REFORMULATED DIESEL FUEL - THE CHALLENGE FOR U.S. REFINERIES

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BACKGROUND

Diesel engines have potential for use in a large number of future vehicles in the United States. However, to achieve this potential, proponents of diesel engine technologies must solve diesel's pollution problems, including objectionable levels of emissions of particulates and oxides of nitrogen. To meet emissions reduction goals, diesel fuel quality improvements could enable diesel engines with advanced aftertreatment systems to achieve the necessary emissions performance, and it is likely that diesel fuel would have to be reformulated to be as clean as future gasolines.

If adequate volumes of reformulated diesel (RFD) fuel can be produced at reasonable cost, then the full market potential for advanced diesel engine vehicles could be realized. With evidence that RFD will be available in adequate volumes at reasonable costs, policy makers could better defend current activities like the promotion of diesel engine technologies in vehicles developed through the Partnership for a New Generation of Vehicles.

However, if it is shown that RFD cannot be supplied in adequate volumes at reasonable costs, then policy makers can make informed and appropriate responses, for example, by defining new research programs for diesel engine combustion or aftertreatment catalysts.

While the actual changes needed in future diesel fuels are not known, we have assumed that petroleum refineries would produce RFD by reducing sulfur and aromatics in the fuel. These property changes would be accomplished by changing blendstock qualities and/or blendstock percentages. In addition to reformulation of diesel fuel, we have assumed that vehicle fleet changes will result in a significantly greater fraction of RFD and a lesser fraction of gasoline. Because of the increased processing difficulty and costs for fuel property improvements, a large demand for RFD will present technical and economic challenges for the U.S. refining industry. It is important to the national economy and security that these challenges to the U.S. refining industry do not adversely affect the efficiency and reliability of the transportation fuel production and distribution system. RFD could have significant impacts on:

1. Shifts in diesel fuel blendstocks, possibly including refinery purchases of ultra-clean blendstocks from gas-to-liquids (GTL) plants.
2. Refinery investment.
3. Refining costs, fuel product costs, and refinery energy use.
4. Refinery viability.
5. Refinery technology.
6. Global shifts in production and imports/exports of distillates and gasoline.

This paper presents an evaluation of the first two items in the list of significant impact areas, highlighting the types and costs of refinery changes required to make RFD. Results are based on a qualitative analysis drawn from limited published information. No new quantitative analysis or modeling has been done. Therefore, projected impacts should be viewed as preliminary and directional in nature, with the understanding that required changes will differ among individual refineries.

CURRENT DIESEL FUEL PRODUCTION

Tables 1 and 2 show current diesel fuel production and quality data (DOE 1998; API/NPRA 1996). For the combined regions listed in the tables, the average sulfur content of diesel fuel sulfur is well above 340 ppm and the average aromatics content is above 31 volume percent. Because Petroleum Administration for Defense District III (PADD III, U.S. Gulf Coast) produces the greatest amount of diesel fuel, the analysis of RFD production will focus on that region.

Typical blendstocks for low sulfur diesel fuel produced in PADD III are summarized in Table 3, which shows only two blendstocks (hydrotreated and hydrocracked light distillate) with sulfur contents less than 100 ppm. These blendstocks comprise only 7 volume percent of the low sulfur diesel fuel product (API/NPRA 1996).

ASSUMPTIONS

We assume that RFD will be required in year 2005 for all diesel vehicles, and low sulfur gasoline will be required for gasoline-powered vehicles. Greater volumes and proportions of diesel fuel will be required. Current (1997) diesel fuel production in PADD III is 960 MBD, or 12 percent of total production of refined products in that region (DOE 1998) . Production of RFD in year 2005 is assumed to be 1450 MBD, which is based on an assumed 25 percent increase in on-road diesel fuel to satisfy new Light Duty Vehicle demand and expected growth in current Heavy Duty Vehicle markets, plus constant production of off-road diesel fuel. Table 4 shows that the premised RFD will have very low sulfur and aromatics contents. T90 will be lower and cetane number will be higher. We also assume that additive technologies will be developed so that acceptable diesel fuel qualities such as lubricity and pour point can be maintained.

RFD PRODUCTION

To achieve RFD quality and production requirements, refiners will have to improve the quality of blendstocks through operational changes and investment in desulfurization and dearomatization technologies. Additionally, we should expect changes in volume percentages of blendstocks through operational changes in the hydrocracker, and introduction of ultra-clean stocks from GTL technologies.

A spreadsheet technique has been used to derive a blendstock mix which could satisfy RFD requirements, The technique accounts for blendstock quality improvements through operational changes, limits on refinery stream availability, and the plausibility of alternate disposition of streams within the refinery. RFD blendstocks are shown in Table 5, with volume percentages, sulfur and aromatics contents, and key processes for blendstock production. Production of blendstocks for RFD will require rebalancing of refinery operations, with a 15 percent reduction in gasoline production. The fluid catalytic cracker and hydrocracker will shift from gasoline to distillate production modes. There will be adjustments in the utilization of gasoline production processes (e.g., reformers, alkylation, etc), Fischer-Tropsch (F-T) blendstocks will be purchased from GTL plants, and there will be substantial refinery investment. We use SynSat (licensed by ABB Lummus Crest Inc./Criterion Catalyst Co.) to represent deep desulfurization and dearomatization technologies, although competitive technologies will be available from other licensors (Gulf Publishing Co. 1994). Refinery investment in SynSat and supporting hydrogen capacity is shown in Table 6. If typically-sized units were installed, then sixty percent of the refineries in PADD III would invest in SynSat capacity. Total refinery investment would be $3.8 billion for the region.

The RFD sulfur specification can be achieved, albeit with virtually no margin for blending error, with SynSat technology. However, the aromatics specification cannot be met unless cleaner-than-SynSat blendstocks are used. To satisfy the RFD aromatics specification, aromatics-free F-T blendstocks could be purchased. Fifteen percent of RFD would be F-T blendstocks, and there would be no margin for aromatics blending error. Production of F-T for RFD would require an investment of $8 billion in GTL processes, as shown in Table 7 (Pennwell Publishing Co. 1998).

Capital costs are very sensitive to costs reported for SynSat and GTL investments. Operating costs are not estimated in this analysis.

CONCLUSIONS

Depending on the volume and specification requirements, RFD could be a “big deal” for refiners and others in the fuels industry. Refinery investment in desulfurization, dearomatization, and hydrogen production would be about a third of current refinery market value. The refinery capital cost component alone would be 3 cents per gallon of RFD.

Outside of refineries, the GTL capital cost component would be 3-6 cents per gallon of RFD. With total projected investments of $11.8 billion (6 to 9 cents per gallon of RFD), financing would be a major issue/uncertainty for both refinery and GTL investments.

Processing adjustments needed for RFD could have significant interactions with crude oil and gasoline quality issues. Purchase of ultra low sulfur/low aromatics blendstocks (like F-T) may be an important part of compliance strategies. The low aromatics specification is binding and has a big influence on RFD production. If the aromatics target had been 12 vol percent, instead of 10 vol percent, then F-T blendstocks would not have been used in the RFD production example.

REFERENCES

American Petroleum Institute/National Petroleum Refiners Association (API/NPRA). Final Report 1996 American Petroleum Institute/National Petroleum Refiners Association Survey of Refining Operations and Product Quality, July 1997.

Gulf Publishing Co., “Refining Processes ‘94,” Hydrocarbon Processing, November 1994.

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U.S. Department of Energy (DOE), Energy Information Administration. Petroleum Supply Annual 1997, June 1998.

Table 1. Diesel fuel production in 1997 for U.S. excluding PADD V (West Coast) (Source: DOE 1998; API/NPRA 1996)			
Fuel	1000 barrels per day (MBD)	Sulfur ppm	Aromatics vol percent
Low sulfur diesel	1810	340	32
Off- road diesel	>480	3000	31

Table 2. U.S. regional production of low sulfur diesel fuel in 1997 (Source: DOE 1998)	
Region	Percent of total national production
PADD I (East Coast)	8
PADD II (Midwest)	33
PADD III (Gulf Coast)	53
PADD IV (Rocky Mountain)	6

Table 3. Typical blendstocks for low sulfur diesel fuel in PADD III (Source: API/NPRA 1996)				
Blendstock	Vol percent	Sulfur ppm	Aromatics vol percent	Key processes*
Straight-run	10	570	27	CRU
Cracked unhydrotreated	1	4400	40	FDS, FCC
Hydrotreated (Non-cracked and cracked):				
Naphtha (200-370 ^{o}F)	1	430(?)	11	HDS, H2
Light distillate (350-500 ^{o}F)	6	70	21	HDS, H2
Heavy distillate (500-650 ^{o}F)	71	540	39	HDS, H2
Light gas oil (650-700 ^{o}F)	6	1000	50	FDS, FCC, HDS, H2
Hydrocracked:				
Light distillate	1	10	31	HCR, H2
Heavy distillate	3	270	24	HCR, H2
*CRU - crude distillation; FDS - desulfurization of feed for fluid catalytic cracker (FCC); HDS - hydrotreating; H2 - hydrogen production; HCR - hydrocracking.				

Table 4. Reformulated diesel fuel assumed requirements	
Production in PADDs I - IV	2740 MBD*
Production in PADD III	1450 MBD*
Sulfur ppm	30
Aromatics vol percent	10
Cetane number	Higher
T90	Lower
Lubricity**	Maintain quality
Pour***	Current specifications
Flash point, etc.	Current specifications

*On-road diesel fuel with an assumed 25 percent increase to meet increased Light Duty Vehicle demand + plus off-road diesel fuel.
**Lubricity can be degraded with hydrocracked blendstocks.
***Fischer-Tropsch (F-T) blendstocks can have high pour points.

Table 5. Blendstocks for reformulated diesel fuel in PADD III

Blendstock	Vol percent	Sulfur ppm	Aromatics vol percent	Key processes
Straight-run	0	570	27	
Cracked unhydrotreated	0	4400	40	
Deep Hydrotreating:				
Naphtha	nil	10	10	SynSat,*H2
Light distillate	7	10	10	SynSat, H2
Heavy distillate	46	10	10	SynSat, H2
Light gas oil	11	10	10	SynSat, H2
Hydrocracked:				
Light distillate	8	7	12	HCR, H2
Heavy distillate	12	10	21	HCR, H2
Other:				
F-T diesel (purchased)	15	0	0	GTL
Total reformulated diesel	100	8	10**	

*SynSat is hydrodesulfurization/dearomatization process licensed by ABB Lummus Crest Inc./Criterion Catalyst Co (Gulf Publishing Co. 1994).
**Binding specification.

Table 6. Refinery process investment including offsites
(Based on: Gulf Publishing Co. 1994; Oak Ridge National Laboratory Refinery Yield Model)

Process	Typical Unit		Total new capacity in PADD III	Total investment in PADD III, million$
	Size	Cost million$		
SynSat	25 MBD	68	940 MBD	2600
Hydrogen production	60 million cubic feet per day (MMcfd)	83	850 MMcfd	1200
Total				3800

Table 7. GTL investment including offsites
(Based on: Pennwell Publishing Co. 1998)

Process	Typical Unit		Total new capacity for PADD III	Total investment for PADD III, million$
	Size	Cost million$		
GTL	65 MBD	1650	320 MBD	8000