivity

Fuel 07 is E10, Hi RON, Low Sensitivity where scenarios were only performed for PADD 3 & California. These conditions result in infeasible solutions in 2040, and challenged solutions in 2022. As an example, in 2022 the reformer severity increase is 7 numbers, which might be feasible “on average” for some refineries, but in reality there are individual refineries that cannot increase severity by that amount. The C5+ liquid recovery decreases substantially over 1% for this scenario versus the Base case.

This lab scenario was originally intended to represent a low gasoline sensitivity of 7.6 (RON – MON), compared to current gasoline sensitivity of about 10. Because the model MON specifications are fixed at 82, the LP case does not capture the low sensitivity intended, but does provide insight into high 100.1 RON specification.

Table 3-7. Fuel 07 Summary

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 07 E10	n/a	n/a	n/a	n/a	n/a	Feasible	Feasible	n/a	n/a	n/a	n/a	n/a	INF	INF

Lab Data	RON Lab	MON Lab
FUEL 07	100.1	92.5

3.8 Fuel 16: E10, Hi RON, Hi Sensitivity

Fuel 16 is E10, Hi RON, Hi Sensitivity where scenarios were only performed for PADD 3 & California. The 101.1 is the highest E10 RON specification in the study. The 101.1 is a number higher in RON versus Fuel 7. Above, the reformer increase in PD3 was 7 numbers; and in this case the severity increase is 9.5 numbers. Reiterating the comments above, this magnitude of increase would jeopardize the capability of any specific refinery. The C5+ liquid recovery decreases over 2% versus the Base 2022. In the end, this is not a realistically achievable case under the case assumptions.

Table 3-8. Fuel 16 Summary

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 16 E10	INF	INF	INF	INF	n/a	Feasible	INF	INF	INF	INF	INF	n/a	INF	INF

Lab Data	RON Lab	MON Lab
FUEL 16	101.1	89.3

The incremental pool octane requirement of Fuel 16 versus today's gasoline is about 9 RON numbers. All of the cases are infeasible for all years, with the exception of a "solved model" for PD3 in 2022. The incremental 9 RON cannot be sourced from the constructed refinery models consistent with current existing refineries.

The single converged case for LP modeling of PD3 in 2022 is a situation discussed earlier: “Feasible but not reasonable.” Here, the reformer severity increases almost 10 numbers which is unlikely across the refining system; C5+ recovery drops over 2%; and margin drop is substantial — all coupled by the perfect blending mechanics of an LP model versus actual refinery blending operations.

Overall, this scenario clarifies limitations to RON increases in an E10 blending world, which in this case — about 9 RON increase to the pool — is unrealistic

3.9 Fuel 20: E20, Mid RON, Hi Sensitivity

Fuel 20 is E20, Mid RON, Hi Sensitivity scenarios performed on PADDs 3 and California and all the configuration models. From a strategic level, producing current E10 gasoline requires a BOB with about 87 RON. This scenario contemplates a finished gasoline about 5 RON higher, but at 20% ethanol. The BOB RON required by the refinery for a finished E10 today is about 87, which is similar to this E20 Scenario.

Table 3-9. Fuel 20 Summary

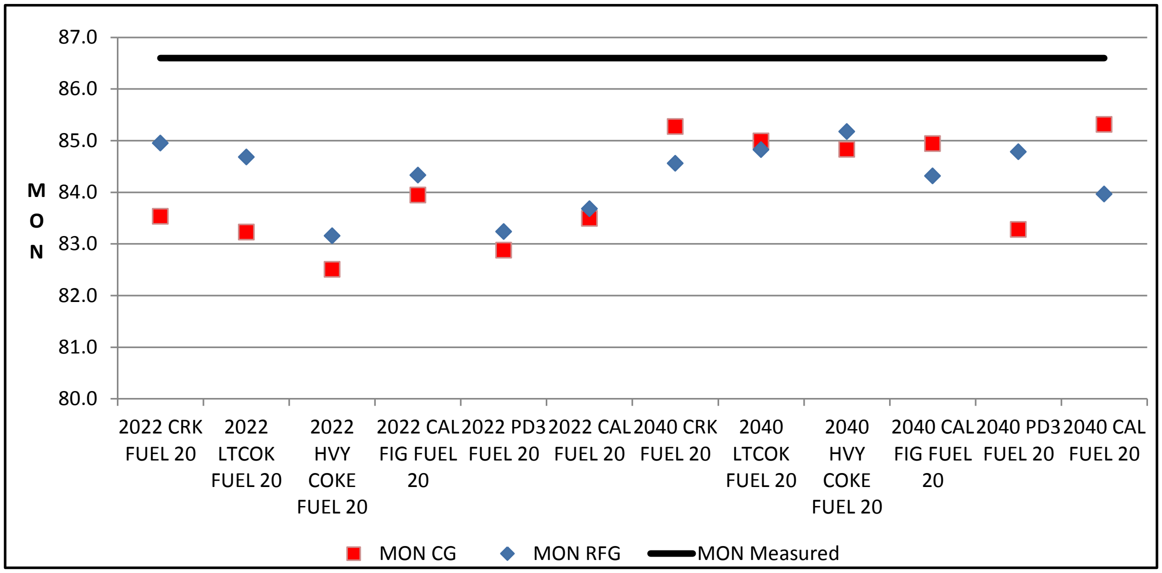
Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 20 E20	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible

Lab Data	RON Lab	MON Lab
FUEL 20	97.3	86.6

At constant refinery throughput, going to E20 from E10 results in more exports because we are holding US demand constant. There is 10% more BOB (of the total gasoline demand) “in the system” with the incremental 10% increase in ethanol.

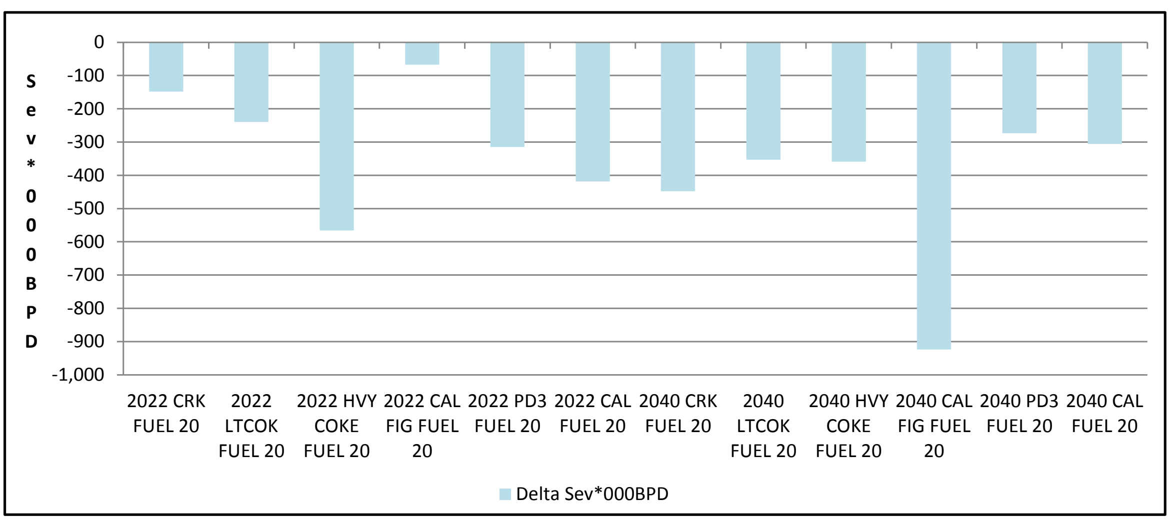
All of the cases are constrained on RON at 97.3 and all the MON are at or exceed the 82 specification but lower than the 86.6 measured lab MON.

Figure 3-8. Fuel 20: Finished MON for CG & RFG



The reformer severity*BPD decreases across all these cases, indicating the E20 case provides sufficient octane to a mid RON blend that incremental refinery-sourced octane is minimized. In most cases, the severity change is limited and the reformer throughput decreases. The low octane naphtha that would otherwise go to the reformer swings to the gasoline pool, which serves another indication that the E20 mid RON is not a challenging case operationally for the refinery.

Figure 3-9. Fuel 20: Delta Sev*000BPD (Normalized)



The overall severity decrease of the refinery operation is reflected in the average C5+ liquid volume gain of 0.6% across all cases. In summary, producing this E20 mid RON grade is reasonable from an octane balance perspective. The incremental gasoline exports from PADD 3 are 250 mbpd and 400 mbpd in 2022 and 2040, respectively, which has market impacts beyond the scope of this Study.

3.10 Fuel 18: E20, Hi RON, Hi Sensitivity

Fuel 18 scenarios are performed on PADDs 3 and California and all configuration models. Even at the higher 20% ethanol, the refinery must produce a BOB about 5 RON higher than today.

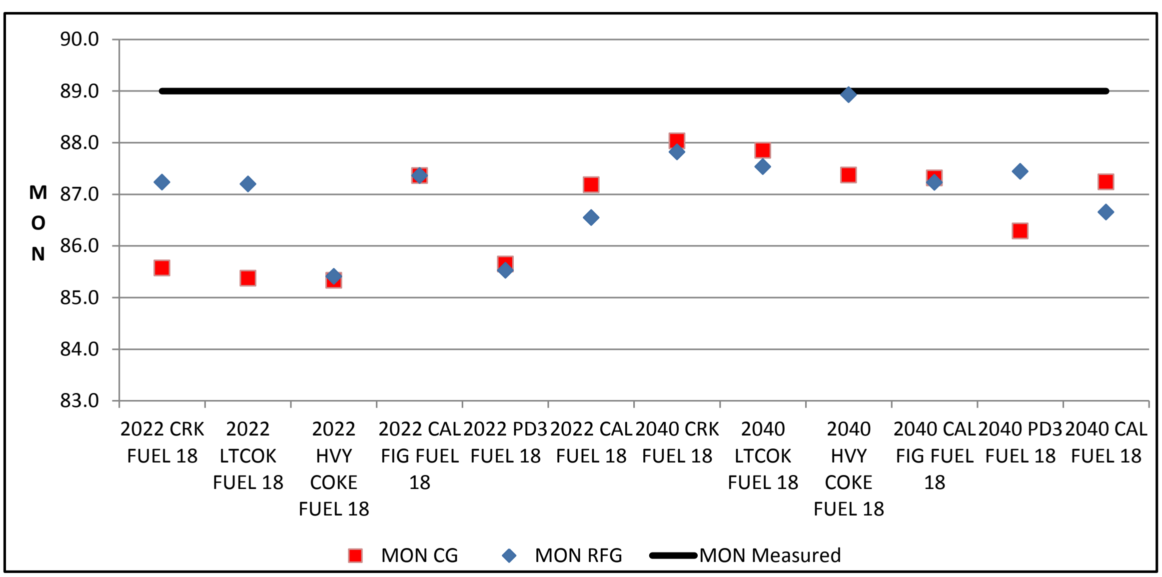
Table 3-10. Fuel 18 Summary

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 18 E20	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible

Lab Data	RON Lab	MON Lab
FUEL 18	101.0	89.0

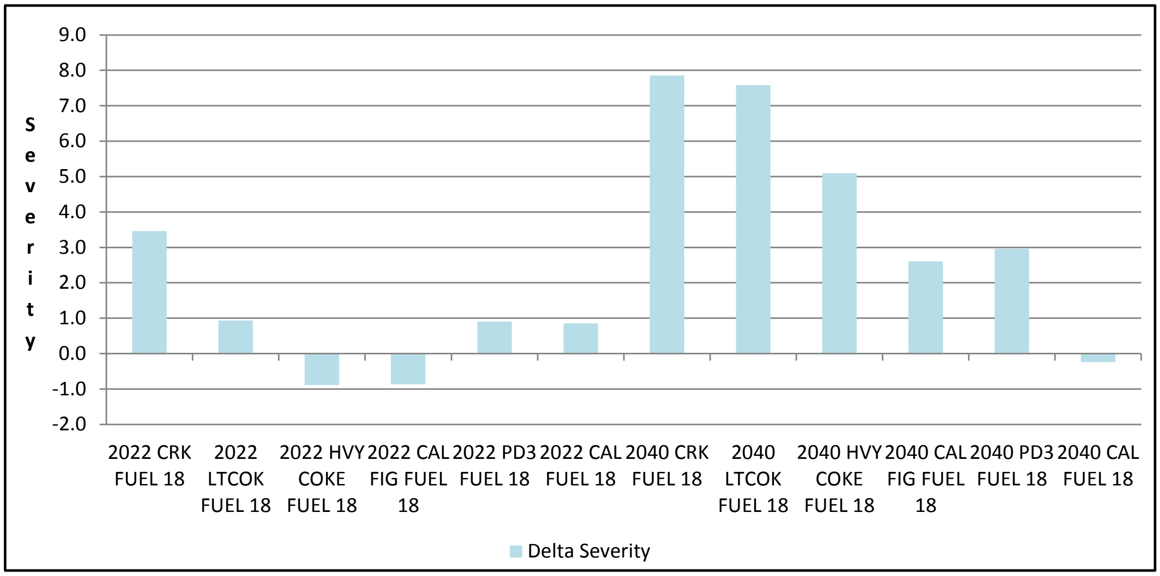
All of the cases are constrained by the 101 RON specification, and the MON all exceed the 82 specification and below the 89.0 measured MON in the lab.

Figure 3-10. Fuel 18: Finished MON for CG & RFG



Reforming operations are significant to achieve the required refinery-sourced octane balance. Figure 3-11 shows the increase in reforming severity versus the base case.

Figure 3-11. Fuel 18: Delta Reforming Severity

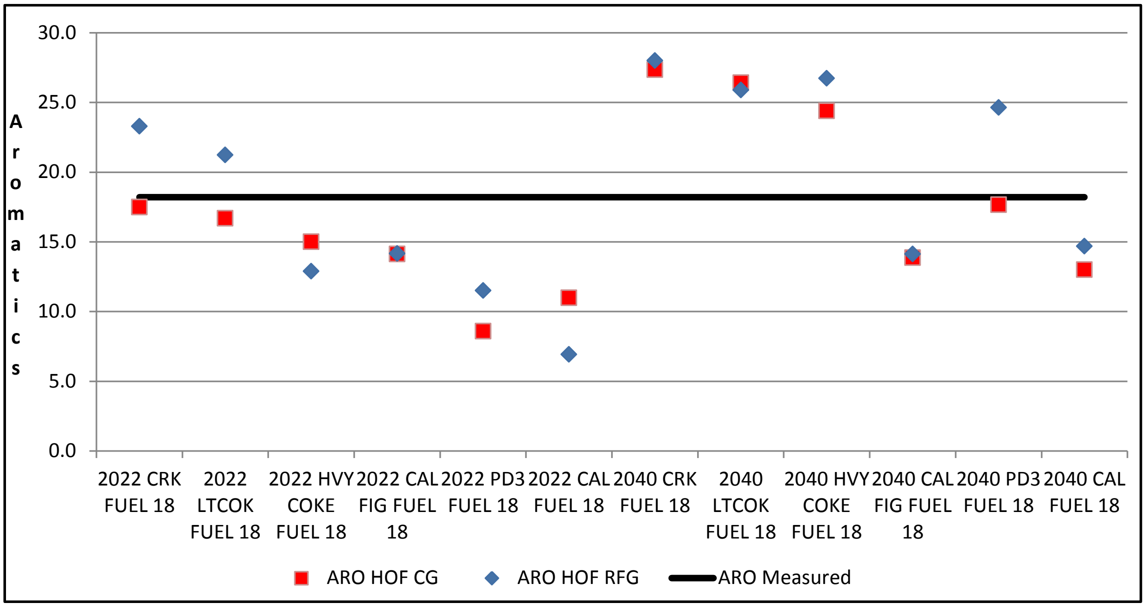


Some of these data hit practical limits of reforming severity gains. The actual severity gain at a refinery is very specific to their operation, ranging from the naphtha feed quality to mechanical limitations. Any given refinery could achieve approximately 7 number gain, but in aggregate across a region the gain might be closer to 5. In this case, the configuration models have increases over 5.

Figure 3-11 indicates some specific configuration refiners might require a 7+ number gain under this scenario (the LTCOK ’40 and CRK in ‘40). Some actual refinery locations would have difficulty achieving this requirement, and would have to investigate other operational considerations to maintain this octane balance. The regional PD3 model above has a gain of 3 which should be practical in the aggregate.

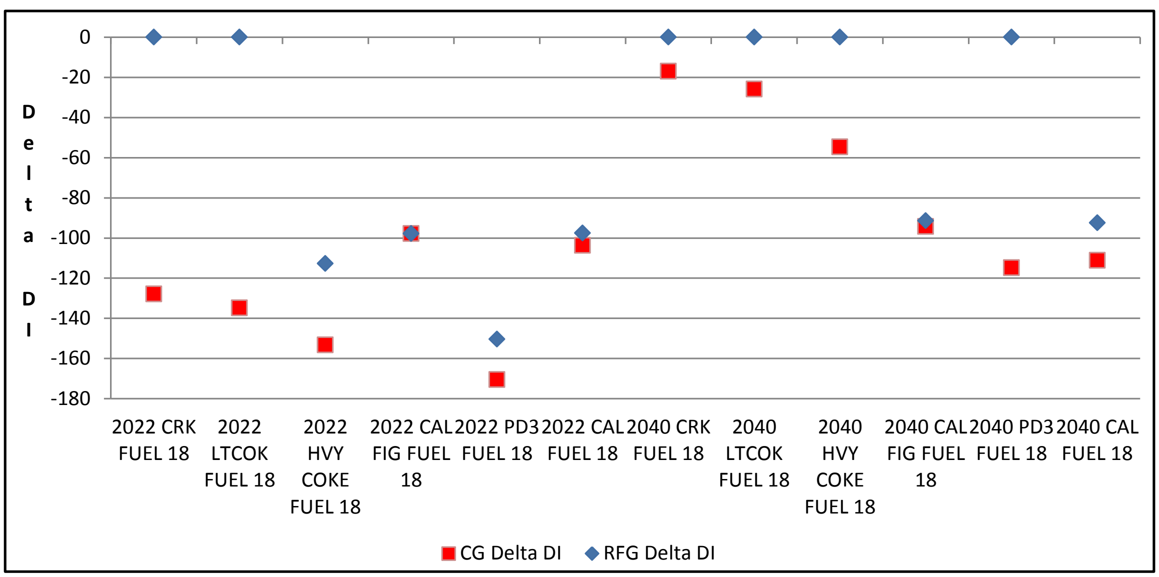
Figure 3-12 shows the clear relationship of the higher aromatic composition in the blend pool from 2022 to 2040.

Figure 3-12. Fuel 18: HOF Aromatics for CG & RFG



With higher aromatics, the DI constraint is limiting on two RFG cases in 2022, and doubles to four cases in 2040. Note: the high severity operations in 2040 CRK and LTCOK are also limited by DI.

Figure 3-13. Fuel 18: Delta DI (LP – Spec)



This case also shows strong incentives for alkylate. Closing the octane balance with alkylate is reasonable because while alkylate RON is lower than reformate, alkylate is also lighter and has less impact on DI.

In summary, this case pushes the limits of refinery-sourced octane production. In aggregate, HOF might be reasonably achievable, but some individual refineries will likely be challenged. Capital spending or other operational changes might be required at some locations. Capital spending for Fuel 18 is examined.

3.11 Fuel 15: E30, Mid RON, Hi Sensitivity

Fuel 15 scenarios are performed on PADD 3 and California. 30 vol% ethanol provides a significant octane boost from the incremental 20% ethanol versus E10 today. At this mid RON spec of 96.5, the E30 BOB pool could be about 7 RON lower than today's E10 BOB.

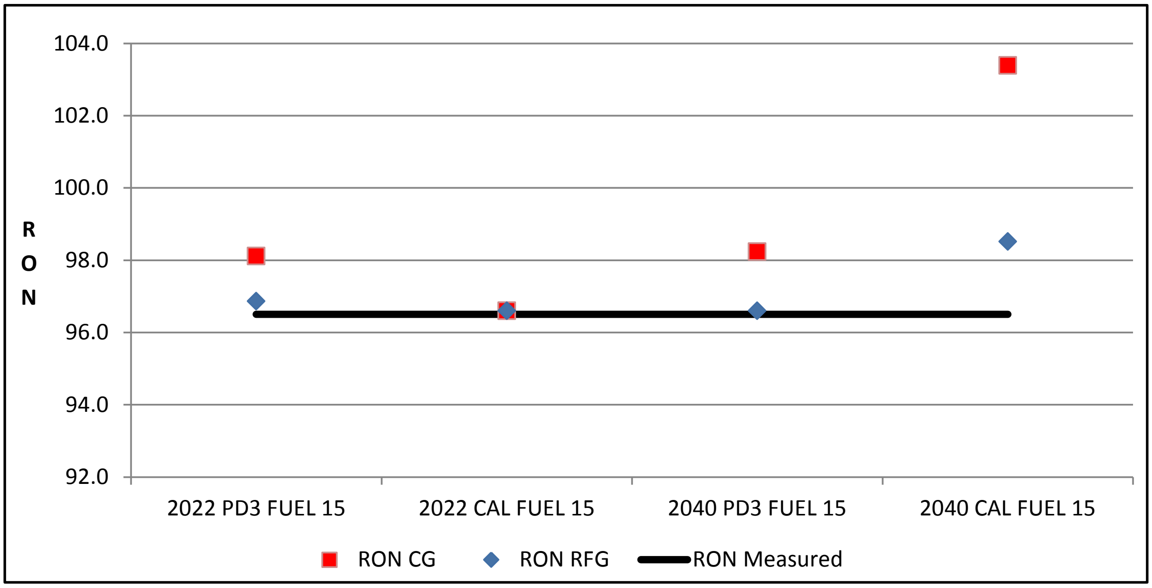
Table 3-11. Fuel 15 Summary

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 15 E30	n/a	n/a	n/a	n/a	n/a	Feasible	Feasible	n/a	n/a	n/a	n/a	n/a	Feasible	Feasible

Lab Data	RON Lab	MON Lab
FUEL 15	96.5	84.9

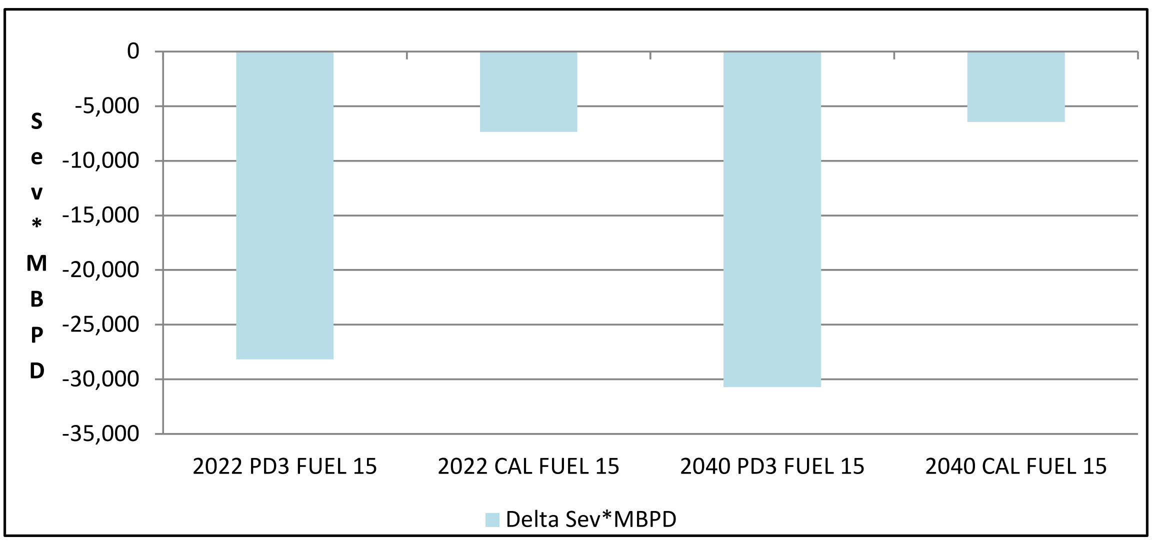
Adding 30% ethanol to this mid RON 96.5 appears to oversupply outside sourced octane to the refining system. The resulting case has giveaway for both RON and MON, although PD3 in 2040 for RFG has no giveaway, but almost 2 numbers for CG. Giving away both RON and MON clearly indicates an excess of octane into the system.

Figure 3-14. Fuel 15: Finished RON for CG & RFG



Reforming severity is reduced in all cases.

Figure 3-15. Fuel 15 Delta Sev*MBPD



Gasoline exports from PADD 3 increase by about 500 MBPD in 2022 to 700 MBPD in 2040, which would have market implications beyond the scope of this Study.

In summary, Fuel 15 allows the refinery to reduce the gasoline octane pool by over 7 numbers. The models have octane giveaway and in general do not need 30% ethanol to produce 96.5 RON even with 100% conversion to HOF in 2040.

3.12 Fuel 19: E30, Hi RON, Hi Sensitivity

Fuel 19 scenarios are performed on PADDs 3 and California and all configuration models. All the models are feasible to achieve the 101.2 RON specification.

Table 3-12. Fuel 19 Summary

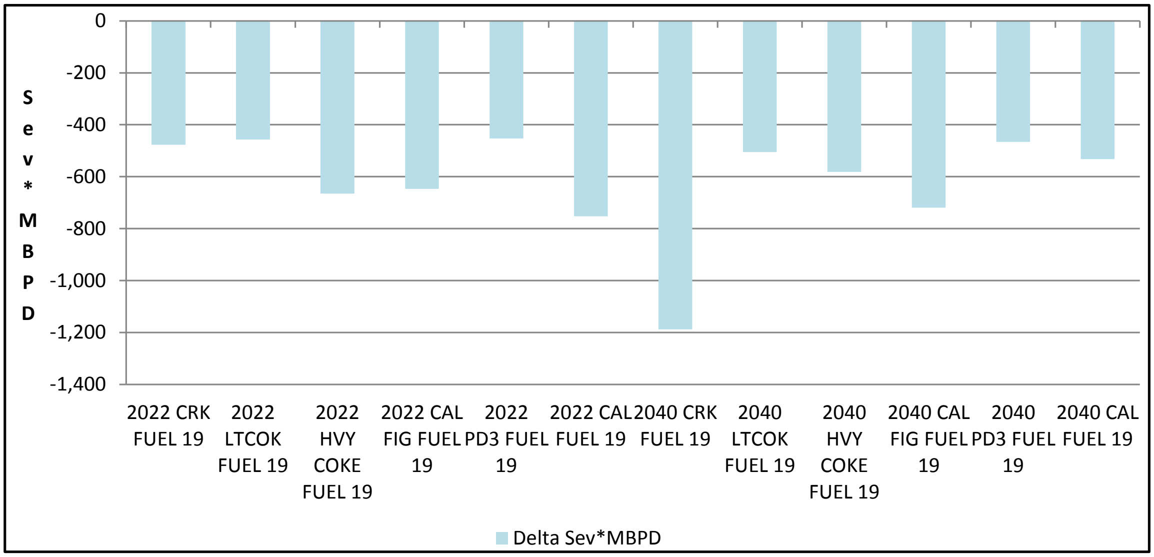
Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
FUEL 19 E30	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	n/a	Feasible	Feasible

Lab Data	RON Lab	MON Lab
FUEL 19	101.2	89.2

All of the cases are limited by RON and all are above the 82 MON specification and below the 89.2 MON lab measured. There is one exception of 2040 California configuration with about 1 RON giveaway. California is typically limited by distillation, and the E30 provides a mechanism to lighten the gasoline pool through higher volume of ethanol blending.

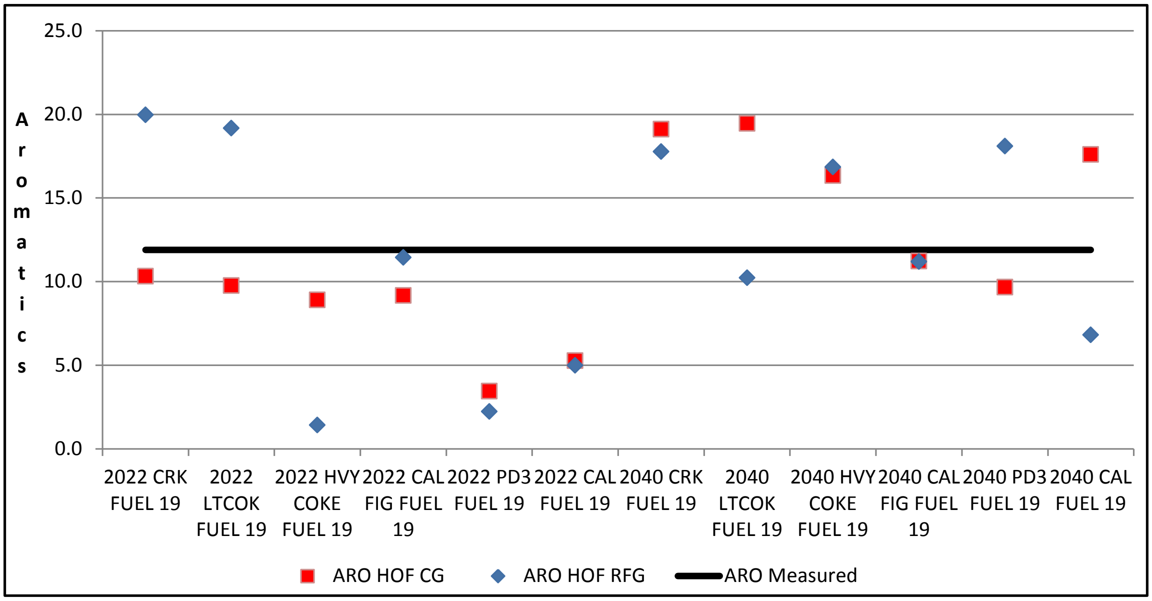
For all cases, there is a drop in reforming Sev*BPD (below the regions are normalized to 150 MBPD crude bases) and there is little incentive for incremental alkylate capacity.

Figure 3-16. Fuel 19: Delta Sev*MBPD



Keep in mind the Sev*MBPD is a reflection of octane production, not total aromatics to the gasoline pool, which are impacted not only by the independent changes of severity and throughput, but by all operations. That is, a reduction in reformer Sev*BPD does not necessarily translate to a reduction in aromatics. The average HOF aromatics increases from about 8 vol% in 2022 to 15 vol% in 2040. This increase in aromatics from 2022 to 2040 is common in the study, explained by the higher ethanol blending RON at low aromatics and by the higher pool RON demand in 2040 at 100% HOF versus 50% HOF in 2022.

Figure 3-17. Fuel 19: HOF Aromatics for CG & RFG



This is the second E30 case under the scenarios (Fuel 15 above was E30 mid RON). There is limited requirement to produce incremental octane under this scenario. That is, today's BOB RON under E10 blending has similar octane to the BOB RON for this 101 high RON under E30 blending.

There are no remarkable incentives on incremental alkylation or on the capability to produce incremental octane. Gasoline exports from PADD 3 increase by about 500 MBPD in 2022 to 750 MBPD in 2040 which would impact the market, but this analysis is beyond the scope of this study.

3.13 Bio-Reformate and Woody Gasoline

There are four bio-reformate blends (V1, V2, V3, and V4) and two woody gasoline blends (B2 and B4). Scenarios were developed for all configurations and regions.

Bio-reformate has excellent octane blending quality at RON 109.4 and low RVP of 0.2, valuable to the gasoline pool. Bio-reformate is essentially aromatics with >98% aromatic content, which have high boiling points. The impact of high aromatics, heavy distillation, and DI blending has been emphasized in this report. The DI blending impact from bio-reformate is approximate 1,670 compared to a gasoline specification of 1,250. The distillation specification in California is lighter (more rigorous) than the rest of the United States.

Table 3-13. Bio-reformate Qualities vs. US Specs

	Carb Regular Specs	PD3 Specs	BR Qualities	Comments
BR benefits				
RON	92.0	92.0	109.4	BR hi octane
MON	82.0	82.0	99.5	BR hi octane
AKI	87.0	87.0	104.5	BR hi octane
RVP	7.0	9.0	0.2	BR low RVP
BR negatives	**Specs**	**Specs**	**BR Qualities**	
Aromatic	22	none	99	BR Hi Aromatic
T10 (Max)	158	158	278	BR Too Hvy
T50 (Max)	213	250	305	BR Too Hvy
T90 (Max)	305	374	348	BR Too Hvy
DI	1,250	1,250	1,679	BR Too Hvy

Woody gasoline has a low RON blending quality at 87.3 and poor RVP at 12.2 psi. These poor blending qualities negatively impact the gasoline pool to meet specifications.

Table 3-14. Woody Gasoline Qualities vs. US Specs

	Carb Regular Specs	PD3 Specs	WG Qualities	Comments
WG benefits				
RON	92.0	92.0	87.3	WG low octane
MON	82.0	82.0	81.3	WG low octane
AKI	87.0	87.0	84.3	WG low octane
RVP	7.0	9.0	12.2	WG high RVP
WG negatives	**Specs**	**Specs**	**WG Qualities**	
Aromatic	22.0	none	26.6	WG Hi Aromatic
T10 (Max)	158	158	73	WG good T10
T50 (Max)	213	250	196	WG good T50
T90 (Max)	305	374	334	WG fairly Hvy
DI	1,250	1,250	1,031	WG fairly Hvy

Below is a summary of the model runs.

Table 3-15. Summary of Model Runs

Year	YEAR 2022							YEAR 2040						
Model Types	CONFIGURATION 2022				REGIONAL 2022			CONFIGURATION 2040				REGIONAL 2040		
LP Models	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL	CRK	LTCOK	HVYCOK	CAL	PD2	PD3	PDCAL
Fuel V1 Mid Ron 10%	INF	INF	INF	INF	Feas w/ TOL	Feasible	INF	INF	INF	INF	INF	INF	INF	INF
Fuel V2 Mid RON 30%	Feasible	Feasible	Feasible	INF	Feasible	Feasible	INF	Feas w/ TOL	Feas w/ TOL	Feas w/ TOL	INF	Feasible	Feasible	INF
Fuel V3 Hi RON 10%	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF
Fuel V4 Hi RON 30%	Feas w/ TOL	Feas w/ TOL	Feas w/ TOL	INF	Feas w/ TOL	Feas w/ TOL	INF	Feas w/ TOL	Feas w/ TOL	Feas w/ TOL	INF	Feas w/ TOL	Feas w/ TOL	INF
Fuel B2 Mid RON 10%	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF
Fuel B4 Mid RON 30%	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF	INF

All of the woody gasoline cases are infeasible. The woody gasoline blending RON is too low to achieve the targeted finished RON specifications. Removing ethanol with a blending RON in the range of 135 from the gasoline pool and substituting it with an 87 RON from woody gasoline imposes refinery to increase BOB octane (or refinery-sourced octane) significantly to offset the RON differential, which turns out to be too large to achieve for the refinery.

All of the California cases (regional and configuration) are infeasible. With respect to bio-reformate, the heavy T90 distillation of 348F is too high compared to the California T90 specification of 305F.

The runs for bio-reformate were often infeasible due to the negative distillation blending impact. To provide additional insight, the bio-reformate was substituted with toluene (TOL) in a number of cases. This was a screening attempt to review “what if bio-reformate was recut at the source to a lighter component.” To be clear, this is not a rigorous simulation of re-cutting the bio-reformate, only an approximation.

3.14 Closing the Octane Balance

Closing the octane gap in mid to high RON scenarios is a delicate balance, and will be unique to each refinery. Increasing the refinery-sourced octane pool 2–3 numbers is quite different than 4–5. When large gains are required, the alkylate and reformate are two significant players among the gasoline blending components.

Reformates have advantage of high octane and low RVP, but could also have potential drawbacks include:

1 The amount of naphtha feedstock to the reformer is limited
2 Limits on reforming throughput
3 Practical operational limits on high severity (some refiners might achieve 98 RON, while others might achieve 101 RON)
4 Incremental severity is fully dependent on the base “starting point” – going from 90 to 95 is more likely than 95 to 100, although both are the same 5-point gain
5 Reformate is heavy and impacts the DI or T90 blending specifications
6 Higher severity reduces liquid volume recovery, negatively impacting margin

Alkylate production is typically limited by the amount of olefin feedstock to the unit. The olefin feedstock is primarily supplied by the FCC. Some of the factors that influence the amount of olefins produced from the unit include the throughput of the unit, catalyst type, and operating conditions. The other factor influencing alkylate is the capacity of the alkylation unit. There are octane differences in C3 versus C4 alkylate. C3 alkylate is about 6 RON lower than C4 and incremental olefins are often made using ZSM5 which preferentially produces C3 propylene, or pulls propylene from sales to the alkylation feed. Alkylation units are typically designed for C4 feed, although C3 alkylation occurs.

Other high octane and low RVP blendstocks include iso-octene, iso-octane, and the other ethers, which are not currently in use in the United States. These are usually produced outside of a refinery and not considered in this study for meeting RON specification.

3.15 RVP Analysis

We analyzed how a component quality impacts the value. One traditional approach – and the one we used – compares octane (RON) and RVP. This approach is well suited because RON and RVP are constraining specifications.

Throughout the LP scenarios, RVP is a constraining specification. This is the reality at the refinery, especially during summer blending. Usually a refiner will trim the blend with inexpensive NC4 until the blend is optimized without RVP give-away to reach the allowable RVP specification.

With the analysis of RVP and RON we attempt to quantify the impact that both RVP and RON have on the blend value of a component. For this analysis, we use Fuel 14 (E10 mid RON) and

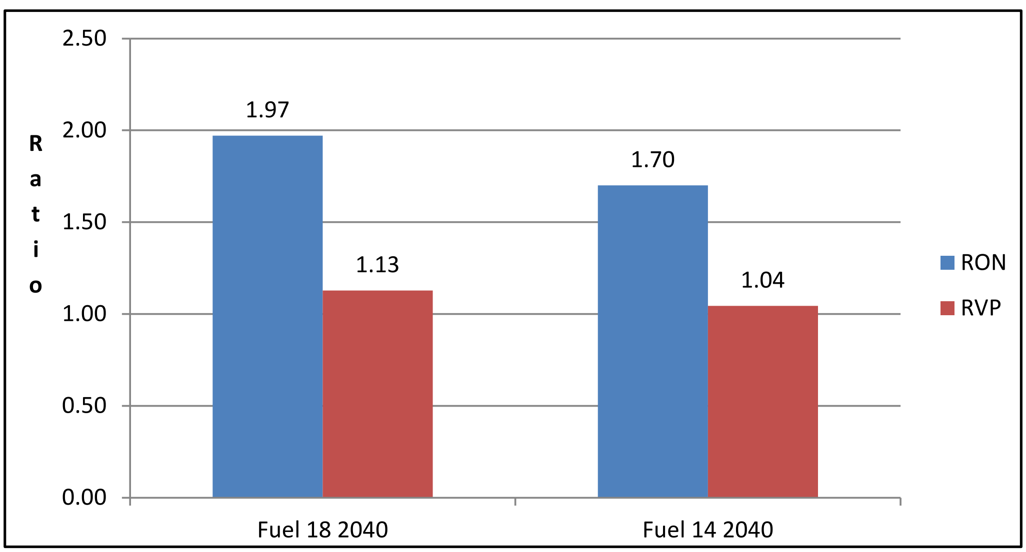
Fuel 18 (E20 high RON) because they are heavily constrained cases. From the analysis, we developed the following component blend values ($/BBL) as a function of RVP and RON

Base Blend Values = RON (0.38) + RVP (-1.11) + 102.37
Fuel 18 Blend Values = RON (0.88) + RVP (-1.24) + 63.80
Fuel 14 Blend Values = RON (0.79) + RVP (-1.19) + 68.63

The coefficients for RON and RVP represent the “slope” of the impact these two qualities have on the component blend value. A larger slope translates to a higher impact the quality makes of the blend value. Clearly the “positive” RON coefficient increases the value and the “negative” RVP coefficient decreases the value. Above, the value of a blend component in the base case is a function of 0.38 times RON. In Fuel 18, the blend value increases from a function of 0.38 * RON to 0.88 * RON, over two times higher. This is in stark contrast to the RVP coefficient, which remains relatively flat from 1.11 to 1.24. In other words, blending to high RON does not significantly impact the RVP balance at the refinery. This is in part because the higher RON blends are accomplished with alkylate and reformate, both have low RVP, which tends to reduce the pool RVP.

If we perform a similar analysis on the incentives associated with specification, we get similar results. Incentives reported in the LP reflect how much the specification impacts the margin.

Figure 3-18. Specification Incentives: Ratio of HOF/Base



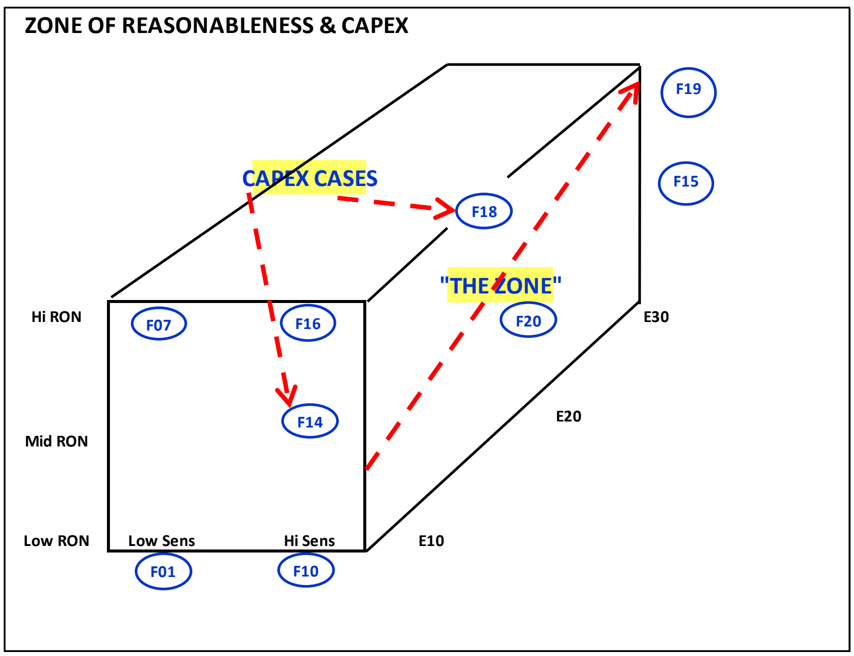
With respect to RVP, there is little change compared to the base case.

While we fully expect the RON quality to impact a component's blending value, and RON incentives are more challenging for Fuel 14 and 18, we identify that RVP does not behave the same way. That is, high HOF scenarios at higher ethanol blends (E20 was examined in these examples) do not appear to significantly impact the refiners' RVP position.

To be clear, this quantitative assessment is provided to demonstrate the "order of magnitude" impacts for RVP and RON, which only applies to Fuel 14 and Fuel 18 under the full set of assumptions within these LP models.

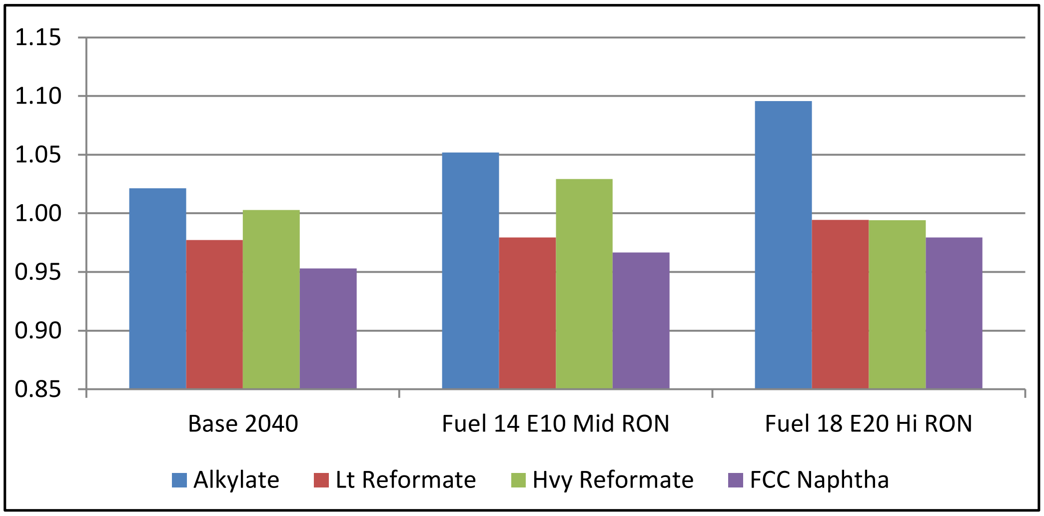
3.16 Capital Analysis

There are two 2040 cases which are evaluated for capital: Fuel 14 (mid RON E10) and Fuel 18 (high RON E20). Both cases have significant pressure to produce the incremental octane requirements. Cases in 2040 are more significant because 100% of the fuel is converted to HOF.



We estimate component blending values from the LP, shown below for four major blend components: Alkylate, Light (Lt) Reformate, Heavy (Hvy) Reformate, and FCC Naphtha. The combination of alkylate, reformate, and FCC naphtha comprises about 80% of the total gasoline pool.

Figure 3-19. Approximate Component Values vs. ULR



In the base 2040 case, prior to HOF production, Alkylate has a value approximately 1.02 X ULR. In Fuel 14 and Fuel 18, the value of alkylate grows to 1.05 and 1.1 times ULR, clearly component with the strongest growth value. Heavy reformate increases in Fuel 14, but decreases in Fuel 18.

This data provides clear indication that alkylate is the preferred component when incremental refinery-sourced octane is required. The high blending value of alkylate is consistent with all the HOF cases. The use of high octane reformate can be limited to the heavy distillation associated with blending.

Consequently, alkylate is the focus for the investment analysis. Alkylate is produced from C3 and C4 olefins. In the refinery, these olefins are primarily produced from the FCC. Both isobutane and C4 olefins are required for C4 alkylate production, and the FCC typically generates 90% of these in a refinery. Generally speaking, the volume of alkylate produced is directly related to the FCC throughput which is the feedstock source. C3 alkylate is about 90 RON versus C4 alkylate of 96 RON, making C4 alkylate preferential to increase the octane balance.

If olefin feedstock is limiting alkylation production, a refiner could use a different catalyst additive to increase overall FCC LPG production, including C3/C4 olefins. Increasing FCC conversion can increase LPG production. These two opportunities will likely fall short for any significant increase in alkylation production. A capital spending option is available, which is a C4 dehydrogenation unit that converts NC4 to C4 olefins and can provide sufficient alkylate olefin feedstock. The C4 dehydrogenation is the basis for this analysis

C4s are required for alkylation and dehydrogenation. On balance, the US refining industry is a net buyer of C4s. C4 production has grown directionally with higher production of Tight Light Oil (TLO) in recent year, and should continue to track TLO. Most refiners with pipeline access should have the capability to purchase C4's. There are capital spending options to convert NC4 to IC4 with a but we have assumed purchases are available versus capital investment.

The assumptions of the study include a reduction in G/D which creates a "tug of war" with respect to FCC throughput. A reduction in gasoline creates pressure to reduce FCC throughput, however there is incentive to run the unit for higher LPG production to feed the alkylation unit. This balance will be different for specific refiners.

To summarize the capital spending development: PADD 3 cases in 2040 were utilized; Capital Spending was allowed for C4 Dehydrogenation and Alkylation; Incremental IC4 and NC4 purchases were allowed; FCC is allowed to optimize on throughput and severity; these assumptions are used for both Fuel 14 and Fuel 18

To be clear, this is not an optimized investment analysis. Individual refineries will have unique reconfiguration opportunities. The intent was to develop a realistic aggregate scenario on highly constrained cases to analyze capital impact.

With the addition of capital, there is an increase in variable margin, about $0.60/Bbl for both cases examined. Some of the margin gain is from incremental crude and gasoline production because the severe octane production constraint is improved from more available alkylate. More alkylate allows lowering reformer severity, which contributes to an overall C5+recovery improvement of 2%. This variable margin gain would be offset by the cost of capital and incremental fixed costs which was incorporated to achieve that gain. The objective of this analysis is not to present detailed economics of the two cases, rather to make observations on the impact of capital spending to a strained octane condition. Accordingly, capital spending– specifically around the alkylation area -can improve refinery operations in an otherwise constrained octane position from high HOF demands. This will have limits, emphasizing this analysis was on two cases that were near the "zone of reasonableness" described above.

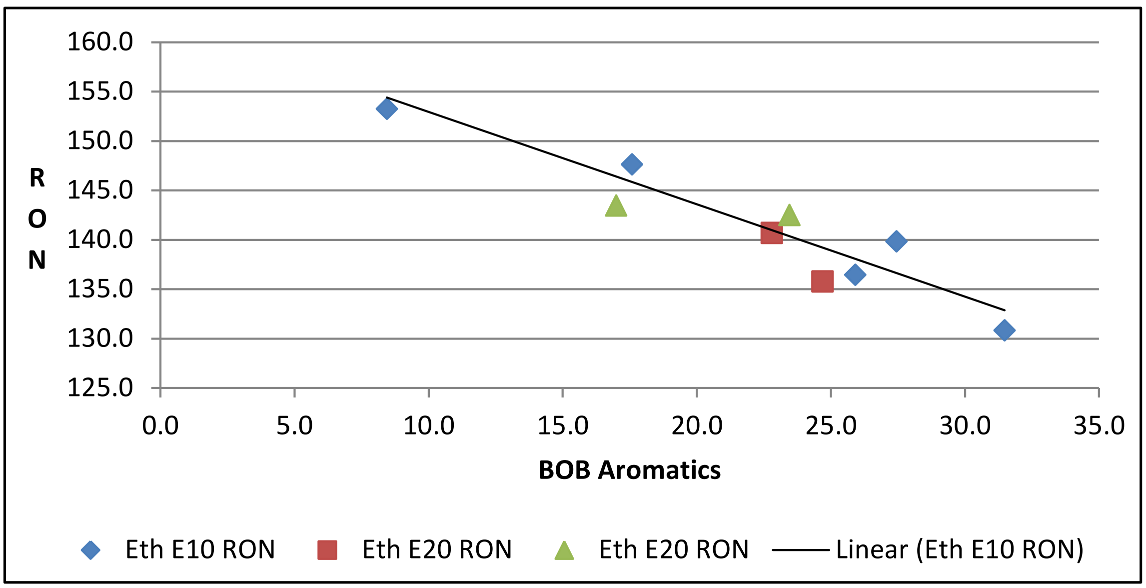
An interesting outcome for both capital cases is reformer throughput increases because there is more alkylate to blend off with the heavy reformate. Reformer severity reduces with the production of incremental Octane production cost drops by ~ 0.5 cents/oct*gal for the capital cases.

4. Conclusions

The emphasis of this analysis is a matrix approach to high octane fuel (HOF) at different RON levels (low, mid, high) and different ethanol blending levels (E10, E20, E30). The analysis incorporates LP methods using regional/aggregate models and generic configuration models. Two scenario years (2022 and 2040) are the model basis, in which 50% of the current gasoline pool is converted to HOF in 2022, and 100% in 2040.

Ethanol Blending. The Study identified a relationship of ethanol blending RON as a function of the BOB composition. We used aromaticity as the variable to define composition. Figure 4-1 is based on the measured lab data to develop the ethanol blending RON versus BOB aromatics shown below:

Figure 4-1. Lab RON Data vs. BOB Aromatics



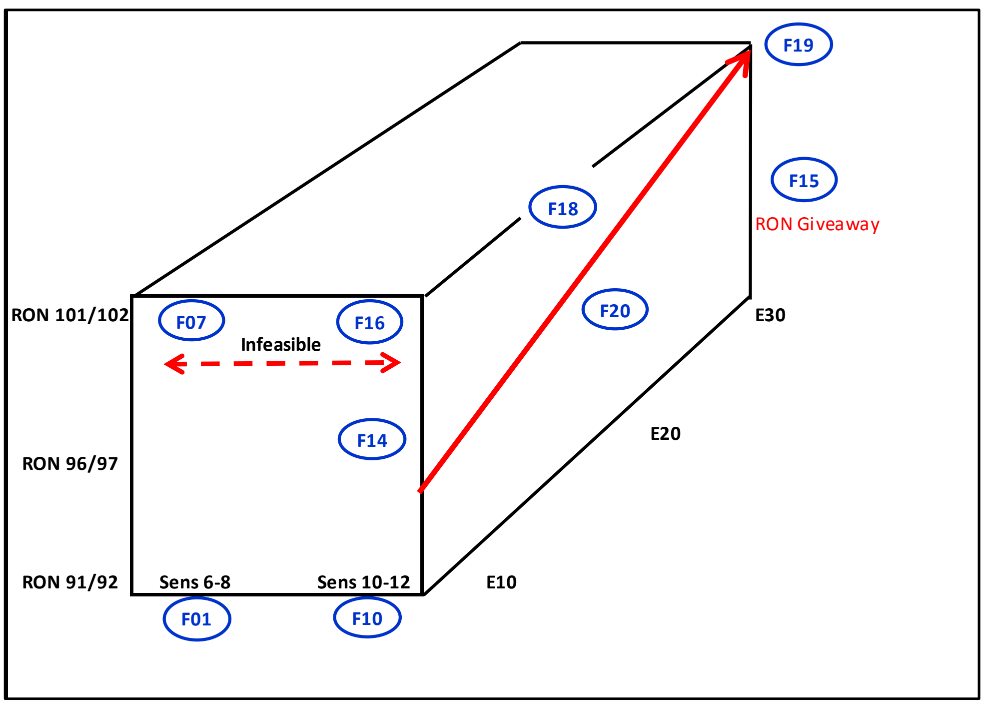
This relationship is used in the modeling strategies so that the refinery LP operations optimize BOB aromaticity and ethanol blending values. A low aromatic (high paraffin) BOB will benefit more from ethanol RON blending value compared to a high aromatic (low paraffin) BOB.

An identified trend is noted between in the modeling responses between 2022 and 2040. In 2022, only 50% of the pool is converted to HOF versus 100% in 2040; consequently, the need for incremental refinery-sourced octane is lower in 2022. We observe that initial “increments” of octane take advantage of a lower aromatic blend to gain a higher blend RON from ethanol. At some point, however, the ethanol blend impacts from BOB aromaticity are insufficient to overcome the octane imbalance and the refiner is forced to a higher aromatic blend. The higher aromatic blend generally comes from a combination of more and higher severity reformate.

To be clear, just as the above blends were produced in a lab to represent batch blends, every refinery will have different blending patterns. Understanding the ethanol blend behavior will likely be a study area for all refiners.

Overview of Results. One cannot presume that all refiners will have the same results as those of the aggregate model. Every refinery is unique. Nor can one take the configuration responses and extrapolate to an aggregate solution. Using a bell curve analogy, the top of the bell curve would be our expectations for the aggregate approach. We know, however, that there are "more distressed" and "less-distressed" refiners to the left and right of the average. This is often referred to as "winners and losers" and the study does not attempt to make this distinction. However, with this matrix approach, combined with our modeling strategies and experience in refinery operations, we define a "zone of reasonableness" within the matrix, shown below:

Figure 4-2. Zone of Reasonableness



Reasonableness can take on different meanings as explained in the beginning of this report the simplest requires that all cases are feasible under the HOF scenarios. Beyond that, other “gauges” for reasonableness include:

- Minimal capital costs. Costs may include fractionation, storage, piping, and blending systems to manage and “cherry pick” streams for more accurate blending. Process expansions could be in this category, but could extend to new process units.
- No or limited RON giveaway
- No remarkable changes in marginal octane production costs (marginal values)
- Reformer severity increases approximately 5 numbers or less versus base
- Reasonably consistent component blend values versus base
- No significant drops in production, crude runs, or operations
- No excess gasoline exports to “dump” bad quality into non-US gasoline

Using these generalizations, the following statements are offered regarding the “zone of reasonableness” under the matrix:

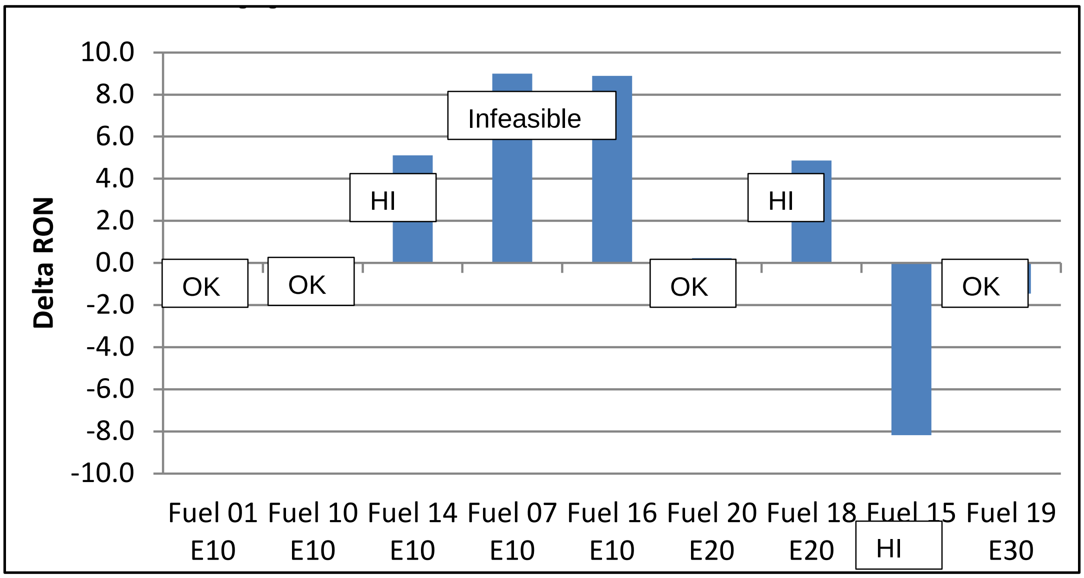
- **LOW RON:** essentially today’s E10 gasoline made under a Fuel 01 or Fuel 10 scenario
- **MID RON**: more likely under a Fuel 20 E20 scenario with minimal capital investment or E10 Fuel 14 with more extensive investment which potentially places some refiners “at-risk.” E30 for mid RON Fuel 15 provides excessive octane to the system
- **HI RON:** likely under a Fuel 19 E30 scenario with minimal investment, or Fuel 18 E20 with more extensive investment and potentially placing some refiners “at-risk”
- **HI RON E10:** scenarios Fuel 16 and Fuel 07 are considered unreasonable and infeasible under conditions and constraints of the study
- **E20 cases** are flexible under mid and high RON conditions. Fuel 20 is likely for mid-RON with minimal capital investment. E20 for high RON would likely require more extensive investment and potentially places some refiners “at-risk.”

Incremental Octane. The figure below shows the approximation of the **incremental** refinery-sourced octane requirements for each scenario. These are approximations because ethanol blend values change based on composition, and all models will have slightly differential octane requirements. Nevertheless, this generalized approach provides insight to this analysis.

To clarify, the figure below shows the approximate incremental BOB RON versus today's BOB RON. For example, Fuel 14 requires a BOB RON increase of about 5.1 and Fuel 18 requires a BOB RON increase of 4.9. Increasing the refinery pool by more than a couple numbers through operations alone (no capital) is a challenge. A 3-4 to increase will likely require some level of capital spending or operational changes, and would likely place some refiners "at-risk." Fuel 07 and Fuel 16 have increases of about 9 RON and are infeasible.

These approximations of delta BOB RON for each HOF scenario are below:

Figure 4-3. Approximate BOB Pool Delta RON



Fuel 15 has a BOB RON **reduction** of about 8, which can raise the question of what is wrong with dropping the refinery-sourced octane demand. Refinery operations have significant flexibility within a range, but above or below design conditions potentially create operational challenges. A refinery is designed and configured for a specific crude quality input to produce specification grade products. This is done with interactions between all of the process units to produce gasoline components for blending. If a refinery is producing pool RON of 87 and then the requirement drops to 79 RON, while the refinery can likely make this adjustment, it is not designed to that point. A sub-optimal operation is very much indicated in our modeling because of the RON give-way in this case. Very few US refinery operations have octane giveaway, and if it exists it is much lower than 8 numbers. A refinery would likely respond with a reconfiguration analysis to re-optimize their operation.

There are four scenarios with a RON delta about 1 or less, and two scenarios with an incremental RON around 5 numbers. The delta BOB RON gap between 1 RON and 5 RON was not in the scenario matrix, but would be an opportunity for future study efforts.

Market Issues. It has been stated that 2040 gasoline PADD 3 exports in the E20 and E30 cases increased by 400 mbpd (Fuel 20) and 750 mbpd (Fuel 10), respectively, versus the 2040 non-HOF base case. The study basis was to match US gasoline demand using the EIA forecast reduction. Clearly, if today's E10 pool is converted to an E20 or E30 pool, there is excess gasoline blendstock material. Another outcome could be a drop in crude throughput to minimize exports, but our methodology did not capture that outcome. The market impact due to excess exports is out of scope, but large exports could result in lower gasoline prices which could indicate a refinery throughput reduction.

Another market factor which could influence HOF scenarios is naphtha. Light naphtha is low octane, high RVP material, which would generally not be a preferred gasoline blending component. As stated throughout this report, we hold material balances reasonably tight versus target, including naphtha. Light naphtha can be sold into the petrochemical markets, including steam cracking operations. Naphtha competes, however, with other feeds, so we do not assume that an HOF scenario can simply "sell to the cracking market" to help the HOF production scenario.

Some refiners manage light naphtha seasonally be sending the material to storage in the summer, and blending off that inventory in the winter. Winter gasoline has higher RVP specification, making the high RVP, low octane easier to blend off. We know this strategy is used, but we cannot quantify the significance. In HOF scenarios, refiners might evaluate similar storage and blending strategies.

Seasonal. All of the Study's models are for the more rigorous low RVP summer specification. We would expect the summer results to be reflective of the most rigorous condition to evaluate the HOF scenarios. (Restated, winter would be easier.)

Operations. For higher refinery-sourced octane requirements, alkylation unit increases are prevalent. Reformer throughput and severity increases are also prevalent, up to distillation specification constraints. Increasing refinery-sourced octane will always remain a refinery specific optimization exercise. Some refiners have more robust reformers than others, while others have more potential for incremental alkylate.

Acknowledgements

We would like to acknowledge the support received during this project from the US Department of Energy, Argonne National Laboratory, and USCAR Fuels Working Group.

Appendix A. Summary Modeling Results

Appendix A: Summary Modeling Results

CASE ID ==>	2015 PD2	2015 PD3	2015 CAL	2022 PD2	2022 PD3	2022 CAL	2040 PD2	2040 PD3	2040 CAL
Crude	3,597,042	8,616,512	1,734,766	3,703,237	8,870,897	1,763,124	3,652,060	9,432,498	1,818,012
Other C3+ Input	286,710	593,292	123,774	299,190	1,077,542	144,160	289,239	1,107,284	188,660
LPG produced	148,089	385,376	59,826	156,745	466,140	60,394	132,395	397,048	39,320
Finished Mogas	2,148,782	4,259,261	965,736	2,016,536	4,253,573	1,006,125	1,633,365	3,976,537	755,812
USA Mogas	2,147,782	3,979,355	964,736	2,015,536	3,813,708	880,550	1,632,365	3,024,404	698,307
USA non-HOF	2,147,782	3,979,355	964,736	2,015,536	3,813,708	880,550	1,632,365	3,024,404	698,307
USA non-HOF CG	1,833,002	3,179,073	114,683	1,724,389	3,046,739	104,676	1,393,125	2,416,171	83,011
USA non-HOF RFG	314,780	800,282	850,053	291,148	766,969	775,874	239,240	608,233	615,295
USA Gasoline HOF	0	0	0	0	0	0	0	0	0
USA HOF CG	0	0	0	0	0	0	0	0	0
USA HOF RFG	0	0	0	0	0	0	0	0	0
Export Gasoline	1,000	279,906	1,000	1,000	439,865	125,575	1,000	952,133	57,505
Ethanol	215,852	399,925	96,956	202,561	383,278	88,495	164,069	303,983	70,187
Total Diesel	1,070,173	2,772,562	366,573	1,254,565	3,372,796	395,808	1,524,591	4,055,886	718,391
US Diesel	1,070,173	1,806,136	366,573	1,166,849	2,045,271	395,808	1,259,491	2,199,012	427,233
Export Diesel	0	966,426	0	87,716	1,327,525	0	265,101	1,856,873	291,158
Total Jet	243,030	844,469	302,213	252,344	907,087	309,297	294,441	1,012,926	347,253
Total Distillate	1,313,203	3,617,031	668,787	1,506,909	4,279,883	705,105	1,819,032	5,068,812	1,065,644
Heavies	213,495	458,575	87,271	221,732	460,325	106,351	236,076	496,585	103,605
Other Lights	31,093	519,482	70,029	29,373	526,570	33,971	31,319	536,067	24,692
C5+ Recovery	96.8%	96.1%	96.8%	95.8%	96.7%	98.4%	96.5%	96.8%	99.4%
UNIT OPERATIONS									
Crude Tower	3,597,042	8,616,512	1,734,766	3,703,237	8,870,897	1,763,124	3,652,060	9,432,498	1,818,012
Vacuum Tower	1,565,972	3,677,788	886,970	1,848,027	3,751,111	927,168	1,843,885	4,193,640	977,690
Sats Gas Plant	198,565	473,101	159,220	189,511	448,782	163,747	161,659	415,344	118,246
Unsats Gas Plant	338,773	687,540	173,503	341,477	891,670	180,743	287,210	787,924	142,241
FCC	1,096,577	2,368,170	571,467	1,041,832	2,486,475	511,133	868,924	2,409,130	385,888
Total HYK	264,000	964,128	405,100	293,380	1,048,383	456,812	368,797	1,224,688	543,510
Delayed Coker	515,298	1,418,416	371,920	715,593	1,396,942	371,278	712,040	1,684,132	392,957
Total Reforming	674,555	1,617,760	291,389	544,898	1,680,475	272,313	521,597	1,785,089	235,578
Avg Reforming Severity	90.0	90.7	95.3	90.0	90.0	92.2	90.0	90.4	92.1
000Sev*BPD	60,710	146,764	27,765	49,041	151,243	25,094	46,944	161,423	21,695
C5/C6 Isomerization	164,800	117,209	35,504	185,655	121,207	79,495	212,872	130,012	76,885
Total Alky	266,672	436,343	186,271	284,272	605,483	219,698	269,571	581,703	178,911
TOTAL ULSD+DHT	1,004,359	2,431,255	263,575	1,127,433	2,762,332	324,211	1,237,613	3,180,176	576,665
VGO Feed HDT	449,294	1,342,877	389,965	567,714	1,387,218	421,272	536,902	1,440,482	275,561
Hydrogen Plant MSCFD	796,950	1,510,000	1,099,851	825,265	1,563,649	1,307,874	871,807	1,651,833	1,381,632
Sulfur TPD	5,415	18,305	2,980	7,950	18,706	3,313	8,121	21,491	3,770
Tota HYD SCF/BblCrude	457	570	830	505	582	920	568	622	971
Reformer HYD SCF/BblCrude	186	184	185	146	180	167	141	187	140
BLEND SUMMARIES									
NON-HOF Blend Percents									
C4s	3%	2%	0%	3%	2%	0%	2%	2%	0%
Naphtha	10%	12%	18%	11%	11%	19%	8%	10%	13%
Isomerate	8%	3%	4%	9%	3%	4%	13%	4%	8%
Alklate (inc. dim/poly)	13%	10%	21%	14%	10%	25%	17%	12%	26%
Reformate	27%	31%	25%	23%	36%	19%	27%	36%	25%
FCC	30%	32%	21%	30%	28%	23%	23%	26%	19%
Oxygenate (inc. BR/WG)	10%	10%	10%	10%	10%	10%	10%	10%	10%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
HOF Blend Percents									
C4s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Naphtha	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Isomerate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Alklate (inc. dim/poly)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Reformate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FCC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oxygenate (inc. BR/WG)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix A: Summary Modeling Results

CASE ID ==>	2022 CRK BASE	2022 LTCOK BASE	2022 HVY COKE BASE	2022 CAL FIG BASE	2040 CRK BASE	2040 LTCOK BASE	2040 HVY COKE BASE	2040 CAL FIG BASE	2022 PD3BASE
Crude	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	8,870,897
Other C3+ Input	8,885	10,555	8,657	16,684	8,109	9,181	7,552	21,737	1,077,542
LPG produced	8,563	9,032	9,883	8,651	8,740	8,904	9,211	7,777	466,140
Finished Mogas	80,008	85,929	86,125	84,811	74,009	77,153	73,634	85,796	4,253,573
USA Mogas	79,998	85,919	86,115	84,801	73,999	77,143	73,624	85,786	3,813,708
USA non-HOF	79,998	85,919	86,115	84,801	73,999	77,143	73,624	85,786	3,813,708
USA non-HOF CG	61,598	66,157	69,896	8,703	56,979	59,400	58,236	8,823	3,046,739
USA non-HOF RFG	18,400	19,761	16,219	76,097	17,020	17,743	15,387	76,963	766,969
USA Gasoline HOF	0	0	0	0	0	0	0	0	0
USA HOF CG	0	0	0	0	0	0	0	0	0
USA HOF RFG	0	0	0	0	0	0	0	0	0
Export Gasoline	10	10	10	10	10	10	10	10	439,865
Ethanol	8,040	8,635	8,655	8,522	7,438	7,754	7,400	8,622	383,278
Total Diesel	43,117	48,944	46,413	45,076	48,486	58,317	58,553	53,795	3,372,796
US Diesel	43,107	48,934	46,403	45,066	48,476	58,307	58,543	53,785	2,045,271
Export Diesel	10	10	10	10	10	10	10	10	1,327,525
Total Jet	10,500	12,101	11,162	18,000	10,500	10,500	10,500	18,000	907,087
Total Distillate	53,617	61,045	57,575	63,076	58,986	68,817	69,053	71,795	4,279,883
Heavies	16,697	0	0	0	16,513	0	0	0	460,325
Other Lights	10	10	10	8,561	10	10	10	4,874	526,570
C5+ Recovery	95.1%	92.7%	90.6%	98.7%	95.0%	92.5%	90.7%	99.3%	96.7%
UNIT OPERATIONS									
Crude Tower	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	8,870,897
Vacuum Tower	46,624	67,445	77,343	75,236	46,624	67,445	77,343	75,236	3,751,111
Sats Gas Plant	7,235	4,905	7,240	8,806	7,312	5,102	6,232	7,264	448,782
Unsats Gas Plant	11,195	15,411	13,978	17,578	10,391	13,106	12,091	16,216	891,670
FCC	37,397	48,761	41,823	48,814	34,421	46,295	40,138	44,405	2,486,475
Total HYK	0	0	21,669	34,289	0	0	22,500	37,500	1,048,383
Delayed Coker	0	34,429	43,158	38,574	0	34,859	43,579	38,181	1,396,942
Total Reforming	36,748	31,955	29,604	20,404	37,241	33,547	28,704	22,767	1,680,475
Avg Reforming Severity	90.0	90.0	90.9	93.5	90.0	90.0	91.9	90.0	90.0
000Sev*BPD	3,307	2,876	2,691	1,907	3,352	3,019	2,637	2,049	151,243
C5/C6 Isomerization	6,000	6,000	6,000	3,760	6,000	6,000	6,000	3,443	121,207
Total Alky	6,796	8,630	7,552	21,256	6,308	7,222	6,397	19,476	605,483
TOTAL ULSD+DHT	43,053	53,153	42,402	28,509	48,433	61,993	50,731	46,509	2,762,332
VGO Feed HDT	0	24,377	40,063	45,856	0	24,537	38,275	41,074	1,387,218
Hydrogen Plant MSCFD	0	30,677	86,482	100,000	0	36,399	91,326	100,000	1,563,649
Sulfur TPD	38	339	487	245	39	346	490	251	18,706
Tota HYD SCF/BblCrude	224	426	792	912	228	476	825	989	582
Reformer HYD SCF/BblCrude	224	210	201	162	228	222	202	165	180
BLEND SUMMARIES									
NON-HOF Blend Percents									
C4s	2%	2%	1%	0%	2%	1%	1%	0%	2%
Naphtha	5%	5%	14%	9%	5%	4%	12%	17%	11%
Isomerate	7%	7%	7%	4%	8%	8%	8%	4%	3%
Alklate (inc. dim/poly)	8%	10%	9%	25%	8%	9%	9%	28%	10%
Reformate	39%	33%	31%	32%	42%	39%	34%	24%	36%
FCC	29%	33%	28%	19%	25%	29%	26%	17%	28%
Oxygenate (inc. BR/WG)	10%	10%	10%	10%	10%	10%	10%	10%	10%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
HOF Blend Percents									
C4s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Naphtha	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Isomerate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Alklate (inc. dim/poly)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Reformate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FCC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oxygenate (inc. BR/WG)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix A: Summary Modeling Results

CASE ID ==>	2022 CAL	2040 PD3BASE	2040 CAL	2022 PD3 FUEL 01	2022 CAL FUEL 01	2040 PD3 FUEL 01	2040 CAL FUEL 01	2022 PD3 FUEL 07	2022 CAL FUEL 07
Crude	1,763,124	9,432,498	1,818,012	8,870,897	1,763,124	9,432,498	1,818,012	8,870,897	1,756,593
Other C3+ Input	144,160	1,107,284	188,660	1,080,325	147,994	1,109,962	190,283	1,072,747	188,177
LPG produced	60,394	397,048	39,320	448,726	57,091	379,551	40,976	524,476	72,341
Finished Mogas	1,006,125	3,976,537	755,812	4,292,393	1,016,607	4,023,370	809,458	4,112,979	1,018,942
USA Mogas	880,550	3,024,404	698,307	3,813,708	849,757	3,024,404	695,051	3,738,929	863,284
USA non-HOF	880,550	3,024,404	698,307	1,906,854	426,748	0	0	1,906,854	440,275
USA non-HOF CG	104,676	2,416,171	83,011	1,523,370	52,338	0	0	1,523,370	52,338
USA non-HOF RFG	775,874	608,233	615,295	383,484	374,410	0	0	383,484	387,937
USA Gasoline HOF	0	0	0	1,906,854	423,009	3,024,404	695,051	1,832,075	423,009
USA HOF CG	0	0	0	1,523,370	50,285	2,416,171	79,756	1,463,630	50,285
USA HOF RFG	0	0	0	383,484	372,724	608,233	615,295	368,446	372,724
Export Gasoline	125,575	952,133	57,505	478,685	166,850	998,966	114,407	374,050	155,658
Ethanol	88,495	303,983	70,187	382,324	85,189	302,440	69,505	374,846	86,549
Total Diesel	395,808	4,055,886	718,391	3,372,796	395,808	4,055,886	671,054	3,427,294	395,808
US Diesel	395,808	2,199,012	427,233	2,045,271	395,808	2,199,012	427,233	2,045,271	395,808
Export Diesel	0	1,856,873	291,158	1,327,525	0	1,856,873	243,821	1,382,023	0
Total Jet	309,297	1,012,926	347,253	907,087	309,297	1,012,926	347,253	907,087	309,297
Total Distillate	705,105	5,068,812	1,065,644	4,279,883	705,105	5,068,812	1,018,307	4,334,381	705,105
Heavies	106,351	496,585	103,605	460,325	98,913	496,585	103,605	460,325	106,351
Other Lights	33,971	536,067	24,692	526,570	39,093	536,067	26,229	506,235	33,865
C5+ Recovery	98.4%	96.8%	99.4%	97.1%	98.7%	97.3%	99.9%	95.5%	96.9%
UNIT OPERATIONS									
Crude Tower	1,763,124	9,432,498	1,818,012	8,870,897	1,763,124	9,432,498	1,818,012	8,870,897	1,756,593
Vacuum Tower	927,168	4,193,640	977,690	3,751,111	927,168	4,193,640	977,690	3,751,111	923,733
Sats Gas Plant	163,747	415,344	118,246	429,933	155,650	394,093	125,008	516,705	175,916
Unsats Gas Plant	180,743	787,924	142,241	891,670	179,877	787,924	159,030	871,031	197,336
FCC	511,133	2,409,130	385,888	2,486,475	569,598	2,409,130	401,936	2,412,804	526,850
Total HYK	456,812	1,224,688	543,510	1,048,383	426,111	1,224,688	531,364	1,048,383	439,987
Delayed Coker	371,278	1,684,132	392,957	1,396,942	381,468	1,684,132	390,043	1,391,714	370,460
Total Reforming	272,313	1,785,089	235,578	1,518,734	231,487	1,602,574	226,532	1,826,744	318,933
Avg Reforming Severity	92.2	90.4	92.1	90.0	93.1	90.0	91.2	97.0	97.3
000Sev*BPD	25,094	161,423	21,695	136,686	21,550	144,232	20,656	177,131	31,023
C5/C6 Isomerization	79,495	130,012	76,885	121,207	79,739	130,012	46,969	175,023	79,223
Total Alky	219,698	581,703	178,911	605,483	219,698	581,703	199,366	605,483	219,698
TOTAL ULSD+DHT	324,211	3,180,176	576,665	2,762,332	390,233	3,180,176	576,665	2,813,249	243,904
VGO Feed HDT	421,272	1,440,482	275,561	1,387,218	444,982	1,440,482	275,561	1,352,562	451,107
Hydrogen Plant MSCFD	1,307,874	1,651,833	1,381,632	1,563,649	1,307,874	1,651,833	1,381,632	1,563,649	1,175,822
Sulfur TPD	3,313	21,491	3,770	18,708	3,392	21,492	3,738	18,732	3,280
Tota HYD SCF/BblCrude	920	622	971	576	898	614	950	601	900
Reformer HYD SCF/BblCrude	167	187	140	160	145	162	129	241	219
BLEND SUMMARIES									
NON-HOF Blend Percents									
C4s	0%	2%	0%	3%	0%	N/A	N/A	0%	0%
Naphtha	19%	10%	13%	9%	19%	N/A	N/A	14%	15%
Isomerate	4%	4%	8%	1%	4%	N/A	N/A	5%	2%
Alklate (inc. dim/poly)	25%	12%	26%	11%	32%	N/A	N/A	1%	15%
Reformate	19%	36%	25%	47%	15%	N/A	N/A	39%	28%
FCC	23%	26%	19%	18%	20%	N/A	N/A	31%	30%
Oxygenate (inc. BR/WG)	10%	10%	10%	10%	10%	N/A	N/A	10%	10%
Total	100%	100%	100%	100%	100%	N/A	N/A	100%	100%
HOF Blend Percents									
C4s	N/A	N/A	N/A	0%	0%	1%	0%	4%	0%
Naphtha	N/A	N/A	N/A	23%	26%	15%	22%	0%	12%
Isomerate	N/A	N/A	N/A	5%	0%	4%	0%	0%	5%
Alklate (inc. dim/poly)	N/A	N/A	N/A	16%	20%	11%	29%	32%	50%
Reformate	N/A	N/A	N/A	6%	11%	24%	19%	30%	23%
FCC	N/A	N/A	N/A	39%	33%	36%	20%	25%	0%
Oxygenate (inc. BR/WG)	N/A	N/A	N/A	10%	10%	10%	10%	10%	10%
Total	N/A	N/A	N/A	100%	100%	100%	100%	100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2040 PD3 FUEL 07	2040 CAL FUEL 07	2022 CRK FUEL 10	2022 LTCOK FUEL 10	2022 HVY COKE FUEL 10	2022 CAL FIG FUEL 10	2022 PD3 FUEL 10	2022 CAL FUEL 10	2040 CRK FUEL 10	2040 LTCOK FUEL 10
Crude	**No Soln**	**No Soln**	150,000	150,000	150,000	150,000	8,870,897	1,763,124	150,000	150,000
Other C3+ Input			8,999	10,770	8,806	28,532	1,087,460	142,691	8,222	9,289
LPG produced			8,114	8,478	9,483	8,468	452,612	58,240	8,182	8,369
Finished Mogas			81,137	88,020	87,823	103,004	4,276,485	1,013,207	75,137	78,273
USA Mogas			81,127	88,010	87,813	102,994	3,813,708	864,963	75,127	78,263
USA non-HOF			39,601	42,950	44,062	50,807	1,906,854	426,748	0	0
USA non-HOF CG			32,906	35,685	36,572	4,027	1,523,370	52,338	0	0
USA non-HOF RFG			6,696	7,265	7,491	46,780	383,484	374,410	0	0
USA Gasoline HOF			41,526	45,060	43,751	52,188	1,906,854	438,216	75,127	78,263
USA HOF CG			34,467	37,400	36,313	3,979	1,523,370	50,285	62,135	64,413
USA HOF RFG			7,059	7,660	7,438	48,209	383,484	387,930	12,993	13,849
Export Gasoline			10	10	10	10	462,777	148,244	10	10
Ethanol			8,133	8,823	8,804	10,325	382,324	86,710	7,513	7,826
Total Diesel			42,776	49,425	46,205	44,998	3,406,381	395,808	48,486	58,317
US Diesel			42,766	49,415	46,195	44,988	2,045,271	395,808	48,476	58,307
Export Diesel			10	10	10	10	1,361,110	0	10	10
Total Jet			10,500	10,500	10,500	18,000	907,087	309,297	10,500	10,500
Total Distillate			53,276	59,925	56,705	62,998	4,313,468	705,105	58,986	68,817
Heavies			16,697	0	0	0	460,325	106,351	16,513	0
Other Lights			10	10	10	3,103	506,235	32,189	10	10
C5+ Recovery			95.6%	93.2%	91.0%	99.3%	97.0%	98.8%	95.6%	93.2%
UNIT OPERATIONS										
Crude Tower			150,000	150,000	150,000	150,000	8,870,897	1,763,124	150,000	150,000
Vacuum Tower			46,624	67,445	77,343	75,236	3,751,111	927,168	46,624	67,445
Sats Gas Plant			7,134	4,756	7,122	8,567	440,521	162,556	7,125	4,931
Unsats Gas Plant			11,195	15,411	13,978	17,578	879,617	180,895	10,391	13,106
FCC			37,397	48,761	41,823	48,814	2,443,686	491,905	34,421	46,295
Total HYK			0	0	21,669	34,289	1,048,383	472,070	0	0
Delayed Coker			0	34,429	43,158	38,574	1,393,899	368,834	0	34,859
Total Reforming			35,856	32,041	29,513	20,209	1,599,240	259,266	35,528	31,697
Avg Reforming Severity			90.0	90.0	90.0	90.0	90.3	91.5	90.0	90.0
000Sev*BPD			3,227	2,884	2,656	1,819	144,393	23,718	3,198	2,853
C5/C6 Isomerization			6,000	6,000	6,000	1,775	141,406	79,178	6,000	6,000
Total Alky			6,796	8,630	7,552	21,256	605,483	219,698	6,308	7,222
TOTAL ULSD+DHT			42,709	53,067	42,724	31,426	2,791,911	309,007	48,433	61,993
VGO Feed HDT			0	24,377	40,063	45,856	1,367,167	394,695	0	24,537
Hydrogen Plant MSCFD			0	31,386	87,165	100,000	1,563,649	1,307,874	0	37,806
Sulfur TPD			38	340	487	246	18,777	3,347	39	346
Tota HYD SCF/BblCrude			217	428	789	919	578	909	214	470
Reformer HYD SCF/BblCrude			217	208	193	141	171	156	214	207
BLEND SUMMARIES										
NON-HOF Blend Percents										
C4s			2%	4%	3%	0%	3%	0%	N/A	N/A
Naphtha			3%	7%	8%	19%	9%	14%	N/A	N/A
Isomerate			10%	0%	5%	3%	0%	4%	N/A	N/A
Alklate (inc. dim/poly)			8%	15%	6%	31%	7%	21%	N/A	N/A
Reformate			38%	34%	40%	19%	42%	28%	N/A	N/A
FCC			29%	29%	28%	18%	30%	24%	N/A	N/A
Oxygenate (inc. BR/WG)			10%	10%	10%	10%	10%	10%	N/A	N/A
Total			100%	100%	100%	100%	100%	100%	N/A	N/A
HOF Blend Percents										
C4s			3%	1%	1%	0%	1%	0%	2%	2%
Naphtha			8%	5%	22%	30%	20%	33%	7%	7%
Isomerate			5%	13%	9%	0%	7%	0%	8%	8%
Alklate (inc. dim/poly)			9%	5%	11%	29%	22%	29%	8%	9%
Reformate			36%	31%	20%	17%	16%	8%	40%	36%
FCC			28%	35%	27%	14%	24%	20%	25%	28%
Oxygenate (inc. BR/WG)			10%	10%	10%	10%	10%	10%	10%	10%
Total			100%	100%	100%	100%	100%	100%	100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2040 HVY COKE FUEL 10	2040 CAL FIG FUEL 10	2040 PD3 FUEL 10	2040 CAL FUEL 10	2022 CRK FUEL 14	2022 LTCOK FUEL 14	2022 HVY COKE FUEL 14	2022 CAL FIG FUEL 14	2022 PD3 FUEL 14	2022 CAL FUEL 14
Crude	150,000	150,000	9,432,498	1,818,012	150,000	150,000	150,000	**No Soln**	8,870,897	1,763,124
Other C3+ Input	7,664	22,015	1,115,933	171,689	8,545	10,193	8,376		1,074,036	144,718
LPG produced	8,738	8,011	376,372	40,283	9,194	9,698	10,547		480,804	65,944
Finished Mogas	74,764	89,454	4,037,978	791,640	77,608	83,351	83,541		4,236,517	1,003,962
USA Mogas	74,754	89,444	3,024,404	698,307	77,598	83,341	83,531		3,813,708	849,757
USA non-HOF	0	0	0	0	38,799	41,671	41,766		1,906,854	426,748
USA non-HOF CG	0	0	0	0	29,875	32,086	33,899		1,523,370	52,338
USA non-HOF RFG	0	0	0	0	8,924	9,584	7,866		383,484	374,410
USA Gasoline HOF	74,754	89,444	3,024,404	698,307	38,799	41,671	41,766		1,906,854	423,009
USA HOF CG	61,606	12,614	2,416,171	83,011	29,875	32,086	33,899		1,523,370	50,285
USA HOF RFG	13,149	76,829	608,233	615,295	8,924	9,584	7,866		383,484	372,724
Export Gasoline	10	10	1,013,574	93,333	10	10	10		422,810	154,205
Ethanol	7,475	8,944	302,440	69,831	7,779	8,355	8,374		382,324	85,189
Total Diesel	58,553	50,272	4,055,886	684,478	44,457	52,039	48,617		3,372,797	395,808
US Diesel	58,543	50,262	2,199,012	427,233	44,447	52,029	48,607		2,045,271	395,808
Export Diesel	10	10	1,856,873	257,245	10	10	10		1,327,527	0
Total Jet	10,500	18,000	1,012,926	347,253	10,500	10,500	10,500		907,087	309,297
Total Distillate	69,053	68,272	5,068,812	1,031,731	54,957	62,539	59,117		4,279,884	705,105
Heavies	0	0	496,585	103,605	16,697	0	0		460,325	95,998
Other Lights	10	5,689	521,326	24,178	10	10	10		526,570	38,332
C5+ Recovery	91.3%	99.7%	97.3%	99.5%	94.6%	92.1%	90.1%		96.5%	97.8%
UNIT OPERATIONS										
Crude Tower	150,000	150,000	9,432,498	1,818,012	150,000	150,000	150,000		8,870,897	1,763,124
Vacuum Tower	77,343	75,236	4,193,640	977,690	46,624	67,445	77,343		3,751,111	927,168
Sats Gas Plant	6,057	7,688	404,938	131,414	7,622	5,304	7,695		461,559	166,917
Unsats Gas Plant	12,091	16,668	787,924	135,995	11,195	15,411	14,099		891,670	188,062
FCC	40,138	45,870	2,409,130	387,180	37,397	48,761	42,273		2,486,475	565,471
Total HYK	22,500	36,433	1,224,688	544,679	0	0	21,192		1,048,383	429,678
Delayed Coker	43,579	38,312	1,684,132	395,884	0	34,429	43,193		1,396,942	382,693
Total Reforming	27,995	16,460	1,688,839	236,188	37,228	33,164	33,223		1,739,864	311,510
Avg Reforming Severity	90.0	94.1	90.3	91.1	94.0	93.9	93.4		91.6	93.0
000Sev*BPD	2,520	1,549	152,501	21,525	3,498	3,114	3,105		159,359	28,974
C5/C6 Isomerization	6,000	100	130,012	76,966	6,000	6,000	6,000		121,207	79,502
Total Alky	6,397	20,067	601,710	171,254	6,796	8,630	7,625		605,483	219,698
TOTAL ULSD+DHT	50,731	46,509	3,180,176	576,665	44,403	55,690	44,489		2,762,346	416,554
VGO Feed HDT	38,275	42,663	1,440,482	275,561	0	24,377	40,566		1,387,218	472,112
Hydrogen Plant MSCFD	93,348	100,000	1,651,833	1,381,632	0	28,464	83,868		1,563,649	1,307,874
Sulfur TPD	490	251	21,491	3,776	38	340	487		18,709	3,383
Tota HYD SCF/BblCrude	821	964	617	985	259	449	822		591	949
Reformer HYD SCF/BblCrude	184	130	174	136	259	248	249		198	196
BLEND SUMMARIES										
NON-HOF Blend Percents										
C4s	N/A	N/A	N/A	N/A	1%	1%	0%		4%	0%
Naphtha	N/A	N/A	N/A	N/A	9%	8%	21%		21%	5%
Isomerate	N/A	N/A	N/A	N/A	15%	14%	14%		0%	4%
Alklate (inc. dim/poly)	N/A	N/A	N/A	N/A	4%	4%	4%		12%	19%
Reformate	N/A	N/A	N/A	N/A	58%	45%	50%		53%	36%
FCC	N/A	N/A	N/A	N/A	3%	17%	0%		0%	25%
Oxygenate (inc. BR/WG)	N/A	N/A	N/A	N/A	10%	10%	10%		10%	10%
Total	N/A	N/A	N/A	N/A	100%	100%	100%		100%	100%
HOF Blend Percents										
C4s	1%	0%	2%	0%	2%	3%	2%		0%	0%
Naphtha	13%	28%	13%	22%	0%	0%	0%		0%	0%
Isomerate	8%	0%	4%	5%	0%	0%	0%		0%	0%
Alklate (inc. dim/poly)	9%	28%	16%	26%	14%	17%	14%		16%	34%
Reformate	33%	16%	30%	18%	22%	24%	20%		10%	32%
FCC	26%	17%	24%	19%	53%	47%	54%		64%	24%
Oxygenate (inc. BR/WG)	10%	10%	10%	10%	10%	10%	10%		10%	10%
Total	100%	100%	100%	100%	100%	100%	100%		100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2040 CRK FUEL 14	2040 LTCOK FUEL 14	2040 HVY COKE FUEL 14	2040 CAL FIG FUEL 14	2040 PD3 FUEL 14	2040 CAL FUEL 14	2022 CRK FUEL 20	2022 LTCOK FUEL 20	2022 HVY COKE FUEL 20	2022 CAL FIG FUEL 20
Crude	150,000	150,000	150,000	**No Soln**	9,488,048	1,818,012	150,000	150,000	150,000	150,000
Other C3+ Input	7,798	9,257	7,683		1,121,544	198,136	12,490	14,416	13,522	22,081
LPG produced	9,588	10,327	10,349		455,572	46,712	8,703	9,307	9,550	7,632
Finished Mogas	71,985	76,732	72,850		4,020,103	806,602	78,717	84,048	83,838	87,273
USA Mogas	71,975	76,722	72,840		3,024,404	670,922	78,707	84,038	83,828	87,083
USA non-HOF	0	0	0		0	0	39,908	42,368	42,063	43,672
USA non-HOF CG	0	0	0		0	0	30,432	32,715	34,140	4,482
USA non-HOF RFG	0	0	0		0	0	9,476	9,652	7,922	39,190
USA Gasoline HOF	71,975	76,722	72,840		3,024,404	670,922	38,799	41,671	41,766	43,411
USA HOF CG	59,740	63,679	60,457		2,416,171	79,756	29,875	32,086	33,899	4,221
USA HOF RFG	12,236	13,043	12,383		608,233	591,166	8,924	9,584	7,866	39,190
Export Gasoline	10	10	10		995,700	135,680	10	10	10	190
Ethanol	7,198	7,672	7,284		302,440	67,092	11,771	12,592	12,580	13,071
Total Diesel	47,173	56,475	56,546		4,008,787	666,091	48,486	56,614	54,075	51,455
US Diesel	47,163	56,465	56,536		2,199,012	427,233	48,476	56,604	54,065	51,445
Export Diesel	10	10	10		1,809,774	238,858	10	10	10	10
Total Jet	10,500	10,500	10,500		1,012,926	347,253	10,500	10,500	10,500	18,000
Total Distillate	57,673	66,975	67,046		5,021,713	1,013,344	58,986	67,114	64,575	69,455
Heavies	16,623	0	0		496,585	103,605	16,513	0	0	0
Other Lights	1,682	470	1,271		536,067	27,017	10	10	10	5,240
C5+ Recovery	94.1%	91.4%	89.8%		96.3%	99.0%	95.3%	93.0%	91.3%	99.3%
UNIT OPERATIONS										
Crude Tower	150,000	150,000	150,000		9,488,048	1,818,012	150,000	150,000	150,000	150,000
Vacuum Tower	46,624	67,445	77,343		4,219,457	977,690	46,624	67,445	77,343	75,236
Sats Gas Plant	8,154	5,965	6,953		452,728	136,259	7,078	4,705	5,370	6,928
Unsats Gas Plant	10,873	14,768	13,833		866,638	163,179	10,391	14,713	14,717	17,307
FCC	36,204	46,264	41,254		2,410,965	408,989	34,421	46,048	44,572	47,938
Total HYK	0	0	20,841		1,224,688	522,581	0	0	19,057	34,928
Delayed Coker	0	34,209	43,108		1,684,132	389,561	0	34,190	43,379	38,496
Total Reforming	37,347	33,877	32,107		1,898,020	296,505	35,102	29,297	23,609	19,665
Avg Reforming Severity	97.3	97.7	96.7		94.6	94.7	90.0	90.0	90.0	93.6
000Sev*BPD	3,633	3,310	3,104		179,557	28,078	3,159	2,637	2,125	1,840
C5/C6 Isomerization	6,000	6,000	6,000		136,967	76,976	6,000	6,000	6,000	939
Total Alky	6,600	8,245	7,466		639,630	204,674	6,308	8,211	7,996	20,902
TOTAL ULSD+DHT	47,130	60,140	49,644		3,133,135	576,665	48,430	60,279	47,625	28,509
VGO Feed HDT	0	24,295	39,572		1,445,195	312,746	0	24,288	43,106	44,905
Hydrogen Plant MSCFD	0	27,202	81,477		1,651,833	1,381,632	0	37,851	90,855	100,000
Sulfur TPD	38	340	487		21,459	3,755	39	341	486	244
Tota HYD SCF/BblCrude	286	476	822		626	984	211	451	768	898
Reformer HYD SCF/BblCrude	286	283	265		225	190	211	187	148	156
BLEND SUMMARIES										
NON-HOF Blend Percents										
C4s	N/A	N/A	N/A		N/A	N/A	2%	2%	2%	0%
Naphtha	N/A	N/A	N/A		N/A	N/A	3%	3%	3%	20%
Isomerate	N/A	N/A	N/A		N/A	N/A	15%	14%	14%	2%
Alklate (inc. dim/poly)	N/A	N/A	N/A		N/A	N/A	6%	6%	7%	31%
Reformate	N/A	N/A	N/A		N/A	N/A	53%	50%	56%	20%
FCC	N/A	N/A	N/A		N/A	N/A	11%	14%	7%	17%
Oxygenate (inc. BR/WG)	N/A	N/A	N/A		N/A	N/A	10%	10%	10%	10%
Total	N/A	N/A	N/A		N/A	N/A	100%	100%	100%	100%
HOF Blend Percents										
C4s	2%	1%	1%		2%	0%	1%	1%	0%	0%
Naphtha	2%	3%	5%		3%	7%	11%	15%	21%	21%
Isomerate	8%	8%	8%		0%	3%	0%	0%	0%	0%
Alklate (inc. dim/poly)	9%	11%	10%		17%	33%	10%	13%	13%	17%
Reformate	42%	37%	37%		32%	25%	22%	12%	0%	22%
FCC	27%	30%	28%		37%	22%	37%	40%	46%	19%
Oxygenate (inc. BR/WG)	10%	10%	10%		10%	10%	20%	20%	20%	20%
Total	100%	100%	100%		100%	100%	100%	100%	100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2022 PD3 FUEL 20	2022 CAL FUEL 20	2040 CRK FUEL 20	2040 LTCOK FUEL 20	2040 HVY COKE FUEL 20	2040 CAL FIG FUEL 20	2040 PD3 FUEL 20	2040 CAL FUEL 20	2022 CRK FUEL 18	2022 LTCOK FUEL 18
Crude	8,870,897	1,763,124	137,053	150,000	150,000	150,000	9,445,160	1,818,012	150,000	150,000
Other C3+ Input	1,271,952	189,097	15,936	17,795	16,449	28,629	1,430,272	244,131	12,339	14,327
LPG produced	451,160	52,410	8,164	8,604	8,352	7,525	389,365	37,020	9,230	10,008
Finished Mogas	4,502,477	1,068,277	76,438	83,832	77,356	94,206	4,367,060	829,402	77,884	83,648
USA Mogas	3,813,708	878,497	76,428	81,468	77,346	94,196	3,024,404	698,307	77,874	83,638
USA non-HOF	1,906,854	440,275	0	0	0	0	0	0	39,075	41,967
USA non-HOF CG	1,523,370	52,338	0	0	0	0	0	0	30,088	32,315
USA non-HOF RFG	383,484	387,937	0	0	0	0	0	0	8,987	9,652
USA Gasoline HOF	1,906,854	438,222	76,428	81,468	77,346	94,196	3,024,404	698,307	38,799	41,671
USA HOF CG	1,523,370	50,285	63,435	67,618	64,197	12,614	2,416,171	83,011	29,875	32,086
USA HOF RFG	383,484	387,937	12,993	13,849	13,149	81,582	608,233	615,295	8,924	9,584
Export Gasoline	688,769	189,780	10	2,364	10	10	1,342,656	131,095	10	10
Ethanol	573,010	131,892	15,286	16,294	15,469	18,839	604,881	139,661	11,687	12,552
Total Diesel	3,376,547	395,808	43,381	58,317	62,340	52,208	4,045,078	724,619	48,251	55,937
US Diesel	2,045,271	395,808	43,371	58,307	62,330	52,198	2,199,012	427,233	48,241	55,927
Export Diesel	1,331,276	0	10	10	10	10	1,846,066	297,386	10	10
Total Jet	907,087	309,297	10,500	10,500	10,500	18,000	1,012,926	347,253	10,500	10,500
Total Distillate	4,283,634	705,105	53,881	68,817	72,840	70,208	5,058,004	1,071,872	58,751	66,437
Heavies	460,325	106,351	15,088	0	0	0	496,585	103,605	16,533	0
Other Lights	506,235	30,432	10	2,805	1,575	6,466	521,326	14,772	10	10
C5+ Recovery	97.1%	99.2%	95.5%	93.5%	91.7%	100.1%	97.5%	99.5%	94.7%	92.3%
UNIT OPERATIONS										
Crude Tower	8,870,897	1,763,124	137,053	150,000	150,000	150,000	9,445,160	1,818,012	150,000	150,000
Vacuum Tower	3,751,111	927,168	42,600	67,445	77,343	75,236	4,199,525	977,690	46,624	67,445
Sats Gas Plant	424,855	159,775	6,494	4,741	4,529	7,016	394,127	116,406	7,492	5,195
Unsats Gas Plant	891,689	179,052	9,494	13,106	12,091	16,216	805,951	131,336	10,477	14,983
FCC	2,486,467	467,791	31,450	46,295	40,138	44,405	2,409,484	387,920	34,741	47,097
Total HYK	1,048,383	481,696	0	0	22,500	37,500	1,224,688	545,465	0	0
Delayed Coker	1,396,926	367,039	0	34,859	43,579	38,181	1,684,132	397,853	0	34,282
Total Reforming	1,473,498	217,676	32,265	29,627	25,316	12,501	1,602,119	196,466	36,541	33,887
Avg Reforming Severity	90.0	92.7	90.0	90.0	90.0	90.0	90.0	91.5	93.5	90.9
000Sev*BPD	132,615	20,171	2,904	2,666	2,278	1,125	144,191	17,984	3,415	3,082
C5/C6 Isomerization	141,491	79,297	6,000	6,000	6,000	3,947	130,700	77,022	6,000	6,000
Total Alky	605,483	219,698	5,763	7,222	6,397	19,476	621,059	155,844	6,360	8,373
TOTAL ULSD+DHT	2,762,341	252,237	43,344	61,993	50,011	46,509	3,169,381	576,665	48,197	59,604
VGO Feed HDT	1,387,395	370,828	0	24,537	38,275	41,074	1,441,540	275,561	0	24,322
Hydrogen Plant MSCFD	1,563,649	1,307,874	0	39,507	92,436	100,000	1,651,833	1,381,632	0	33,409
Sulfur TPD	18,815	3,290	35	346	490	251	21,484	3,774	39	340
Tota HYD SCF/BblCrude	573	887	213	465	793	960	616	965	249	466
Reformer HYD SCF/BblCrude	154	134	213	190	162	83	162	110	249	233
BLEND SUMMARIES										
NON-HOF Blend Percents										
C4s	2%	0%	N/A	N/A	N/A	N/A	N/A	N/A	2%	2%
Naphtha	8%	18%	N/A	N/A	N/A	N/A	N/A	N/A	11%	7%
Isomerate	5%	2%	N/A	N/A	N/A	N/A	N/A	N/A	15%	14%
Alklate (inc. dim/poly)	7%	26%	N/A	N/A	N/A	N/A	N/A	N/A	5%	6%
Reformate	45%	24%	N/A	N/A	N/A	N/A	N/A	N/A	58%	57%
FCC	23%	20%	N/A	N/A	N/A	N/A	N/A	N/A	0%	4%
Oxygenate (inc. BR/WG)	10%	10%	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%
Total	100%	100%	N/A	N/A	N/A	N/A	N/A	N/A	100%	100%
HOF Blend Percents										
C4s	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%
Naphtha	26%	33%	6%	5%	9%	25%	15%	20%	0%	0%
Isomerate	3%	0%	8%	7%	8%	4%	0%	3%	0%	0%
Alklate (inc. dim/poly)	20%	25%	8%	8%	8%	23%	11%	22%	12%	14%
Reformate	3%	1%	36%	31%	29%	12%	18%	14%	20%	14%
FCC	27%	22%	22%	27%	25%	16%	36%	21%	48%	52%
Oxygenate (inc. BR/WG)	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2022 HVY COKE FUEL 18	2022 CAL FIG FUEL 18	2022 PD3 FUEL 18	2022 CAL FUEL 18	2040 CRK FUEL 18	2040 LTCOK FUEL 18	2040 HVY COKE FUEL 18	2040 CAL FIG FUEL 18	2040 PD3 FUEL 18	2040 CAL FUEL 18
Crude	150,000	150,000	8,870,897	1,763,124	139,961	150,000	150,000	150,000	9,490,252	1,818,012
Other C3+ Input	12,582	21,729	1,254,392	184,143	14,853	17,803	16,080	32,543	1,426,240	252,366
LPG produced	10,576	8,601	483,657	60,367	9,357	10,534	10,042	8,082	470,145	43,454
Finished Mogas	83,838	88,458	4,437,844	1,051,778	71,985	82,231	75,378	94,206	4,322,665	842,119
USA Mogas	83,828	87,083	3,753,968	863,284	71,975	81,468	75,368	94,196	3,024,404	698,307
USA non-HOF	42,063	43,672	1,906,854	440,275	0	0	0	0	0	0
USA non-HOF CG	34,140	4,482	1,523,370	52,338	0	0	0	0	0	0
USA non-HOF RFG	7,922	39,190	383,484	387,937	0	0	0	0	0	0
USA Gasoline HOF	41,766	43,411	1,847,114	423,009	71,975	81,468	75,368	94,196	3,024,404	698,307
USA HOF CG	33,899	4,221	1,463,630	50,285	59,740	67,618	62,219	12,614	2,416,171	83,011
USA HOF RFG	7,866	39,190	383,484	372,724	12,236	13,849	13,149	81,582	608,233	615,295
Export Gasoline	10	1,374	683,876	188,494	10	763	10	10	1,298,261	143,812
Ethanol	12,580	13,071	561,062	128,849	14,395	16,294	15,074	18,839	604,881	139,661
Total Diesel	52,708	48,553	3,374,658	395,808	44,528	56,976	61,055	52,601	4,008,404	704,519
US Diesel	52,698	48,543	2,045,271	395,808	44,518	56,966	61,045	52,591	2,199,012	427,233
Export Diesel	10	10	1,329,387	0	10	10	10	10	1,809,392	277,286
Total Jet	10,500	18,000	907,087	309,297	10,500	10,500	10,500	18,000	1,012,926	347,253
Total Distillate	63,208	66,553	4,281,745	705,105	55,028	67,476	71,555	70,601	5,021,330	1,051,773
Heavies	0	0	460,325	106,351	15,408	0	0	0	496,585	103,605
Other Lights	10	5,756	506,235	30,780	2,737	2,790	1,817	8,021	536,067	13,800
C5+ Recovery	90.5%	98.6%	96.6%	98.5%	94.0%	91.7%	90.1%	99.4%	96.4%	99.1%
UNIT OPERATIONS										
Crude Tower	150,000	150,000	8,870,897	1,763,124	139,961	150,000	150,000	150,000	9,490,252	1,818,012
Vacuum Tower	77,343	75,236	3,751,111	927,168	43,504	67,445	77,343	75,236	4,220,481	977,690
Sats Gas Plant	7,312	8,313	453,150	168,019	7,681	5,956	5,688	7,322	437,796	124,881
Unsats Gas Plant	13,984	17,578	891,679	180,890	9,696	14,372	13,408	16,990	868,221	156,166
FCC	41,872	48,814	2,486,472	473,392	32,118	46,101	39,685	46,912	2,411,461	383,566
Total HYK	22,500	34,289	1,048,383	478,057	0	0	22,500	35,674	1,224,688	541,259
Delayed Coker	43,168	38,574	1,396,935	367,526	0	34,332	42,984	38,405	1,684,132	387,317
Total Reforming	32,902	27,420	1,688,348	282,451	34,835	33,922	30,834	21,857	1,843,048	289,162
Avg Reforming Severity	90.0	92.6	90.9	93.0	97.9	97.6	97.0	92.6	93.4	91.9
000Sev*BPD	2,961	2,539	153,482	26,270	3,409	3,310	2,990	2,024	172,119	26,560
C5/C6 Isomerization	6,000	2,354	141,491	79,310	6,000	6,000	6,000	6,028	191,953	76,727
Total Alky	7,556	21,256	605,483	219,698	5,885	8,001	7,210	20,488	639,630	182,049
TOTAL ULSD+DHT	46,498	28,509	2,762,337	261,774	44,490	60,643	48,717	46,509	3,132,769	576,665
VGO Feed HDT	40,028	45,856	1,387,261	381,670	0	24,341	37,817	43,793	1,445,449	275,561
Hydrogen Plant MSCFD	89,927	100,000	1,563,649	1,275,775	0	27,435	80,704	100,000	1,651,833	1,381,632
Sulfur TPD	487	245	18,762	3,304	36	342	487	250	21,454	3,760
Tota HYD SCF/BblCrude	837	934	585	912	288	477	807	976	623	979
Reformer HYD SCF/BblCrude	223	220	187	177	288	283	255	176	211	172
BLEND SUMMARIES										
NON-HOF Blend Percents										
C4s	1%	0%	2%	0%	N/A	N/A	N/A	N/A	N/A	N/A
Naphtha	14%	9%	12%	16%	N/A	N/A	N/A	N/A	N/A	N/A
Isomerate	14%	2%	4%	1%	N/A	N/A	N/A	N/A	N/A	N/A
Alklate (inc. dim/poly)	7%	17%	5%	17%	N/A	N/A	N/A	N/A	N/A	N/A
Reformate	51%	44%	47%	35%	N/A	N/A	N/A	N/A	N/A	N/A
FCC	4%	18%	20%	22%	N/A	N/A	N/A	N/A	N/A	N/A
Oxygenate (inc. BR/WG)	10%	10%	10%	10%	N/A	N/A	N/A	N/A	N/A	N/A
Total	100%	100%	100%	100%	N/A	N/A	N/A	N/A	N/A	N/A
HOF Blend Percents										
C4s	0%	0%	0%	0%	1%	1%	1%	0%	1%	0%
Naphtha	3%	11%	12%	26%	0%	0%	0%	9%	2%	5%
Isomerate	0%	2%	2%	0%	8%	7%	8%	6%	0%	3%
Alklate (inc. dim/poly)	11%	31%	24%	35%	8%	10%	10%	27%	15%	26%
Reformate	19%	16%	10%	2%	39%	34%	36%	20%	25%	24%
FCC	47%	19%	31%	17%	24%	28%	26%	17%	37%	22%
Oxygenate (inc. BR/WG)	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2022 PD3 FUEL 15	2022 CAL FUEL 15	2040 PD3 FUEL 15	2040 CAL FUEL 15	2022 CRK FUEL 19	2022 LTCOK FUEL 19	2022 HVY COKE FUEL 19	2022 CAL FIG FUEL 19	2022 PD3 FUEL 19
Crude	8,870,897	1,763,124	9,461,866	1,818,012	150,000	150,000	150,000	150,000	8,870,897
Other C3+ Input	1,461,784	223,544	1,719,301	329,482	16,570	18,823	17,524	25,573	1,466,312
LPG produced	420,372	43,390	353,594	34,695	8,047	8,744	8,748	6,946	415,778
Finished Mogas	4,670,081	1,125,262	4,676,422	907,608	83,471	89,100	85,900	89,325	4,666,489
USA Mogas	3,738,929	866,817	3,024,404	698,307	79,998	85,919	85,890	87,083	3,753,968
USA non-HOF	1,906,854	440,275	0	0	41,199	44,248	44,124	43,672	1,906,854
USA non-HOF CG	1,523,370	52,338	0	0	31,723	34,071	35,771	4,482	1,523,370
USA non-HOF RFG	383,484	387,937	0	0	9,476	10,177	8,353	39,190	383,484
USA Gasoline HOF	1,832,075	426,542	3,024,404	698,307	38,799	41,671	41,766	43,411	1,847,114
USA HOF CG	1,463,630	50,285	2,416,171	83,011	29,875	32,086	33,899	4,221	1,463,630
USA HOF RFG	368,446	376,256	608,233	615,295	8,924	9,584	7,866	39,190	383,484
Export Gasoline	931,152	258,445	1,652,018	209,301	3,473	3,181	10	2,241	912,521
Ethanol	741,261	172,210	907,321	209,492	15,780	16,948	16,964	17,412	745,773
Total Diesel	3,430,811	395,808	4,063,951	730,273	48,486	56,614	57,258	54,217	3,438,022
US Diesel	2,045,271	395,808	2,199,012	427,233	48,476	56,604	57,248	54,207	2,045,271
Export Diesel	1,385,540	0	1,864,939	303,040	10	10	10	10	1,392,751
Total Jet	907,087	309,297	1,012,926	347,253	10,500	10,500	10,500	18,000	907,087
Total Distillate	4,337,898	705,105	5,076,877	1,077,526	58,986	67,114	67,758	72,217	4,345,109
Heavies	460,325	106,351	506,738	103,605	16,513	0	0	0	460,325
Other Lights	506,235	26,620	536,067	17,498	20	10	10	5,488	506,235
C5+ Recovery	97.6%	99.9%	97.8%	100.3%	95.9%	93.6%	92.0%	99.8%	97.6%
UNIT OPERATIONS									
Crude Tower	8,870,897	1,763,124	9,461,866	1,818,012	150,000	150,000	150,000	150,000	8,870,897
Vacuum Tower	3,751,111	927,168	4,207,289	977,690	46,624	67,445	77,343	75,236	3,751,111
Sats Gas Plant	413,076	161,366	378,710	109,806	6,733	4,472	5,557	6,376	414,624
Unsats Gas Plant	869,262	160,015	789,625	131,336	10,391	14,713	13,408	16,009	866,816
FCC	2,400,816	410,581	2,415,265	387,920	34,421	46,048	39,685	43,726	2,398,320
Total HYK	1,048,383	526,963	1,224,688	545,465	0	0	22,500	37,500	1,048,383
Delayed Coker	1,390,593	363,087	1,684,132	397,853	0	34,190	42,984	38,119	1,390,688
Total Reforming	1,367,649	190,208	1,452,504	169,363	30,727	26,874	22,508	13,923	1,383,219
Avg Reforming Severity	90.0	93.2	90.0	90.0	92.1	90.0	90.0	90.5	90.0
000Sev*BPD	123,088	17,726	130,725	15,243	2,830	2,419	2,026	1,260	124,490
C5/C6 Isomerization	100	18,817	100	100	6,000	4,893	2,318	4,729	100
Total Alky	605,483	202,537	583,598	158,843	6,308	8,211	7,210	19,206	605,483
TOTAL ULSD+DHT	2,816,492	223,925	3,188,502	576,665	48,430	60,279	48,398	29,007	2,823,266
VGO Feed HDT	1,353,726	260,850	1,444,319	275,561	0	24,288	37,817	40,388	1,345,718
Hydrogen Plant MSCFD	1,563,649	1,307,874	1,651,833	1,381,632	0	39,311	94,757	100,000	1,563,649
Sulfur TPD	18,745	3,284	21,524	3,774	39	341	487	247	18,739
Tota HYD SCF/BblCrude	574	878	608	949	199	441	785	891	564
Reformer HYD SCF/BblCrude	139	113	142	87	191	167	139	94	142
BLEND SUMMARIES									
NON-HOF Blend Percents									
C4s	3%	0%	N/A	N/A	2%	2%	3%	0%	2%
Naphtha	6%	9%	N/A	N/A	6%	4%	5%	12%	7%
Isomerate	0%	0%	N/A	N/A	14%	11%	5%	2%	0%
Alklate (inc. dim/poly)	9%	30%	N/A	N/A	5%	8%	8%	32%	7%
Reformate	48%	16%	N/A	N/A	50%	43%	53%	28%	38%
FCC	23%	34%	N/A	N/A	12%	21%	17%	17%	36%
Oxygenate (inc. BR/WG)	10%	10%	N/A	N/A	10%	10%	10%	10%	10%
Total	100%	100%	N/A	N/A	100%	100%	100%	100%	100%
HOF Blend Percents									
C4s	1%	0%	2%	0%	1%	1%	0%	0%	1%
Naphtha	38%	55%	24%	31%	19%	21%	31%	25%	41%
Isomerate	0%	0%	0%	0%	0%	0%	0%	8%	0%
Alklate (inc. dim/poly)	0%	15%	0%	16%	9%	10%	9%	11%	19%
Reformate	10%	0%	29%	14%	8%	8%	0%	9%	0%
FCC	21%	0%	15%	9%	32%	30%	29%	17%	8%
Oxygenate (inc. BR/WG)	30%	30%	30%	30%	30%	30%	30%	30%	30%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2022 CAL FUEL 19	2040 CRK FUEL 19	2040 LTCOK FUEL 19	2040 HVY COKE FUEL 19	2040 CAL FIG FUEL 19	2040 PD3 FUEL 19	2040 CAL FUEL 19	2022 CRK FUEL 16	2022 LTCOK FUEL 16	2022 HVY COKE FUEL 16
Crude	1,763,124	117,671	150,000	150,000	150,000	9,473,942	1,818,012	**No Soln**	**No Soln**	**No Soln**
Other C3+ Input	238,296	23,565	25,974	24,230	35,768	1,736,449	330,105			
LPG produced	44,505	6,259	8,135	7,711	6,663	347,199	34,831			
Finished Mogas	1,127,968	76,438	95,285	87,401	99,526	4,728,892	907,687			
USA Mogas	863,284	76,428	81,468	77,346	94,976	3,024,404	698,307			
USA non-HOF	440,275	0	0	0	0	0	0			
USA non-HOF CG	52,338	0	0	0	0	0	0			
USA non-HOF RFG	387,937	0	0	0	0	0	0			
USA Gasoline HOF	423,009	76,428	81,468	77,346	94,976	3,024,404	698,307			
USA HOF CG	50,285	63,435	67,618	64,197	13,395	2,416,171	83,011			
USA HOF RFG	372,724	12,993	13,849	13,149	81,582	608,233	615,295			
Export Gasoline	264,684	10	13,817	10,055	4,549	1,704,488	209,380			
Ethanol	171,150	22,928	24,440	23,204	28,493	907,321	209,492			
Total Diesel	395,808	35,739	58,317	62,340	58,257	4,053,644	730,273			
US Diesel	395,808	35,729	58,307	62,330	58,247	2,199,012	427,233			
Export Diesel	0	10	10	10	10	1,854,632	303,040			
Total Jet	309,297	10,500	10,500	10,500	18,000	1,012,926	347,253			
Total Distillate	705,105	46,239	68,817	72,840	76,257	5,066,570	1,077,527			
Heavies	106,351	12,954	0	0	0	506,738	103,605			
Other Lights	29,186	10	10	10	3,079	521,326	17,811			
C5+ Recovery	100.1%	96.5%	94.1%	92.5%	99.6%	98.0%	100.3%			
UNIT OPERATIONS										
Crude Tower	1,763,124	117,671	150,000	150,000	150,000	9,473,942	1,818,012			
Vacuum Tower	927,168	36,576	67,445	77,343	75,236	4,212,901	977,690			
Sats Gas Plant	157,109	5,183	4,585	4,316	6,510	380,039	110,084			
Unsats Gas Plant	173,209	8,151	13,106	12,091	13,983	806,812	131,336			
FCC	453,872	27,003	46,295	40,138	38,728	2,415,608	387,920			
Total HYK	486,125	0	0	22,500	37,500	1,224,688	545,465			
Delayed Coker	366,667	0	34,859	43,579	37,849	1,684,132	397,853			
Total Reforming	173,452	24,038	27,936	22,843	14,776	1,466,371	169,362			
Avg Reforming Severity	93.7	90.0	90.0	90.0	90.0	90.0	90.0			
000Sev*BPD	16,253	2,163	2,514	2,056	1,330	131,973	15,243			
C5/C6 Isomerization	79,367	6,000	6,000	5,338	100	100	29,251			
Total Alky	219,698	4,948	7,222	6,397	15,922	622,053	159,188			
TOTAL ULSD+DHT	241,208	35,730	61,993	50,011	50,738	3,178,224	576,665			
VGO Feed HDT	325,385	0	24,537	38,275	35,335	1,445,329	275,561			
Hydrogen Plant MSCFD	1,307,874	0	40,245	93,918	100,000	1,651,833	1,381,632			
Sulfur TPD	3,298	30	346	490	252	21,514	3,774			
Tota HYD SCF/BblCrude	859	193	456	782	946	602	951			
Reformer HYD SCF/BblCrude	106	176	176	141	98	144	87			
BLEND SUMMARIES										
NON-HOF Blend Percents										
C4s	0%	N/A	N/A	N/A	N/A	N/A	N/A			
Naphtha	20%	N/A	N/A	N/A	N/A	N/A	N/A			
Isomerate	2%	N/A	N/A	N/A	N/A	N/A	N/A			
Alklate (inc. dim/poly)	34%	N/A	N/A	N/A	N/A	N/A	N/A			
Reformate	23%	N/A	N/A	N/A	N/A	N/A	N/A			
FCC	10%	N/A	N/A	N/A	N/A	N/A	N/A			
Oxygenate (inc. BR/WG)	10%	N/A	N/A	N/A	N/A	N/A	N/A			
Total	100%	N/A	N/A	N/A	N/A	N/A	N/A			
HOF Blend Percents										
C4s	0%	1%	1%	1%	0%	1%	0%			
Naphtha	44%	9%	11%	14%	27%	25%	29%			
Isomerate	0%	8%	4%	7%	0%	0%	0%			
Alklate (inc. dim/poly)	17%	6%	6%	6%	16%	12%	18%			
Reformate	0%	27%	20%	22%	11%	13%	4%			
FCC	9%	19%	27%	21%	15%	18%	20%			
Oxygenate (inc. BR/WG)	30%	30%	30%	30%	30%	30%	30%			
Total	100%	100%	100%	100%	100%	100%	100%			

Appendix A: Summary Modeling Results

CASE ID ==>	2022 CAL FIG FUEL 16	2022 PD3 FUEL 16	2022 CAL FUEL 16	2040 CRK FUEL 16	2040 LTCOK FUEL 16	2040 HVY COKE FUEL 16	2040 CAL FIG FUEL 16	2040 PD3 FUEL 16	2040 CAL FUEL 16	2022 PD3 FUEL V1
Crude	**No Soln**	8,870,897	**No Soln**	**No Soln**	**No Soln**	**No Soln**	**No Soln**	**No Soln**	**No Soln**	8,870,897
Other C3+ Input		1,059,639								1,035,434
LPG produced		570,325								518,154
Finished Mogas		4,097,940								4,157,759
USA Mogas		3,723,891								3,783,709
USA non-HOF		1,891,815								1,906,854
USA non-HOF CG		1,523,370								1,523,370
USA non-HOF RFG		368,446								383,484
USA Gasoline HOF		1,832,075								1,876,855
USA HOF CG		1,463,630								1,493,371
USA HOF RFG		368,446								383,484
Export Gasoline		374,050								374,050
Ethanol		373,337								360,556
Total Diesel		3,322,560								3,353,678
US Diesel		2,045,271								2,045,271
Export Diesel		1,277,289								1,308,407
Total Jet		907,087								907,087
Total Distillate		4,229,647								4,260,764
Heavies		460,325								460,325
Other Lights		514,010								506,235
C5+ Recovery		94.5%								95.5%
UNIT OPERATIONS										
Crude Tower		8,870,897								8,870,897
Vacuum Tower		3,751,111								3,751,111
Sats Gas Plant		496,320								519,697
Unsats Gas Plant		952,089								898,327
FCC		2,671,677								2,510,020
Total HYK		1,048,383								1,048,383
Delayed Coker		1,408,519								1,398,600
Total Reforming		1,826,744								1,826,744
Avg Reforming Severity		99.5								96.7
000Sev*BPD		181,707								176,673
C5/C6 Isomerization		120,510								175,598
Total Alky		605,483								605,483
TOTAL ULSD+DHT		2,735,677								2,745,796
VGO Feed HDT		1,678,954								1,399,541
Hydrogen Plant MSCFD		1,563,649								1,563,649
Sulfur TPD		18,959								18,694
Tota HYD SCF/BblCrude		615								604
Reformer HYD SCF/BblCrude		252								241
BLEND SUMMARIES										
NON-HOF Blend Percents										
C4s		0%								1%
Naphtha		9%								14%
Isomerate		4%								2%
Alklate (inc. dim/poly)		0%								12%
Reformate		31%								32%
FCC		46%								29%
Oxygenate (inc. BR/WG)		10%								10%
Total		100%								100%
HOF Blend Percents										
C4s		3%								3%
Naphtha		0%								0%
Isomerate		0%								7%
Alklate (inc. dim/poly)		34%								15%
Reformate		36%								33%
FCC		17%								34%
Oxygenate (inc. BR/WG)		10%								7%
Total		100%								100%

Appendix A: Summary Modeling Results

CASE ID ==>	2022 PD2 FUEL V1	2022 PD3 FUEL V2	2022 CAL FUEL V2	2022 PD2 FUEL V2	2022 CRK V2	2022 LTCOK V2	2022 HVY COKE V2	2022 CAL FIG V2	2040 PD3 FUEL V2
Crude	3,703,237	8,870,897	**No Soln**	3,661,266	150,000	150,000	150,000	**No Soln**	9,598,822
Other C3+ Input	272,097	1,399,063		473,505	15,111	17,199	16,201		1,606,919
LPG produced	173,598	405,184		132,000	7,794	8,983	8,850		396,460
Finished Mogas	2,014,092	4,553,877		2,063,259	79,519	85,884	84,641		4,697,953
USA Mogas	2,013,092	3,753,968		2,058,377	79,509	85,394	84,631		3,024,404
USA non-HOF	1,024,264	1,906,854		1,029,189	40,710	43,724	42,866		0
USA non-HOF CG	878,350	1,523,370		878,350	31,723	34,071	34,943		0
USA non-HOF RFG	145,913	383,484		150,838	8,987	9,652	7,922		0
USA Gasoline HOF	988,828	1,847,114		1,029,189	38,799	41,671	41,766		3,024,404
USA HOF CG	843,905	1,463,630		878,350	29,875	32,086	33,899		2,416,171
USA HOF RFG	144,923	383,484		150,838	8,924	9,584	7,866		608,233
Export Gasoline	1,000	799,909		4,882	10	490	10		1,673,549
Ethanol	191,943	690,360		381,314	14,568	15,646	15,585		816,619
Total Diesel	1,189,876	3,437,783		1,350,193	48,486	56,219	55,857		3,989,581
US Diesel	1,166,849	2,045,271		1,166,849	48,476	56,209	55,847		2,199,012
Export Diesel	23,026	1,392,512		183,344	10	10	10		1,790,569
Total Jet	252,344	907,087		252,344	10,500	10,500	10,500		1,012,926
Total Distillate	1,442,220	4,344,869		1,602,537	58,986	66,719	66,357		5,002,508
Heavies	221,732	460,325		222,280	16,513	0	0		496,585
Other Lights	30,631	526,570		30,631	1,993	543	10		536,067
C5+ Recovery	94.6%	97.2%		96.4%	95.4%	92.5%	91.2%		97.0%
UNIT OPERATIONS									
Crude Tower	3,703,237	8,870,897		3,661,266	150,000	150,000	150,000		9,598,822
Vacuum Tower	1,848,027	3,751,111		1,827,082	46,624	67,445	77,343		4,270,939
Sats Gas Plant	220,185	473,070		186,140	7,978	6,265	6,608		463,860
Unsats Gas Plant	354,473	866,816		354,983	10,391	14,870	14,304		946,176
FCC	1,041,842	2,398,319		1,047,186	34,421	46,659	42,993		2,435,916
Total HYK	293,380	1,048,383		293,380	0	0	19,003		1,224,688
Delayed Coker	715,613	1,390,688		705,239	0	34,244	43,244		1,684,132
Total Reforming	656,009	1,738,144		567,276	34,064	33,393	27,625		1,778,965
Avg Reforming Severity	99.2	93.9		95.2	99.0	100.0	99.2		97.3
000Sev*BPD	65,070	163,234		54,016	3,372	3,339	2,741		173,136
C5/C6 Isomerization	185,655	121,032		185,655	3,246	1,297	6,000		168,444
Total Alky	284,272	605,483		284,272	6,308	8,306	7,748		639,630
TOTAL ULSD+DHT	1,114,661	2,823,264		1,176,465	48,430	59,886	49,312		3,114,749
VGO Feed HDT	567,888	1,345,719		611,572	0	24,308	41,515		1,457,989
Hydrogen Plant MSCFD	825,265	1,563,649		825,265	0	26,799	82,148		1,651,833
Sulfur TPD	7,938	18,733		7,824	38	340	486		21,504
Tota HYD SCF/BblCrude	527	590		549	265	479	795		621
Reformer HYD SCF/BblCrude	229	209		180	265	290	233		220
BLEND SUMMARIES									
NON-HOF Blend Percents									
C4s	1%	2%		1%	2%	1%	1%		N/A
Naphtha	16%	17%		14%	18%	17%	21%		N/A
Isomerate	15%	6%		18%	8%	3%	14%		N/A
Alklate (inc. dim/poly)	22%	6%		9%	5%	8%	3%		N/A
Reformate	13%	48%		33%	47%	44%	48%		N/A
FCC	23%	11%		15%	9%	17%	4%		N/A
Oxygenate (inc. BR/WG)	10%	10%		10%	10%	10%	10%		N/A
Total	100%	100%		100%	100%	100%	100%		N/A
HOF Blend Percents									
C4s	6%	5%		7%	5%	5%	5%		4%
Naphtha	0%	0%		0%	0%	0%	0%		0%
Isomerate	3%	0%		0%	0%	0%	0%		3%
Alklate (inc. dim/poly)	6%	24%		18%	10%	12%	16%		10%
Reformate	39%	8%		12%	20%	19%	6%		18%
FCC	38%	36%		35%	38%	37%	47%		38%
Oxygenate (inc. BR/WG)	8%	27%		27%	27%	27%	27%		27%
Total	100%	100%		100%	100%	100%	100%		100%

Appendix A: Summary Modeling Results

CASE ID ==>	2040 CAL FUEL V2	2040 PD2 FUEL V2	2040 CRK V2	2040 LTCOK V2	2040 HVY COKE V2	2040 CAL FIG V2	2022 PD3 FUEL V4	2022 CAL FUEL V4	2022 PD2 FUEL V4
Crude	**No Soln**	3,436,671	120,142	150,000	150,000	**No Soln**	8,870,897	**No Soln**	3,703,237
Other C3+ Input		598,173	21,634	24,140	22,358		1,373,217		460,017
LPG produced		101,775	5,030	6,431	6,229		441,417		147,347
Finished Mogas		1,897,207	76,438	91,912	84,633		4,548,864		2,062,716
USA Mogas		1,632,365	76,428	81,468	77,346		3,738,929		2,018,017
USA non-HOF		0	0	0	0		1,906,854		1,029,189
USA non-HOF CG		0	0	0	0		1,523,370		878,350
USA non-HOF RFG		0	0	0	0		383,484		150,838
USA Gasoline HOF		1,632,365	76,428	81,468	77,346		1,832,075		988,828
USA HOF CG		1,393,125	63,435	67,618	64,197		1,463,630		843,905
USA HOF RFG		239,240	12,993	13,849	13,149		368,446		144,923
Export Gasoline		264,842	10	10,444	7,287		809,934		44,699
Ethanol		440,755	20,636	21,997	20,884		686,299		370,427
Total Diesel		1,379,394	36,714	58,317	62,340		3,376,547		1,352,969
US Diesel		1,259,491	36,704	58,307	62,330		2,045,271		1,166,849
Export Diesel		119,904	10	10	10		1,331,276		186,120
Total Jet		294,441	10,500	10,500	10,500		907,087		252,344
Total Distillate		1,673,835	47,214	68,817	72,840		4,283,634		1,605,314
Heavies		236,076	13,226	0	0		460,325		222,280
Other Lights		31,319	10	2,805	1,835		526,570		30,631
C5+ Recovery		98.0%	97.2%	95.1%	93.2%		96.7%		95.7%
UNIT OPERATIONS									
Crude Tower		3,436,671	120,142	150,000	150,000		8,870,897		3,703,237
Vacuum Tower		1,735,137	37,343	67,445	77,343		3,751,111		1,848,027
Sats Gas Plant		174,124	6,072	5,213	5,027		486,467		196,921
Unsats Gas Plant		309,378	8,323	13,106	12,091		891,689		353,584
FCC		788,294	27,570	46,295	40,138		2,486,467		1,016,184
Total HYK		368,797	0	0	22,500		1,048,383		293,380
Delayed Coker		636,851	0	34,859	43,579		1,396,926		712,556
Total Reforming		529,828	29,906	33,240	28,702		1,739,864		586,482
Avg Reforming Severity		98.6	93.2	92.0	93.5		95.5		97.4
000Sev*BPD		52,256	2,787	3,057	2,684		166,209		57,101
C5/C6 Isomerization		199,103	6,000	6,000	6,000		121,207		185,655
Total Alky		295,063	5,052	7,222	6,397		605,483		284,272
TOTAL ULSD+DHT		1,092,911	36,704	61,993	50,011		2,762,341		1,176,465
VGO Feed HDT		488,065	0	24,537	38,275		1,387,395		593,917
Hydrogen Plant MSCFD		871,807	0	34,075	86,605		1,563,649		825,265
Sulfur TPD		7,439	31	346	490		18,813		7,925
Tota HYD SCF/BblCrude		570	254	473	804		590		530
Reformer HYD SCF/BblCrude		194	254	234	212		223		196
BLEND SUMMARIES									
NON-HOF Blend Percents									
C4s		N/A	N/A	N/A	N/A		1%		1%
Naphtha		N/A	N/A	N/A	N/A		13%		13%
Isomerate		N/A	N/A	N/A	N/A		6%		17%
Alklate (inc. dim/poly)		N/A	N/A	N/A	N/A		5%		20%
Reformate		N/A	N/A	N/A	N/A		37%		18%
FCC		N/A	N/A	N/A	N/A		28%		22%
Oxygenate (inc. BR/WG)		N/A	N/A	N/A	N/A		10%		10%
Total		N/A	N/A	N/A	N/A		100%		100%
HOF Blend Percents									
C4s		6%	5%	5%	5%		6%		7%
Naphtha		1%	2%	0%	2%		0%		0%
Isomerate		12%	8%	3%	5%		0%		0%
Alklate (inc. dim/poly)		8%	7%	2%	3%		7%		5%
Reformate		23%	33%	35%	33%		35%		29%
FCC		23%	19%	27%	25%		26%		32%
Oxygenate (inc. BR/WG)		27%	27%	27%	27%		27%		27%
Total		100%	100%	100%	100%		100%		100%

Appendix A: Summary Modeling Results

CASE ID ==>	2022 CRK V4	2022 LTCOK V4	2022 HVY COKE V4	2022 CAL FIG V4	2040 PD3 FUEL V4	2040 CAL FUEL V4	2040 PD2 FUEL V4	2040 CRK V4	2040 LTCOK V4
Crude	150,000	150,000	150,000	**No Soln**	9,556,720	**No Soln**	3,867,512	144,160	150,000
Other C3+ Input	16,020	18,394	17,215		1,609,301		535,896	19,974	22,270
LPG produced	8,376	8,990	9,752		428,998		153,296	7,425	8,282
Finished Mogas	83,063	90,130	92,924		4,597,586		2,063,812	80,197	88,427
USA Mogas	83,053	90,120	92,914		3,024,404		1,574,626	72,803	77,231
USA non-HOF	41,526	45,060	46,457		0		0	0	0
USA non-HOF CG	34,467	37,400	38,559		0		0	0	0
USA non-HOF RFG	7,059	7,660	7,898		0		0	0	0
USA Gasoline HOF	41,526	45,060	46,457		3,024,404		1,574,626	72,803	77,231
USA HOF CG	34,467	37,400	38,559		2,416,171		1,338,493	59,810	63,679
USA HOF RFG	7,059	7,660	7,898		608,233		236,133	12,993	13,551
Export Gasoline	10	10	10		1,573,182		489,186	7,395	11,196
Ethanol	15,386	16,696	17,213		816,619		425,165	19,657	20,853
Total Diesel	46,654	53,649	47,695		3,996,853		1,489,524	46,184	56,614
US Diesel	46,644	53,639	47,685		2,199,012		1,259,491	46,174	56,604
Export Diesel	10	10	10		1,797,840		230,033	10	10
Total Jet	10,500	10,500	10,500		1,012,926		294,441	10,500	10,500
Total Distillate	57,154	64,149	58,195		5,009,779		1,783,965	56,684	67,114
Heavies	16,667	0	0		496,585		236,076	15,870	0
Other Lights	269	10	676		536,067		42,554	3,000	3,000
C5+ Recovery	95.0%	92.6%	90.8%		96.4%		95.4%	95.1%	92.8%
UNIT OPERATIONS									
Crude Tower	150,000	150,000	150,000		9,556,720		3,867,512	144,160	150,000
Vacuum Tower	46,624	67,445	77,343		4,251,372		1,952,664	44,809	67,445
Sats Gas Plant	8,174	6,023	8,572		479,699		212,680	8,683	6,745
Unsats Gas Plant	11,063	15,411	14,126		916,443		367,391	9,986	14,713
FCC	36,910	48,761	42,412		2,426,529		932,319	33,081	46,048
Total HYK	0	0	22,500		1,224,688		368,797	0	0
Delayed Coker	0	34,429	43,213		1,684,132		747,894	0	34,190
Total Reforming	36,472	32,249	33,192		1,843,911		710,993	35,879	33,875
Avg Reforming Severity	97.9	99.0	97.0		98.5		100.8	101.0	101.0
000Sev*BPD	3,571	3,193	3,220		181,646		71,653	3,624	3,421
C5/C6 Isomerization	6,000	6,000	6,000		205,792		215,279	6,000	5,787
Total Alky	6,716	8,630	7,641		639,630		300,303	6,062	8,211
TOTAL ULSD+DHT	46,612	57,312	42,823		3,121,662		1,252,204	46,139	60,279
VGO Feed HDT	0	24,377	40,574		1,441,633		656,675	0	24,288
Hydrogen Plant MSCFD	0	26,162	80,870		1,651,833		871,807	0	24,187
Sulfur TPD	38	340	487		21,467		8,570	37	340
Tota HYD SCF/BblCrude	282	461	830		618		585	307	474
Reformer HYD SCF/BblCrude	282	275	277		232		244	307	302
BLEND SUMMARIES									
NON-HOF Blend Percents									
C4s	0%	0%	0%		N/A		N/A	N/A	N/A
Naphtha	10%	10%	15%		N/A		N/A	N/A	N/A
Isomerate	14%	11%	6%		N/A		N/A	N/A	N/A
Alklate (inc. dim/poly)	4%	4%	2%		N/A		N/A	N/A	N/A
Reformate	40%	30%	27%		N/A		N/A	N/A	N/A
FCC	23%	35%	39%		N/A		N/A	N/A	N/A
Oxygenate (inc. BR/WG)	10%	10%	10%		N/A		N/A	N/A	N/A
Total	100%	100%	100%		N/A		N/A	N/A	N/A
HOF Blend Percents									
C4s	6%	6%	6%		5%		6%	5%	5%
Naphtha	0%	0%	0%		0%		0%	0%	0%
Isomerate	0%	2%	7%		0%		6%	5%	3%
Alklate (inc. dim/poly)	12%	15%	14%		0%		5%	5%	6%
Reformate	30%	30%	33%		37%		28%	35%	30%
FCC	24%	21%	13%		30%		28%	24%	29%
Oxygenate (inc. BR/WG)	27%	27%	27%		27%		27%	27%	27%
Total	100%	100%	100%		100%		100%	100%	100%

Appendix A: Summary Modeling Results

CASE ID ==>	2040 HVY COKE V4	2040 CAL FIG V4	Fuel 14 Capex	Fuel18 Capex
Crude	150,000	**No Soln**	9,488,048	9,537,905
Other C3+ Input	20,486		1,362,952	1,678,168
LPG produced	7,579		400,099	406,375
Finished Mogas	82,346		4,268,989	4,622,208
USA Mogas	72,840		3,024,404	3,024,404
USA non-HOF	0		0	0
USA non-HOF CG	0		0	0
USA non-HOF RFG	0		0	0
USA Gasoline HOF	72,840		3,024,404	3,024,404
USA HOF CG	60,457		2,416,171	2,416,171
USA HOF RFG	12,383		608,233	608,233
Export Gasoline	9,506		1,244,586	1,597,805
Ethanol	19,668		302,440	604,881
Total Diesel	58,868		4,008,754	4,012,530
US Diesel	58,858		2,199,012	2,199,012
Export Diesel	10		1,809,741	1,813,518
Total Jet	10,500		1,012,926	1,012,926
Total Distillate	69,368		5,021,680	5,025,456
Heavies	0		496,585	506,738
Other Lights	3,000		521,326	521,326
C5+ Recovery	91.2%		98.6%	98.8%
UNIT OPERATIONS				
Crude Tower	150,000		9,488,048	9,537,905
Vacuum Tower	77,343		4,219,457	4,242,628
Sats Gas Plant	6,530		442,157	424,906
Unsats Gas Plant	13,283		867,157	884,305
FCC	39,181		2,411,066	2,421,624
Total HYK	21,590		1,224,688	1,224,688
Delayed Coker	42,936		1,684,132	1,684,132
Total Reforming	33,397		1,897,628	1,792,462
Avg Reforming Severity	101.0		93.3	92.4
000Sev*BPD	3,373		177,074	165,558
C5/C6 Isomerization	4,820		133,028	135,704
Total Alky	7,135		855,335	873,853
TOTAL ULSD+DHT	48,229		3,133,070	3,137,244
VGO Feed HDT	37,400		1,433,101	1,439,925
Hydrogen Plant MSCFD	73,366		1,651,833	1,651,833
Sulfur TPD	487		21,442	21,481
Tota HYD SCF/BblCrude	801		610	604
Reformer HYD SCF/BblCrude	298		216	197
BLEND SUMMARIES				
NON-HOF Blend Percents				
C4s	N/A			
Naphtha	N/A		N/A	N/A
Isomerate	N/A		N/A	N/A
Alklate (inc. dim/poly)	N/A		N/A	N/A
Reformate	N/A		N/A	N/A
FCC	N/A		N/A	N/A
Oxygenate (inc. BR/WG)	N/A		N/A	N/A
Total	N/A		N/A	N/A
			N/A	N/A
HOF Blend Percents				
C4s	5%		2%	1%
Naphtha	0%		3%	6%
Isomerate	3%		0%	0%
Alklate (inc. dim/poly)	6%		21%	17%
Reformate	33%		27%	19%
FCC	27%		37%	37%
Oxygenate (inc. BR/WG)	27%		10%	20%
Total	100%		100%	100%