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Prospects for Adequate Supply of Ultra Low Sulfur Diesel Fuel in the Transition Period (2006-2007)

An Analysis of Technical and Economic Driving Forces for Investment in ULSD Capacity in the U.S. Refining Sector

Prepared for

The Alliance of Automobile Manufacturers

and

The Engine Manufacturers Association

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Executive Summary

EPA's Tier 2 diesel rule [Ref. 1] sets a cap of 15 ppm on the sulfur content of highway diesel fuel, effective July 2006. (Diesel fuel conforming to that cap is often called ultra-low sulfur diesel, or ULSD.)

Essentially all interested parties agree that in the *long term* – beginning say twelve to twenty-four months after the start of the ULSD program – supply of ULSD will be adequate to meet demand. However, controversy exists regarding the adequacy of ULSD supply in the *transition period* – the first twelve to twenty-four months of the program.

To shed light on this issue, the Alliance of Automobile Manufacturers and the Engine Manufacturers Association retained MathPro Inc. to assess the *likelihood* that the U.S. refining sector will produce enough ULSD to meet demand in the transition period. This report is the work product of that engagement.

OBJECTIVE AND SCOPE

This study examines the prospects for adequate ULSD supply in the transition period. To that end, it addresses key technical and economic issues that we expect will shape investment decisions in the U.S. refining sector. These issues involve both refining techno-economics and the nature and characteristics of regional markets for refined products. These latter issues were not addressed in prior studies of prospective ULSD supply (most notably [Refs. 2 and 6]).

These studies predicted a national shortfall in ULSD supply in the transition period of up to 320 K Bbl/day (relative to estimated year 2007 highway diesel production capacity, after giving effect to capacity creep and demand growth). The key assumption in these studies is that no "high-cost" refineries – that is, refineries whose estimated cost of ULSD production were above some arbitrary threshold value – would invest in ULSD capacity. These decisions not to invest would cause the predicted shortfall in ULSD supply.

The objective of our analysis was not to provide explicit predictions regarding refiners' investment decisions. Rather, it was to delineate the relevant refining techno-economics, regional diesel fuel markets, and prospective diesel fuel regulations, and to assess whether these driving forces are *likely* to promote (rather than deter) investment in ULSD production capacity for the transition period.

The study comprised analyses of four key technical and economic issues bearing on the prospects for capital investments by the U.S. refining sector to produce ULSD in the transition period.

- The unique nature of the diesel fuel market in *PADD 4*, in relation to those in PADDs 1, 2, and 3;

- The *location and competitive position* of refineries in PADDs 1, 2, and 3[1] that are likely to have *high ULSD production costs*;
- Prospects for multi-refinery projects that capture *economies of scale* for ULSD production; and
- The market prospects for and economics of *downgrading* refinery streams and products from *highway* to *non-highway* diesel fuel.

KEY RESULTS AND FINDINGS

The analyses done in this study collectively support the proposition that ULSD supplies are *likely* to be sufficient to meet demand in the transition period. In particular, most U.S. refineries are likely to find the economic driving forces for investment in ULSD capacity to be substantial, and (importantly) the alternatives to producing ULSD to be unattractive. Most, if not all, U.S. refineries that now produce EPA diesel will have economic incentives to upgrade their facilities to produce ULSD and therefore are likely to do so. Further, some refineries that do not now produce EPA diesel may have incentives to produce ULSD.

PADD 4 Refineries Are Likely to Produce ULSD

Our analysis of diesel fuel supply in PADD 4 led to the finding that PADD 4 refineries are likely to upgrade all of their EPA diesel capacity to ULSD capacity, in time for the transition period. (At least three PADD 4 refineries have already announced their intention to produce ULSD by 2006.)

The PADD 4 refineries now produce about 120 K Bbl/day of highway diesel fuel. PADD 4 is a unique situation, by virtue of its physical isolation from the other PADDs. PADD 4's isolation provides physical and economic barriers that afford protection to PADD 4 refineries from competition from lower-cost refineries in PADDs 2 and 3. Its isolation limits opportunities for downgrading highway diesel to high-sulfur diesel markets within the PADD or outside of it, as an alternative to producing ULSD. In addition, the Geographical Phase-In Area provision of the ULSD rule offers significant additional economic incentives for PADD 4 refineries to produce ULSD.

Consequently, PADD 4 refineries are unlikely to contribute to shortages of ULSD in the transition period, should any occur. This finding addresses ≈ 50 K Bbl/day of the total ULSD shortfall forecast in one of the earlier studies noted above and as much as 120 K Bbl/day of the total ULSD shortfall forecast in the other study.

High-Cost Refineries in PADDs 1–3 That Operate in Niche Markets Are Likely to Produce ULSD

Our analysis of the refining costs of ULSD production indicates that refineries in PADDs 1–3 that have "high" production costs for highway diesel fuel account for about 290 K Bbl/day of highway diesel fuel production. Our assessment of the competitive position of the high-cost refineries indicated

[1] *PADD* denotes Petroleum Administration District for Defense. The U.S. comprises five PADDs, shown on the map on page 57.

that a significant number of these refineries, with aggregate capacity of 150–170 K Bbl/day, operate in niche markets. These refineries face limited competition from supplies of ULSD having lower delivered costs (refining cost plus transportation), absent significant structural changes in the refining and distribution systems. Moreover, because of their locations, most of these refineries have only high-cost means of exporting high-sulfur diesel or distillate streams in the future, as an alternative to producing ULSD.

In summary, these refineries are in a competitive position analogous to that of the PADD 4 refineries.

High-cost refineries in niche markets are more likely to produce ULSD than those who are not. In particular, high-cost refineries that operate in niche markets in PADDs 1–3 are unlikely to contribute to shortages of ULSD in the transition period, should any occur. This finding addresses another ≈ 150 – 170 K Bbl/day of the total potential ULSD shortfall forecast in the earlier studies.

We estimate that high-cost refineries in PADDs 1–3 that face strong competition from lower-cost suppliers account for potential ULSD capacity of 120–140 K Bbl/day. These refineries have difficult choices to make regarding ULSD production, choices that are likely to be influenced by the considerations discussed below.

Capturing Economies of Scale Could Improve Economics of High-Cost Producers

Our analysis of economies of scale in ULSD investments suggests that refineries – especially small refineries – with high costs of ULSD production could reduce their costs significantly by participating in joint production arrangements. Several joint production arrangements – each involving a large-scale (50–100 K Bbl/day) merchant ULSD plant – are now under consideration for locations close to a number of the high-cost refineries that we identified.

In general, refineries outside of niche markets and having high costs of ULSD production could overcome that competitive disadvantage by participating in a venture (e.g., merchant ULSD plants, tolling arrangements, or opportunity capacity) that captures economies of scale for the participants. Such arrangements would not only reduce the participating refineries' cost of ULSD production but also (in some situations) obviate the need for them to invest in ULSD capacity. These economic benefits hold out the prospect of making ULSD production economic for high-cost refineries that otherwise might choose not to produce ULSD – a possibility that the earlier studies did not consider.

One cannot forecast the extent to which joint production arrangements may encompass high-cost refineries with adverse competitive positions in PADDs 1–3 or refineries that do not now produce highway diesel fuel. But, present indications suggest that joint production arrangements are likely to contribute to ULSD supply, a factor to be considered in assessing prospects for ULSD supply.

Downgrading Significant Volumes of Distillate Material from Highway to Non-Highway Markets Is Likely To Be Costly

Our analysis of the potential for and economic implications of on-purpose downgrading of EPA diesel or distillate blendstock volumes indicated that U.S. refineries are likely to find this route unattractive, except perhaps for small volumes. In particular, on-purpose downgrading of distillate material from highway to non-highway markets would be unattractive at the 120–140 K Bbl/day level corresponding to prospective ULSD capacity in the high-cost refineries in PADDs 1–3 that we identified as having adverse competitive positions.

Refineries choosing to curtail or eliminate highway diesel production, rather than produce ULSD, would have to downgrade part or all of their EPA diesel volume – in the form of

- EPA diesel itself;
- Mixtures of distillate blendstocks (diesel fuel components) that could be sold directly as high-sulfur diesel; or
- Low-quality, cracked distillate blendstocks (coker distillate and/or light cycle stock), which would call for further processing or blending to make salable off-highway product.

Regardless of the material downgraded, geography, operational factors, and slow growth or actual decline in demand for high-sulfur diesel in most U.S. market sectors combine to limit the potential routes for large volumes of on-purpose downgrading to three candidates:

- Replacing *highway diesel fuel* now sold in off-highway markets, with the largest potential in PADD 2,
- Increasing *exports* from PADD 3 to markets in Mexico, the Caribbean, Central America, and South America, and
- Displacing *imports* in PADD 1, first imports from remote suppliers, then imports from Venezuela.

The replacement route for downgrading (the first alternative above) would not reduce the supply of ULSD for highway use. Only the off-shore downgrading routes (increasing exports and displacing imports) would reduce the effective supply of ULSD in the U.S.

Off-shore downgrading would incur transportation costs. Moreover, it would increase – barrel-for-barrel – the total supply of high-sulfur diesel in Latin American markets (all else equal). Hence, it would depress market-clearing prices for high-sulfur distillate in the importing countries and in the U.S. We estimate that downgrading in the range of 100 to 300 K Bbl/day would decrease the refinery gate price of high-sulfur diesel fuel by roughly 5 to 20¢/gal or more, throughout PADDs 1–3. The prospect of such price effects would be a strong disincentive for pursuing downgrading.

By contrast, the earlier studies *assumed* that (1) domestic or foreign outlets would exist for whatever distillate volumes might be downgraded to non-highway diesel and (2) on-purpose downgrading would not depress non-highway distillate prices, regardless of the extent to which it were practiced.

In summary, our analysis indicates that market forces in the domestic and off-shore markets for high-sulfur distillate material would make widespread downgrading unattractive to refiners (other than for replacement of highway diesel sold in non-highway markets). The more downgrading were practiced, the more unattractive it would be. The prospect of this market response would give refiners in

PADDs 1, 2, and 3 an incentive to invest in ULSD capacity (or enter into processing arrangements) rather than accept the lower prices for high-sulfur distillate that would result from even moderate volumes of downgrading.

Because its price-depressing effects would be felt throughout PADDs 1–3, widespread downgrading could create economic incentives for refiners to invest in upgrading high-sulfur distillate capacity to ULSD capacity. Such upgrading would either increase domestic supply of ULSD (reducing the call for imports) or offset corresponding volumes of on-purpose downgrading by other refiners.

ADDITIONAL COMMENTS

The earlier studies mentioned above embody novel, detailed, and comprehensive techno-economic analyses; they shed light on important issues in the refining sector. But the conclusions they reach are predictions – based solely on considerations of refinery techno-economics – of the investment decisions that each U.S. refinery will make in response to the ULSD program, in the time interval relevant to the transition period.

In our view, attempting to predict, at arms length, investment decisions of individual enterprises in a complex business and regulatory situation is not likely to be a fruitful endeavor – and the more so when predictions are based solely on techno-economic considerations, however well analyzed. Whether refiners choose to invest in ULSD production will depend not just on the refining techno-economics of sulfur control in individual refineries – and certainly not just on a "go/no-go" criterion based on estimated average ULSD production cost – but on the interplay of techno-economic, strategic, supply/demand, political, and the competitive landscape.

Moreover, the earlier studies mentioned above rest on the assumption that each refiner would respond to the ULSD rule solely on the basis of the refiner's own cost of ULSD production. Under this assumption, each refiner is oblivious to the rest of the refining industry as it plans its response to the ULSD rule. A more useful assumption is that refiners' investment planning involves careful collection and analysis of industry information. That is, refiners are likely to make investment decisions bearing on ULSD supply, in the transition period and later, that are informed by widely available information on the situations, prospects, and intentions of other refineries with which they interact (or could interact).

The body of industry information available to refiners as they respond to the ULSD rule will be enriched by specific provisions of the ULSD rule – notably the Temporary Compliance Option, which includes a credit trading program, and the pre-compliance reporting program.

Our study offers no predictions regarding the investment decisions of individual refiners with respect to ULSD production. Rather, we have sought to (1) delineate key techno-economic factors (both inside and outside refinery battery limits, but primarily outside) that influence decisions on investing for ULSD production, (2) develop first-order estimates of their effects, and (3) indicate how these factors influence the *likelihood* of the refining industry as a whole making the investments needed to assure adequate supplies of ULSD in the transition period.

1. Introduction

1.1 BACKGROUND

EPA's Tier 2 diesel rule [Ref. 1] sets a cap of 15 ppm on the sulfur content of highway diesel fuel, effective July 2006. Diesel fuel conforming to that cap is called ultra-low sulfur diesel, or ULSD.

At least eight studies [Refs. 2 - 9] have addressed the refining economics of producing ULSD under the ULSD rule. All assume or conclude that in the *long run*, the U.S. refining sector will produce sufficient ULSD to meet future demands.

Adequacy of supply in the *transition period* – say, about twelve months following the July 2006 start of the ULSD program – has proven more controversial. Three studies – by EPA [Ref. 3], Charles River Associates /Baker & O'Brien (CRA/BOB) [Ref. 6], and the Energy Information Administration (EIA) [Ref. 2] – have addressed the prospects for ULSD supply in the transition period.

- EPA concluded that ULSD supplies would be adequate in the transition period. Nonetheless, it incorporated a Temporary Compliance Option and various "hardship" provisions in the ULSD rule. The Temporary Compliance Option allows refiners to produce a highway diesel fuel pool containing as little as 80% ULSD and as much as 20% EPA diesel (500 ppm sulfur cap) during the first four years of the ULSD program (with averaging, banking, and trading).

- CRA/BOB concluded that the ULSD rule ". . . will likely lead to a significant loss in domestic diesel make by 2007. . . projected at 320 M Bbl/day, more than 12% of [EIA's] . . . baseline forecast 2007 domestic diesel supply. . . [creating] a likelihood of domestic supply shortages and price instability".

- EIA, after analyzing various combinations of supply and demand scenarios, found ". . . the possibility of a tight diesel market when the ULSD rule is implemented. Supply scenarios that assume more cautious investment [by U.S. refiners] indicate inadequate supply compared with the demand levels projected in the *Annual Energy Outlook 2001*. Only more aggressive investment scenarios or lower demand scenarios show adequate supply. . .".

The CRA/BOB study concludes and the EIA study suggests that U.S. refiners will under-invest initially in ULSD production capacity, leading to shortfalls in ULSD supply and consequent price excursions in the transition period.

The CRA/BOB and EIA studies merit careful study. Both embody novel, detailed, and comprehensive techno-economic analyses. Both build up marginal cost curves for ULSD production in the transition period based on estimated refining economics for *each individual* U.S. refinery; and then, on the strength of these costs, they specify the predicted response of each individual U.S. refinery to the ULSD rule.

In our view, both studies over-reach. The investment behavior of individual refiners, each operating in unique circumstances in a global industry, is difficult to predict, regardless of the sophistication of the analytical approach that one employs.

Moreover, in both studies, specific elements of methodology – scenarios, techno-economic factors, decision rules, premises, and assumptions – largely determine the findings. Other methodologies would lead to different findings regarding ULSD supply in the transition period.

1.2 Objective and Scope of the Analysis

This study examines the prospects for adequate ULSD supply in the transition period. It is neither a direct response to nor a critique of the CRA/BOB and EIA work. Rather, it addresses key technical and economic issues that we expect will shape investment decisions in the U.S. refining sector. These issues involve not only refining techno-economics but also the nature and characteristics of regional markets for refined products. These market-related issues were not addressed in the CRA/BOB and EIA studies.

The objective of our analysis is not to provide explicit predictions regarding refiners' investment decisions. Rather, it is to delineate the relevant refining techno-economics, regional diesel fuel markets, and prospective diesel fuel regulations, and to assess whether these driving forces are *likely* to promote (rather than deter) investment in ULSD production capacity for the transition period.

In particular, the study focused on four technical and economic issues bearing on the prospective supply of ULSD in the transition period:

- The unique nature of the diesel fuel market in *PADD 4*, in relation to those in PADDs 1, 2, and 3;
- The *location and competitive position* of refineries in PADDs 1, 2, and 3 that are likely to have *high ULSD production costs*;
- Prospects for multi-refinery projects that capture *economies of scale* for ULSD production; and
- The market prospects for and economics of *downgrading* refinery streams and products from *highway* to *non-highway* diesel fuel.

1.3 Overview of the Report

Section 2 briefly discusses the four technical and economic issues listed immediately above. Sections 3, 4, 5, and 6, respectively, describe our analyses of these issues. Section 7 briefly summarizes special provisions of EPA's ULSD rule (including the Temporary Compliance Option) aimed at promoting ULSD production in the transition period. Section 8 summarizes the key results, findings, and implications of the analyses, with respect to prospective supply of ULSD in the transition period, and offers additional comments. Section 9 is a list of references.

2. Key Analytical Issues Addressed in the Study

This section provides an overview of the four key technical and economic issues bearing on the prospects for capital investments by the U.S. refining sector to produce ULSD in the transition period. The next four sections provide more detailed discussions of these issues.

2.1 DIESEL FUEL SUPPLY IN PADD 4

The CRA/BOB and EIA studies focused on the refineries in *PADDs 1, 2, 3, and 4*, treating the four PADDs as if they were all interconnected and their market circumstances essentially the same.

> The *CRA/BOB* study covered all five PADDs, but concluded that ULSD supply and demand in PADD 5 would "balance under all circumstances" – meaning that their forecasts of supply short-fall applied only to PADDs 1, 2, 3, and 4.
>
> The *EIA* study covered PADDs 1, 2, 3, and 4, because ". . . supply concerns are less of an issue [in PADD 5] in the transition period, and the [California] requirement for CARB diesel makes the PADD 5 market different from those in PADDs 1-4."

Both studies concluded that PADD 4 would experience especially severe shortfalls in ULSD supply in the transition period.

Our analyses of PADD 4 lead us to conclude that combining PADD 4 with the other PADDs virtually guaranteed – in itself – that the analyses would lead to projections of supply shortfalls. PADD 4 is unique, just as PADD 5 is. PADD 4's unique attributes (especially its isolation from the other PADDs) will work to reduce the likelihood of shortfalls there in ULSD supply. Hence, one must consider PADD 4 separately from PADDs 1, 2, and 3 in assessing the U.S. refining sector's response to the ULSD program.

We conducted an analysis aimed at describing PADD 4's unique characteristics and assessing the likely effects of those characteristics on the investment decisions of PADD 4 refiners. The factors that we examined included:

- Composition of the refining sector (all small refineries);
- Overall refining economics (high investment costs and high average margins – second only to PADD 5);
- Refining costs for producing ULSD (higher than in PADDs 1, 2, and 3, mainly because of refinery size distribution);
- Regulatory treatment (preferential, by virtue of EPA's special provisions for small refiners and a geographical phase-in area);
- Diesel supply pattern (unusually low share of non-highway diesel); and

- Prospects for imports from and exports to other PADDs (severely limited).

This analysis is discussed in Section 3.

2.2 Competitive Position of Refineries With High ULSD Production Costs

The CRA/BOB and EIA studies estimated marginal cost curves, or "supply curves",[2] for ULSD production. These curves express the estimated marginal cost of ULSD production in the U.S. refining sector as an increasing function of cumulative volume produced – the higher the volume produced, the higher the cost of supply. Though using different methodologies, both studies generated their curves through techno-economic analysis applied on a refinery-by-refinery basis.

In particular, both analyses produced estimates of the average cost of ULSD production for each U.S. refinery. Plotting these refinery-specific average costs of ULSD production versus cumulative production yielded estimated marginal cost curves, or supply curves, with each U.S. refinery denoted by a unique point on each curve. Because the analyses used confidential refinery-specific data, neither report identifies the individual refineries denoted by points on its estimated curves.

In both studies, the authors *assumed* that individual refineries that now produce EPA diesel would choose not to invest in ULSD production, at least in the transition period, if their estimated average cost of producing ULSD exceeded the estimated national average cost by some (unstated) amount. In both studies, these cost-driven decisions not to invest create the indicated shortfall in ULSD supply. Neither report identifies the "high-cost" refineries designated as not to produce ULSD (though the analyses, of course, specified which ones they are).

In our view, a refinery's decision on investing to produce ULSD depends not only on its absolute (or relative) cost of ULSD production, as the CRA/BOB and EIA analyses assume, but rather on the refinery's ability to recover its costs (including return on capital) in the marketplace. That ability would depend on the prospective relative prices of ULSD and high-sulfur distillate in the refinery's market area – which in turn would be determined by many factors, such as location and competition, in addition to the refinery's own costs. For example, as discussed in Section 2.1 and (in more detail) in Section 3, PADD 4 refineries tend to have high production costs; but they can pass on their costs and earn high refining margins because of their location and the configuration of the refined products logistics system in PADD 4 and adjacent PADDs.

Accordingly, we undertook an independent techno-economic analysis to (1) identify the individual refineries in PADDs 1, 2, and 3 likely to have the highest average ULSD production costs and (2) assess the ability of these refineries to recover their costs of ULSD production, by virtue of their location and competitive situation.

This analysis is discussed in Section 4.

[2] The CRA/BOB report appears to use the terms "marginal cost curve" and "supply curve" interchangeably; the EIA report usually (but not always) uses the term "marginal cost curve".

2.3 INVESTMENTS IN ULSD CAPACITY THAT EXPLOIT ECONOMIES OF SCALE

As noted in Section 2.2, the CRA/BOB and EIA studies consider only two approaches to complying with the ULSD rule. Each involves an individual refinery acting independently of all other refineries located in its refining center or serving its markets.

The CRA/BOB and EIA studies did not consider possible production arrangements – long-term or ad hoc – involving multiple refineries and aimed at achieving economies of scale.

- A group of refineries or a third party could build a single merchant ULSD plant – that is, a large desulfurization unit processing distillate streams from and producing ULSD for all refineries in the group.

- A large refinery could build a large ULSD unit, over-sized for its own throughput, and then produce ULSD – under contract and for a per-barrel fee – from raw stocks produced by other local refineries who choose not to produce ULSD on their own. Such "tolling" arrangements are common in the refining industry.

- A refinery could build a ULSD unit with excess capacity for occasional surges in throughput (caused by transient changes in refinery operations, re-running off-spec product, etc.) and use the excess capacity in normal operations to produce additional ULSD from raw stocks purchased from other refineries on a contractual or opportunity basis.

Such arrangements would provide economic alternatives to simply downgrading EPA diesel or raw stock for refineries that chose not to produce ULSD in the transition period (or indeed in the long term).

To consider these possibilities is not to assert or predict that merchant ULSD plants, tolling arrangements, or other inter-refinery arrangements will be established. Rather, it is to recognize that (1) some refineries may have strong economic incentives to consider such arrangements, (2) they are technically feasible, and (3) they could well be in the portfolio of approaches that the U.S. refining sector uses to meet the demand for ULSD.

In this study, we conducted a simple analysis to delineate (1) the economics of notional merchant ULSD plants in each of PADDs 1, 2, 3, and 4 (taking into account economies of scale in investment, operating costs, transportation costs, and feedstock values) and (2) the incremental investment to build an "over-sized" ULSD unit in a large refinery, to produce ULSD from raw stocks purchased on a spot or opportunity basis.

This analysis is discussed in Section 5.

2.4 Economic Implications of Diverting Distillate from Highway to Non-highway Markets

The CRA/BOB and EIA studies consider two alternative responses to the ULSD rule by any individual U.S. refiner:

- Invest in independent ULSD production capacity, by building green-field facilities and/or by revamping existing distillate desulfurization facilities (that now produce EPA diesel); or

- Divert EPA diesel or distillate[3] material now used for producing EPA diesel to non-highway distillate markets (domestic or foreign) – that is, reduce out-turns of highway diesel fuel or abandon the highway diesel market. (We call this response "downgrading" or "on-purpose downgrading".)

The downgrading alternative reflects unwillingness to invest in ULSD capacity, because of either a shortage of capital or a perception that the investment would not earn an adequate return. The CRA/BOB and EIA studies deal only with the latter issue (as does this study).

The CRA/BOB and EIA studies address downgrading solely from the viewpoint of producers of highway diesel fuel; they do not consider the responses of the markets for highway diesel fuel and other distillate products. In particular, their analyses rest on the implicit *assumptions* that (1) domestic or foreign outlets exist for whatever distillate volumes the U.S. refining sector might downgrade and (2) downgrading highway diesel volumes would neither depress non-highway distillate prices nor widen the price spread between ULSD and non-highway diesel fuels. These assumptions, in our view, are implausible and inconsistent with likely market behavior.

Modest volumes of downgrading (from say a few refineries) might or might not depress non-highway diesel prices. But what if many refineries chose to downgrade? The CRA/BOB and EIA analyses indicate that significant volumes of EPA diesel – on the order of 200-300 K Bbl/day – would be downgraded in the transition period, causing the presumed shortfall in ULSD supplies. In our view, downgrading significant volumes of distillates into non-highway markets is likely to trigger significant declines in non-highway diesel prices (all else equal).

This consequence of downgrading is of central importance. The prospective price spread (at the refinery gate) between ULSD and high-sulfur diesel fuel is the primary economic driving force for a refiner to produce ULSD – either by investing in onsite ULSD production capacity or by participating in joint production arrangements with other refineries. Price declines in off-highway diesel markets would create incentives for high-cost refiners to convert their distillate volumes to ULSD rather than place them in off-highway diesel markets.

To address downgrading from a market perspective, we analyzed the prospects for and economic consequences of downgrading distillate material (EPA diesel or desulfurization feedstocks) to non-highway diesel markets, by refineries in PADDs 1, 2, and 3. The analysis (1) identified the possible

[3] We use the term "distillate" to denote (variously, depending on the context) high-sulfur diesel fuel, heating oil, and untreated refinery streams or blendstocks (e.g., light cycle oil, straight run distillate, etc.) used in the production of diesel fuel.

markets for additional non-highway distillate in the U.S. and elsewhere, (2) estimated the range of distillate volumes that could be downgraded to these markets, and (3) estimated the effects on high-sulfur distillate prices in the U.S. of downgrading EPA diesel or desulfurization feedstock volumes to non-highway markets.

This analysis is discussed in Section 6.

3. Diesel Fuel Supply in PADD 4

This section describes our technical and economic analysis of PADD 4's unique characteristics and their implications for ULSD production and supply in PADD 4 in the transition period.

The discussion covers eight topics.

1. Refining capacity and crude supply
2. Diesel fuel supply and consumption
3. Estimated refining margins
4. Estimated economics of ULSD production
5. Effect of downgrading on the price of non-highway diesel
6. Implications of the Geographical Preference Area provision of the ULSD program
7. Prospects for loss of ULSD supply due to refinery closure
8. Overall prospects for diesel fuel supply

The Appendix delineates the methodology used to estimate PADD 4 refining margins.

3.1 Refining Capacity and Crude Supply

PADD 4 has fourteen operating refineries, with aggregate refined product output of about 515 K Bbl/day (including about 145 K Bbl/day of diesel fuel) in 1999 and 2000. The refineries have a combined crude running capacity of about 520 K Bbl/day, and, in aggregate, operate at more than 90% of capacity. The refineries are in three clusters, or refining centers: Salt Lake City, East Range (including Denver and Southern Wyoming refineries) and Northern Wyoming/Montana.

PADD 4 refineries are significantly smaller than the U.S. average (≈ 100 K Bbl/day) – eight are between 40 and 60 K Bbl/day; six are less than 30 K Bbl/day.

The small size of the PADD 4 refineries, coupled with a high regional investment multiplier (relative to the Gulf Coast), leads to unit (per-barrel) investment costs for refinery capacity that are significantly higher than for typical refineries in PADDs 2 and 3.

Geographic considerations limit competition between (as opposed to *within*) PADD 4's refining clusters. Some competition exists between East Range and Wyoming/Montana refineries. The Salt Lake City cluster is essentially isolated from the other two. The Salt Lake City and East Range refineries experience some competition from inter-PADD transfers, via pipeline, from PADD 3 and PADD 2 refineries. The volume of these pipeline shipments is limited by pipeline capacity and by economics. The inter-PADD transfers are the marginal supplies of refined products in the Salt Lake City and East Range centers; and their delivered prices incorporate transportation costs.

The three Montana refineries run crude slates comprising mostly imported (Canadian) crude oil; the other eleven run crude slates comprising all or mostly domestic crude. Overall, imports account for about 30% of aggregate crude run in PADD 4. On average, the imported crude is heavier and higher in sulfur content than the domestic crude run in PADD 4.

Slightly less than half the crude oil used by PADD 4 refineries is light, low sulfur crude (API gravity > 30°, sulfur content < 1.0 wt%). Most of the rest is heavy, high sulfur crude (API gravity < 30°, sulfur content > 2.0 wt%). The average sulfur content and API gravity of the PADD 4 crude slate are comparable to the average values nation-wide.

Exhibit 3.1 lists the PADD 4 refineries, their process capacities, and the volume and properties of crude oil imports in 2000, with aggregate volume and properties of domestic crude oil purchases and total crude oil purchases. **Exhibits 3.2 and 3.3** show aggregate PADD 4 refinery inputs and outputs for 1999 and 2000, along with information on refinery operations and aggregate crude oil properties.

3.2 DIESEL FUEL SUPPLY AND CONSUMPTION

Diesel fuel production in the PADD 4 refineries averaged 145 K Bbl/day (about 28% of total refined product out-turn) in 1999 and 2000, of which 120 K Bbl/day was EPA diesel. Total diesel fuel supply in PADD 4 averaged 167 K Bbl/day in 1999 and 2000, of which 138 K Bbl/day was EPA diesel and 29 K Bbl/day was high-sulfur diesel.

The difference between diesel fuel production and total diesel fuel supply in PADD 4 – averaging about 22 K Bbl/day (13% of supply) in 1999 and 2000 – is met by

- *Imports* from Canada: EPA diesel (3 K Bbl/day) and non-highway diesel (3 K Bbl/day); and
- *Net inter-PADD transfers* with PADDs 2, 3, and 5: EPA diesel (16 K Bbl/day)

PADD 4 both imports and exports diesel fuel to adjacent PADDs, via inbound and outbound product pipelines. In 1999 and 2000, the Salt Lake City and Wyoming/Montana refineries sent about 16 K bbl/day of EPA diesel fuel east (to PADD 2) and west (to PADD 5). In the same period, the East Range area received about 32 K bbl/day of EPA diesel fuel from refineries in Kansas (PADD 2) and Texas (PADD 3). The volume of net inter-PADD transfers of EPA diesel has increased from an average of about 13 K Bbl/day in 1996-1998 to about 16 K Bbl/day in 1999-2000.

Exhibit 3.4 provides information on the pipelines that carry refined products into and out of PADD 4. No out-bound pipelines go to PADD 3 or to the West Coast. Tariffs for the in-bound pipelines are in the range of 2½-4¢/gal of refined product.

Exhibit 3.5 shows the annual supply and consumption of diesel fuel in PADD 4 from 1996 to 2000. In PADD 4, EPA diesel constitutes about 83% of diesel fuel *supply* (refinery out-turns plus net imports), significantly more than the national average of 68% and the PADD 1-3 average of 66%. By contrast, highway diesel fuel *sales* are about 60% of total diesel fuel consumption, comparable to the national and PADD 1-3 averages.

These figures indicate that about 25% of PADD 4's diesel fuel supply – about 40 K Bbl/day – is EPA diesel sold for non-highway uses. This overproduction of EPA diesel fuel most likely reflects PADD 4's unique combination of large area and relatively low population density. Product distribution in PADD 4 entails long hauls, relatively small product batches, and relatively low terminal throughputs – leading to relatively high unit distribution costs. Many distribution terminals in PADD 4 find it uneconomic to have facilities for handling more than one grade of diesel fuel. The one grade such terminals handle necessarily would be EPA diesel. These factors tend to minimize the prospects for on-purpose downgrading of additional distillate volumes through the PADD 4 distribution system.

About 80% of off-highway diesel fuel consumption is in the railroad, farm, industrial, and off-highway categories (in decreasing order of volume). Diesel fuel consumption is essentially static in the farm, industrial, and off-highway markets, but is declining in the railroad sector. Railroad diesel fuel is a sink for low-quality (i.e., high-sulfur, low-cetane) diesel blendstocks, primarily light cycle oil. Hence, its volume decline also works to restrict opportunities for diverting additional distillate volumes to off-highway sales.

Exhibit 3.5 shows that PADD 4 now imports only 3-4 K Bbl/day of off-highway diesel fuel and exports none. Hence, little opportunity exists for disposing of high-sulfur diesel fuel or blendstocks by displacing imports or increasing exports.

3.3 Refining Economics and Estimated Refining Margins

PADD 4's geography, the configuration of its refining sector, and the pipeline cost associated with inter-PADD transfers of refined products create economic barriers to product supplies from remote refineries. Where transfers from PADDs 2 and 3 are the marginal supplies, PADD 4 refiners can set refinery gate prices at import parity levels (which includes the estimated tariffs for in-bound pipelines of 2½–4¢/gal of refined product). In general, the PADD 4 refining clusters are protected by geography from competition from PADDs 2 and 3, and face limited competition from elsewhere in PADD 4. Each cluster contains relatively few refineries, operating at high capacity utilization. We understand, from industry sources, that the cost of moving refined products from the Gulf Coast refining center to a PADD 4 center – via a new, as yet un-built pipeline – would be about 7–10¢/gal. These factors suggest that, in most periods, refining margins would tend to be higher in PADD 4 than in PADDs 1, 2, and 3.

This line of reasoning finds support in the average differential in product rack prices between Denver and Houston. In normal conditions, rack prices tend to be 5–6¢/gal higher in Denver than in Houston.

One can further substantiate this line of reasoning by examining *gross refining margins* or *cash operating margins* of PADD 4 refineries, two common measures of financial performance in the refining industry.

Gross refining margin ($/Bbl crude run) =

$$(\Sigma \text{ Product revenues} - \Sigma \text{ Crude \& other feed costs}) / (\text{Bbl crude run})$$

Cash operating margin ($/Bbl crude run) =
(Gross refining margin – Operating costs[4]) / (Bbl crude run)

These measured must be estimated, because information is not published on either one.

Gross refining margin, the point of departure for estimating cash operating margin, may be estimated from average market prices and volumes of refinery input and output streams. (Such information, by PADD, is available from Department of Energy publications). Cash operating margin, an index of pre-tax cash flow per barrel of crude oil run, is harder to estimate (because it involves operating costs, for which specific data are not available from public sources).

We performed a brief analysis to estimate average gross refining margins of PADD 4 refineries, as well as refineries in other PADDs, for each year from 1996 through 2000. **Appendix A** outlines our methodology for this analysis, which relied on data published by the Energy Information Administration on crude oil and refined product prices for each year.

As shown in **Exhibit 3.6**, our analysis indicates that average gross refining margin in PADD 4 has been higher than in PADD 2 and PADD 3 each year, by averages of ≈ $1.20/Bbl and ≈ $2.40/Bbl, respectively.

One can infer that average cash operating margin is correspondingly higher in PADD 4 than in either PADD 2 or PADD 3. We estimate that the average cash operating margin in PADD 4 in 1999 and 2000 was in the range of $3.25–$4.00/Bbl of crude run.

These findings are consistent with the observed rack price differential between Denver and Houston. They reflect the protected situation that PADD 4 refineries enjoy by virtue of their physical isolation and lack of high-volume inter-connections with adjacent PADDs.

For further confirmation, we compared our estimates of 1995–2000 average gross refining margins to reported crack spreads for East Coast, Gulf Coast, and West Coast refineries, published in the *Oil and Gas Journal* [Ref. 14]. These estimates corroborate the PADD-to-PADD pattern of average gross margins estimated in our analysis, lending support to the notion that gross refining margins and cash operating margins are consistently higher in PADD 4 than in PADDs 1, 2, and 3.

3.4 ESTIMATED ECONOMICS OF ULSD PRODUCTION

We estimated the investment requirements and the average production cost of ULSD for each PADD 4 refinery using the methodology described in Section 4.2. The methodology draws upon results of the series of studies that we have conducted (e.g., [Refs. 4 and 11]) on the economics of sulfur control across the U.S. refining sector. For each refinery, the investment and cost estimates apply to their estimated volumes of EPA diesel production in 2000.

[4] Ex income taxes, depreciation, and financial charges

To produce ULSD, every PADD 4 refinery would have to invest in new facilities. (One refinery has already made the necessary investments.) In all but two instances, the indicated investments would be to retrofit existing EPA diesel capacity to ULSD capacity. Our analysis suggests that the two refineries in question produce no EPA diesel, so their investments would be for grass-roots facilities, if they decide to produce ULSD.

Exhibit 3.7 shows our estimates of the capital investments for new process capacity that each PADD 4 refinery would likely make to produce ULSD. Each dot in the chart represents a single refinery. The investment costs are sorted by refinery size, i.e., ordered according to the crude distillation capacity of the refineries.

Estimated investments in ULSD production capacity in PADD 4 are in the range of $10–$30 M per refinery, with most refineries in the range of about $15–$30 M. The estimated total investment requirement for ULSD production capacity in PADD 4 is about $125 M.

The estimates of total investment reflect the relatively high *unit* [5] investment costs in PADD 4. Because of their small size and location, PADD 4 refineries incur higher unit investment costs and capital charges for ULSD production facilities than refineries in the Gulf Coast, the rest of PADD 3, or PADD 2. In turn, the higher capital charges associated with these investments lead to higher average ULSD production costs in PADD 4. (This is the main rationale for the view held by some that PADD 4 refineries are at economic disadvantage with respect to refineries in adjoining PADDs.)

Exhibit 3.8 shows our estimates of the average cost of ULSD production for PADD 4 refineries, in *¢/gal of ULSD*, for the PADD 4 refineries.

- The *Highway* curve applies to ULSD production from retro-fitted EPA diesel capacity, with cumulative production of about 120 K Bbl/day.

- The *Non-highway* curve applies to ULSD production from grass-roots ULSD capacity (processing material formerly dedicated to high-sulfur distillate products), with cumulative production of about 45 K Bbl/day.

- The *Combined* curve is the sum of the other two curves, with cumulative production of about 165 K Bbl/day.

For each curve, refinery-specific cost estimates are ordered from low to high and plotted versus cumulative PADD 4 diesel fuel output – forming a set of ULSD cost curves for PADD 4 refineries.

With regard to average production costs, our analysis indicates that

- Most PADD 4 refineries would incur average ULSD production costs in the range of **5–8¢/gal**.

[5] Unit investment cost is investment per barrel/day of throughput.

- Five PADD 4 refineries – accounting for about 8% of PADD 4's highway diesel fuel output – are likely to incur higher ULSD costs, in the range of **9–14¢/gal**.

  At least some of these five refineries could reduce their costs by entering into joint production arrangements with nearby refineries (as discussed in Section 5) or other arrangements that would facilitate increased ULSD production by other PADD 4 refineries.

By way of comparison, we estimated average ULSD production cost of 4–5¢/gal for refineries in PADDs 1, 2, and 3 (as discussed in Section 4.2). These estimates indicate that PADD 4 refineries accounting for 90–95% of highway diesel out-turn would incur average ULSD production costs ranging from 1–3¢/gal higher than average costs in PADDs 1–3.

3.5 EFFECT OF DOWNGRADING ON THE PRICE OF NON-HIGHWAY DIESEL

PADD 4 refiners who choose to reduce or eliminate their production of highway diesel fuel in response to the ULSD program would have two significant outlets for the volumes of distillate material that they would divert from highway diesel fuel.

- Downgrading to non-highway diesel for markets within PADD 4

- Downgrading to non-highway diesel for markets outside PADD 4

As discussed in Section 3.2, about 40 K Bbl/day of EPA diesel produced in PADD 4 refineries is now sold as non-highway diesel fuel within the region, mainly because of unique characteristics of the product distribution system (e.g., insufficient facilities for handling two grades of diesel fuel throughout the system and thereby delivering two diesel products to end-use markets).

If the PADD 4 refining sector could make the necessary changes in supply patterns and investments in distribution facilities (refinery, pipeline, and terminal tankage, etc.), PADD 4 refiners might be able to satisfy the region's diesel fuel demands during and after the transition period with less ULSD and more high-sulfur diesel. However, those who have analyzed PADD 4's distribution system have concluded that it offers limited potential for the necessary re-structuring.

But at least in principle, re-structuring of the distribution system – at some cost, possibly significant – could allow refineries to reduce out-turns of highway diesel (EPA diesel now; ULSD starting in 2006) by up to 40 K Bbl/day and to increase out-turns of high-sulfur diesel fuel by a like volume, for supply to off-highway diesel fuel markets. This downgrading would result in no reduction in ULSD supplies for on-highway markets and would have no effect on the price of non-highway diesel fuel.

In other words, PADD 4 refiners could decrease production of highway diesel fuel by up to 40 K Bbl/day – the actual amount depending on the extent to which production and distribution were re-structured – without causing shortfalls in ULSD supply (either in PADD 4 or elsewhere). This approach would entail additional investment and operating costs in the distribution system, but would have no effect on the supply of highway and non-highway diesel.

If PADD 4 refiners were to curtail production of highway diesel fuel by more than this threshold volume, they would have to dispose of the additional volumes of off-highway diesel fuel in markets outside PADD 4. This would be neither easy nor cheap. Most importantly, for purposes of this analysis, it would create an unusually large price spread between ULSD and non-highway diesel. Recall that the prospective price spread (at the refinery gate) between ULSD and non-highway diesel fuels is the primary economic driving force for investing in ULSD production capacity.

As discussed in Sections 3.2 and 3.3, PADD 4 refineries have little access to adjacent PADDs or to Canada, due to the location of the refineries and the configuration of the distribution system. No pipelines run from PADD 4 to the refining centers in PADDs 2, 3, or 5. Hence, any movements of distillate out of PADD 4 would have to be by rail – most likely to the Gulf Coast or West Coast (where the distillate would be either processed into ULSD or exported as high-sulfur diesel).

Muse, Stancil [Ref. 9] estimated the rail tariff between "mid-PADD 4" and the Gulf Coast to be 10-12¢/gal, on the basis of other rail tariffs for comparable transfers involving PADD 4 locations. This tariff would reduce by a like amount the netback price that PADD 4 refiners could realize for distillate volumes sold as high-sulfur diesel. This price decline would apply to all high-sulfur diesel fuel produced in PADD 4 – not just to the downgraded volumes moved out of PADD 4.

The potential magnitude and scope of this price change would provide a powerful incentive for PADD 4 refiners to invest in ULSD production.

3.6 Implications of the GPA Provision of the ULSD Program

The ULSD rule includes a *Geographical Phase-In Area (GPA)* provision, which provides an important added incentive for PADD 4 refiners to make timely investments in ULSD production.

EPA's Geographical Phase-In Area – established in connection with the Tier 2 gasoline sulfur control program – covers all of PADD 4 (as well as parts of Alaska). EPA used the GPA to link the ULSD program to the Tier 2 gasoline program (30 ppm sulfur average). In particular, the ULSD rule provides that a refinery in the GPA that meets the ULSD standard by 1 June 2006 – for *all* of its highway diesel out-turn – may receive a two-year extension on its compliance date for Tier 2 gasoline (from 31 December 2006 to 31 December 2008).[6]

In an earlier study [Ref. 10], we examined the refining economics of the Tier 2 gasoline program in PADD 4. We estimated that:

- The investment in desulfurization capacity will be in the range of \$5–25 M per refinery, with most refineries in the range of \$15–25 M (in 1999 \$).

  The estimated total investment requirement is ≈ \$215 M.

[6] To receive the extension, the refinery's ULSD out-turn must be at least 85% of its average production of EPA diesel in 1998 and 1999.

- Most PADD 4 refineries will incur sulfur control costs in the range of 2½–3½¢/gal. A few refineries – accounting for less than 10% of PADD 4's gasoline production – are likely to incur higher sulfur control costs, the range of 4–4½¢/gal.

  These costs are the sum of (1) additional refinery operating costs and (2) capital charges for the required investments in desulfurization capacity. The estimated total additional operating costs (ex capital charges) are on the order of 1¼¢/gal, corresponding to ≈ \$50 M/year (in 1999 \$).

Hence, if all PADD 4 refineries invested in ULSD production, the GPA provision of the ULSD program would result in

- A two-year deferral of the capital investment for gasoline desulfurization, worth ≈ \$40 M (assuming that the cost of capital is 10%); and

- A savings of ≈ \$100 M in refinery operating costs (i.e., two years of gasoline desulfurization costs), which the PADD 4 refiners would capture as increased refining margin.

  PADD 4 refiners would likely capture these savings in operating costs, because gasoline prices in PADD 4 markets are set by the costs of marginal supplies, which come from PADDs 2 and 3. These marginal supplies would have to meet the Tier 2 gasoline sulfur standard of 30 ppm, and their delivered price would reflect the cost of sulfur control.

At current levels of highway diesel production in PADD 4 refineries (about 120 K Bbl/day), these "GPA benefits" would reduce the effective cost of ULSD production for PADD 4 refiners by about 3¾¢/gal in the first two years of the ULSD program (which, of course, includes the transition period).

Alternatively, one can view the GPA benefits as off-setting 60–70% of the total investment required to upgrade all highway diesel production capacity to ULSD production capacity in PADD 4.

Either way, the GPA provision of the ULSD rule offers a strong added incentive – specifically for PADD 4 refineries – to make timely investments in ULSD production.

3.7 PROSPECTS FOR LOSS OF ULSD SUPPLY DUE TO REFINERY CLOSURES IN PADD 4

The refining industry usually views investments made to comply with environmental regulations – such as the ULSD program – as "stay-in-business" investments. For such investments, refineries find that they are able to pass operating costs – but not capital costs – forward to consumers. Because of their limited opportunities for downgrading, PADD 4 refiners might view investments to produce ULSD as stay-in-business investments.

A standard financial measure for evaluating whether to make stay-in-business investments is the *capital charge* (per barrel of crude run).

Capital charge ($/bbl crude run) = Annual capital recovery[7] / Annual crude run

If a stay-in-business investment for a given refinery incurs a capital charge that is high relative to the refinery's cash operating margin, the refinery may prefer not to stay in business – that is, to curtail or end production of the product in question or, in the extreme, to become a candidate for closure. If the capital charge is low relative to cash operating margin, the refinery is likely to make the investment and accept the consequent reduction in cash operating margin.

Exhibit 3.9 shows our estimates of ULSD production costs for the PADD 4 refineries, this time expressed in *$/bbl of crude run*. The lower line shows estimated *capital charges* per barrel; the upper line shows estimated total costs – *capital charges plus operating costs* – per barrel. The estimates are ordered from low to high and plotted versus cumulative percentage of current PADD 4 diesel output.

For PADD 4 refineries, we estimate (1) *average* cash operating margins to be in the range of $3.50–$4.00/Bbl (as discussed in Section 3.3) and (2) capital charges for ULSD production to be in the range of $0.35–$0.40/Bbl.

These estimates indicate that the capital charges for investments required to produce ULSD instead of EPA diesel would be ≈ 10% of average cash operating margin in PADD 4. This finding suggests that refinery closures and consequent reductions in ULSD production in PADD 4 would be an unlikely consequence of the ULSD program – even if PADD 4 refiners could not recover capital investments in ULSD capacity. Moreover, the possibility of joint production arrangements developing in PADD 4 further reduces the likelihood of refinery closures as a consequence of the ULSD program. As discussed in Section 5, such arrangements can reduce or eliminate the capital investment needed to produce ULSD.

3.8 OVERALL PROSPECTS FOR ULSD PRODUCTION BY PADD 4 REFINERIES

As discussed in Section 3.4, PADD 4 refineries are indeed "high cost" refineries. Because they are small, they are likely to incur higher unit investments and higher average costs for ULSD production than most refineries in PADDs 2 and 3, some of which supply ULSD to parts of PADD 4. Probably, the PADD 4 refineries are among the refineries deemed in the CRA/BOB and EIA studies to be unlikely to invest in ULSD production, at least in the transition period.[8]

Nonetheless, our analysis indicates that the PADD 4 refining sector is unlikely to curtail supplies to on-highway diesel fuel markets in response to the ULSD program, either in the transition period or thereafter.

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[7] Includes depreciation, return on investment, and related items

[8] We infer this from (1) our estimates of the refineries' estimated ULSD production costs and (2) the criteria for refinery investment used in the two studies. Neither report identifies specific refineries. We address this subject in some detail in Section 4.

- PADD 4's geography, the configuration of its refining sector, the pipeline cost associated with inter-PADD transfers of refined products, and limited pipeline connections create economic and physical barriers to product supplies from remote refineries. At least in part for these reasons, PADD 4 enjoys higher average refining margins than PADDs 2 or 3, in the range of 3–6¢/gal of refined product. Hence, higher unit investments and higher average costs for ULSD production do not, in themselves, place the PADD 4 refineries at a competitive disadvantage with respect to current and prospective suppliers outside the region. (See Sections 3.2 and 3.3.)

- Capital charges associated with ULSD investments by PADD 4 refineries would be small in relation to their average cash operating margin – on the order of 10–15% of average cash operating margin in 1999 and 2000. Even if PADD 4 refineries were unable to recover their capital for ULSD investments, refining margins would remain strong relative to the national average, and refinery closures due to the ULSD program unlikely. (See Section 3.7.)

- The Geographical Preference Area provision of the ULSD program offers an added incentive exclusively to PADD 4 refiners for investments in ULSD production capacity that are timely with respect to the transition period. We estimate the GPA provision to be worth about 3¾¢/gal of ULSD production in PADD 4 during the first two years of the ULSD program, an amount comparable to the difference in average ULSD production cost between PADD 4 and PADDs 2 and 3. (See Section 3.6.)

- Significant volumes of on purpose downgrading would require transferring these volumes to PADD 3, for processing or export. The associated transportation costs would reduce refinery netback prices of high-sulfur diesel fuel in PADD 4 by 10–12¢/gal. The corresponding reduction in gross refining margin would outweigh the costs of ULSD production and thereby create a strong economic incentive to invest in ULSD capacity, rather than resort to downgrading. (See Section 3.5.)

In summary, the results of this analysis indicate that PADD 4 refineries have strong incentives to invest in ULSD production capacity, in time for the transition period. PADD 4 refineries are likely to invest fully in ULSD production and therefore are unlikely to contribute significantly to shortages of ULSD in the transition period, should any occur.

Hence, we concentrated on PADDs 1, 2, and 3 in the other parts of the study.

4. Competitive Position of Refineries With High ULSD Production Costs

This section describes our analysis to identify the individual refineries in PADDs 1, 2, and 3 likely to have the highest average ULSD production costs and to assess the ability of these refineries to recover their ULSD production costs, by virtue of the special circumstances (such as location) that define their competitive position.

The discussion covers four topics.

1. Rationale for the analysis
2. High-cost refineries for ULSD production
3. Competitive position of individual high-cost refineries
4. Prospects for ULSD production by high-cost refineries in PADDs 1–3

4.1 Overview of the Analysis

In order to assess the competitive position, with respect to ULSD production, of the "high-cost" refineries in PADDs 1, 2, and 3, one must know which ones they are. To this end, we conducted an independent techno-economic analysis to estimate the average cost of ULSD production for each refinery in PADDs 1, 2, and 3. The analysis produced estimated ULSD marginal cost curves for PADDs 1–3 and, in the process, pinpointed high-cost refineries.

We conducted the analysis solely for these purposes – not to replicate, validate, or challenge the comparable analyses in the CRA/BOB and EIA studies.

> Recall that the CRA/BOB and EIA studies included techno-economic analyses that estimated ULSD cost curves and the average costs of ULSD production for each U.S. refinery (not just those in PADDs 1, 2, and 3). But neither report identified the high-cost refineries – those designated as not producing ULSD, at least in the transition period.

We grouped our high-cost refineries by location, in particular by DOE/EPA Refining District. (Each Refining District is a geographical subset of a PADD.) Then, we assessed the competitive situation facing high-cost refineries in these clusters – in particular, their exposure to competition from lower-cost supplies of ULSD, including

- Inter-PADD transfers of ULSD from the Gulf Coast or other low-cost refining center
- Imports of ULSD from foreign countries
- Supplies from near-by refineries having lower ULSD production costs

In Section 5, we address other location-related factors not considered here – such as local markets for highway and non-highway diesel and proximity to out-bound transportation (e.g., product pipelines).

4.2 IDENTIFYING HIGH-COST REFINERIES FOR ULSD PRODUCTION

To identify the refineries having high costs of ULSD production, we developed a spreadsheet representation of the economics of ULSD production for each individual refinery in PADDs 1, 2, and 3 (and in PADD 4 as well, to support the analysis discussed in Section 3.4).

4.2.1 Methodology

In brief summary, the spreadsheet representation of ULSD economics incorporates:

- The *primary economic factors* determining ULSD production costs, developed in our analyses of ULSD economics for the Engine Manufacturers Association [Refs. 4 and 16]:

  - Unit investment requirements ($K/Bbl per day) for ULSD production capacity
  - Capital charges (¢/gal of ULSD production)
  - Total operating costs, including capital charges (¢/gal of ULSD production)
  - A scaling exponent for translating investment requirements from one unit size to another

  These factors apply to the *"Series Retro-fitting"* option defined in [Refs. 4 and 16]. They cover on-site and off-site investments (including hydrogen generation) and apply to a U.S. Gulf Coast location. They were developed for a notional refinery representing aggregate PADD 1–3 refining capacity and producing both ULSD and non-highway diesel fuel.

- Individual *refinery configurations* – specific process units (such as distillate hydrotreaters, hydrocrackers, etc.), their nameplate capacities, and their capacity utilizations – drawn from public sources [Ref. 15]

- Imported *crude oil charges* (volumes and properties), by PADD, drawn from DoE import data and estimated domestic crude oil charges (volumes and average properties) reported by DoE for Refining Districts

As indicated here, we used only information in the public domain.[9]

For each refinery, we (1) estimated current out-turns of EPA diesel and off-highway diesel (and heating oil) from the refinery's capacity profile (e.g., existence and size of distillate hydrotreater, hydrocracker, etc.) and (2) normalized these out-turns so that the estimated aggregate production of ULSD and off-highway diesel fuel in each PADD matches the reported aggregate production volumes for each Refining District in 2000 [Ref. 16].

Then, for each refinery, we estimated investment requirements and average cost of ULSD production for each of two cases:

[9] By contrast, the CRA/BOB and EIA studies had access to proprietary data on refining process capacity, processing conditions, and diesel fuel out-turn for each refinery of interest.

- The refinery retrofits its EPA diesel capacity to ULSD capacity and maintains its out-turn of non-highway diesel fuel and heating oil.

- The refinery retrofits its EPA diesel capacity to ULSD capacity and makes grass-roots investments to produce ULSD in place of non-highway diesel fuel and heating oil. (This case also encompasses refineries that currently produce no EPA diesel fuel.)

The estimated investments are in year 2000 dollars.

Consistent with our usual practice, the per-gallon cost estimates are the sum of (1) capital charges for required investments in distillate desulfurization capacity, (2) additional refinery operating costs, (3) ancillary costs associated with ULSD production, and (4) additional additives costs (e.g., for lubricity control). Capital charges reflect a 10% after-tax return on investment. The cost estimates do not include any allowance for cost reductions that might arise if refineries practiced sulfur credit trading.

Our prior work has indicated that size and location are the primary determinants of ULSD economics. Hence, we developed the investment and cost estimates by applying suitable location factors and scale factors to the corresponding values developed in our previous analyses [Refs. 4 and 16], which considered a notional refinery for PADDs 1–3. In other words, the refinery-to-refinery variations in our estimates depend primarily on ULSD production volume and refinery location. We did not attempt to capture any other refinery-specific effects, such as those associated with crude oil properties and the fraction of cracked stocks in the distillate pool.

4.2.2 Results: ULSD Cost Curves and the High-Cost Refineries

Exhibit 4.1 shows the set of ULSD cost curves for PADDs 1, 2, 3, and 4 generated from our refinery-specific estimates of average costs of ULSD production. Each curve shows refinery-specific average costs of ULSD production versus cumulative production in PADDs 1, 2, 3, and 4 with each refinery denoted by a unique point on each curve.

- The *Highway* curve applies to ULSD production from retro-fitted EPA diesel capacity, with cumulative production of about 2.1 MM Bbl/day.

- The *Non-highway* curve applies to ULSD production from grass-roots ULSD capacity (processing material formerly dedicated to high-sulfur distillate products), with cumulative production of about 1 MM Bbl/day.

- The *Combined* curve is the sum of the other two curves, with cumulative production of about 3.1 MM Bbl/day.

The Highway and Combined curves indicate (1) overall average ULSD production costs of about 4¢/gal and (2) refinery-specific costs ranging from less than 3¢/gal to about 10¢/gal.

These cost estimates are comparable to those in the CRA/BOB and EIA studies. Our estimates are somewhat lower than the others because, as in our earlier work, we assumed that the primary means of creating ULSD capacity is (series) retrofitting of existing EPA diesel capacity.

From the curves in Exhibit 4.1, we defined high-cost refineries to be those whose estimated average ULSD production cost – for retro-fitted EPA diesel capacity – is $\geq$ 4.7¢/gal.[10]

- Twenty-eight (28) refineries producing highway diesel fuel in PADDs 1–3 meet this criterion, as well as all refineries in PADD 4 that currently produce EPA diesel.

- We estimate that this group of refineries would have potential aggregate ULSD capacity of about 410 K Bbl/day – 290 K Bbl/day in PADDs 1–3 and 120 K Bbl/day in PADD 4.

  These volume estimates reflect reported refinery process capacities in 2000; they do not account for any growth in highway diesel production capacity between now and 2007, from either capacity creep prior to 2007 or expansion in the course of retro-fitting to ULSD production.

Recall that our analysis of PADD 4, discussed in the previous section (Section 3), led to the conclusion that the PADD 4 refineries were likely to choose to produce ULSD. Hence, the rest of this discussion addresses only the high-cost refineries in PADDs 1–3.

As indicated above, if all of the high-cost refineries in PADDs 1–3 were to choose not to produce ULSD, those decisions would create a short-fall in ULSD supply of about 290 K Bbl/day (in terms of year 2000 capacities).[11]

Exhibit 4.2 provides selected information on the high-cost refineries that we identified. The first column in the exhibit shows the nine geographic clusters into which we grouped the high-cost refineries.[12] Each entry in column **Refinery** denotes a specific high-cost refinery. For each of the high-cost refineries, Exhibit 4.2 shows estimated ULSD production capacity, average ULSD production cost, and the capital charge component of the average production cost.

4.3 COMPETITIVE POSITION OF THE HIGH-COST REFINERIES

Like the refineries in PADD 4, many of the high-cost refineries in PADDs 1–3 are small; located in or near niche markets (that is, areas beyond easy access by low-cost suppliers in U.S. refining centers and off-shore); and without low-cost access to remote outlets for high-sulfur distillate material, should

[10] We chose this cost threshold so as to obtain an aggregate volume of high-cost ULSD capacity that was consistent with the CRA/BOB analysis.

[11] By way of comparison, the CRA/BOB study projected a shortfall in ULSD supply of 320 K Bbl/day (relative to estimated year 2007 capacities, after giving effect to capacity creep and demand growth).

[12] Each cluster corresponds to a particular refining district, which are geographical sub-sets of the PADDs. (PADD 1 has two refining districts; PADD 2 has three; and PADD 3 has five. For a definition of the refining districts, see Appendix A, District Descriptions and Maps, in the DOE/EIA *Petroleum Supply Annual 2000*.

they choose not to produce ULSD. In our view, the more directly this set of factors bears on a given high-cost refinery, whether in PADD 4 or in PADD 2, the greater the likelihood of that refinery's choosing to produce ULSD.

Accordingly, in this analysis, we sought to assess the extent to which the high-cost refineries identified in this analysis operate in niche markets – that is, markets with limited exposure to competition from supplies of ULSD having lower delivered costs (refining cost plus transportation). Such lower-cost supplies could include

- Inter-PADD transfers of ULSD from the Gulf Coast or other low-cost refining center
- Imports of ULSD from foreign countries
- Supplies from near-by refineries having lower ULSD production costs

High-cost refineries subject to such competition would be less likely to invest to produce ULSD than those who were not.

We based our assessment on estimated costs (refining and transportation) and first-order geographical factors, such as the locations of individual refineries, the routes of product pipelines serving PADDs 1, 2, and 3; and locations of ports through which imports of refined products enter the U.S. In particular, we compared the estimated cost of ULSD production for each refinery with the estimated delivered cost of ULSD from lower-cost refineries – accounting for both refining cost and transportation cost.

Our assessment indicated that high-cost refineries in PADDs 1–3 with aggregate capacity of 150–170 K Bbl/day serve markets in which they would not face strong competition from lower-cost ULSD supplies, absent significant structural changes in the refining and distribution systems. Strong competition from lower-cost ULSD supplies would likely exist for high-cost refineries in PADDs 1–3 with potential aggregate ULSD capacity of 120–140 K Bbl/day, as indicated below.

- PADD 1 refineries: 50–55 K Bbl/day
- PADD 2 refineries: 25–35 K Bbl/day
- PADD 3 refineries: 45–50 K Bbl/day

This volume range is less than half of our estimate of 290 K Bbl/day of potential aggregate ULSD production capacity for all of the high-cost refineries in PADDs 1–3 that now produce EPA diesel (as shown in Exhibit 4.2).

4.4 IMPLICATIONS FOR ULSD SUPPLY

The likelihood that a given high-cost refinery would choose to produce ULSD, during and after the transition period, depends on the interplay of various refinery-specific factors. One of the most important factors is whether a given refinery faces competition from lower-cost supplies.

Our assessment indicates that, of the ≈ 290 K Bbl/day of high-cost ULSD production capacity in PADDs 1–3, about 150–170 K Bbl/day is in refineries that would not face strong competition from lower-cost ULSD supplies. These refineries are in a competitive position analogous to that of the PADD 4 refineries. In other words, they have high costs of ULSD production, but yet can be viewed as having economic incentives to produce ULSD, by virtue of their location.

Other high-cost refineries, with aggregate highway diesel production of about 120–140 K Bbl/day, are less well situated and appear to face strong competition. But even these high-cost refineries could choose to produce ULSD in the transition period (and beyond), due to other considerations that are discussed in Sections 5 and 6.

5. Investments in ULSD Capacity That Exploit Economies of Scale

This section describes our analysis of possible ULSD production arrangements involving multiple refineries and aimed at reducing production costs through economies of scale.

The discussion covers four topics.

1. Economies of scale
2. Types of joint production arrangements
3. Estimated economies of scale in joint production arrangements
4. Implications for ULSD production

5.1 Joint Production Arrangements and Economies of Scale

The capital charge (in ¢/gal), for recovering investment in ULSD capacity, is the largest single component of the cost of ULSD production. Reducing the capital charge, if possible, is the most effective means of reducing the cost of ULSD production. In common with other refining processes, ULSD facilities exhibit economies of scale – the larger the capacity (within limits), the lower the investment required *per gallon of through-put* and the lower the resulting capital charge. Conversely, the smaller the capacity, the higher the resulting capital charge – the main reason that small refineries in a given region tend to have higher costs of ULSD production than large ones in that region.

In other applications, the refining industry has adopted various types of processing arrangements, involving multiple refineries, that convey economies of scale to the participants. Such arrangements hold out the prospect of making ULSD production economic for high-cost refineries that otherwise might choose not to produce ULSD. However, neither the CRA/BOB nor the EIA analyses considered the prospect that high-cost refineries would find ways to capture economies of scale in ULSD production rather than abandon production of highway diesel fuel.

5.2 Possible Joint Production Arrangements

Precedents exist for at least three types of processing arrangements that capture economies of scale for the participants.

- A group of refineries or a third party acting for them builds a single merchant ULSD plant – that is, a large desulfurization unit producing ULSD from distillate streams – EPA diesel, high-sulfur distillate streams, or both – supplied by all refineries in the group, and charging a per-gallon fee (known as a "tolling fee").

- A large refinery builds a large ULSD unit, over-sized for its own throughput, and then produces ULSD – under contract and for a per-barrel fee – from EPA diesel, high-sulfur distillate streams, or both, obtained from other local refineries who choose not to produce ULSD on their own. Such "tolling" arrangements are common in the refining industry, in other applications.

- A large refinery builds a ULSD unit with excess capacity for occasional surges in throughput (caused by transient changes in refinery operations, re-running off-spec product, etc.) and uses the excess capacity in normal operations to produce additional ULSD from raw stocks purchased from other refineries on a contractual or opportunity basis. For want of a better term, we call this "opportunity capacity".

Joint production or tolling arrangements, in their various forms, would provide a means for participating refineries to convert either EPA diesel or high-sulfur distillate streams to ULSD without capital investment and with low ULSD production costs. A merchant ULSD plant would be very large – perhaps 50–100 K Bbl/day – and would therefore have to be a grass-roots facility (not a relatively low-cost retrofit of some existing unit, as would be the case for an in-refinery unit). Such arrangements would incur extra transportation costs, for moving material to and from the ULSD facility, but they would also yield various operating cost savings (as noted below). The overall economics would be dominated by the economies of scale and the resulting low capital charge, yielding a low cost of ULSD production, regardless of the size of the participating refineries.

A large refinery could further exploit its economies of scale by retrofitting to make its ULSD unit large enough to include opportunity capacity, as defined above. A refinery might create opportunity capacity simply by endowing its ULSD unit with more than the customary amount of design "over-capacity" built into process units for temporary situations that require extra through-put, such as

- Surge – to handle peak (as opposed to average) daily throughput rates
- Seasonal requirements – to accommodate the higher average daily production rates in Winter
- Re-running – to handle the re-processing of off-spec material

In addition, refineries would create temporary opportunity capacity (available for the transition period) to the extent that they were to pre-invest in additional ULSD capacity in anticipation of a future extension of the ULSD standard to some or all of the non-highway diesel fuel pool.

Adding opportunity capacity would lower the refinery's per-barrel investment and therefore its capital charge and total cost of ULSD production.

Planning, financing, and construction of joint production arrangements, to the extent that they materialize, would necessarily be matters of public record. On the other hand, a single refinery's building opportunity capacity would likely not be a matter of public record, and therefore would not figure into estimates of industry-wide ULSD production.

Several recent reports in the trade press suggest interest in joint production arrangements for ULSD production and the reasons for this interest.

- *Refiner Seeks Partners for "Midwest ULSD Alliance"*, Diesel Fuel News, Vol. 5, No. 20, 1 October 2001

"Premcor, one of the U.S.'s largest independent refiners, indicated . . . that it's seeking . . . partners to share the cost of making ULSD in the Midwest states region.

Driving this decision is the need to spread the cost of desulfurizing hard-to-treat distillate stocks over a much larger feedstock base than what's . . . found in smaller refineries . . . Cost-sharing would allow smaller refiners to reduce their capital and operating expenses for ULSD production, thus more closely resembling the economies of scale of larger refineries . . .

. . . if a "Midwest ULSD Alliance" could be created to treat a 50 K Bbl/day pool . . . rather than two separate 20 K Bbl/day and 30 K Bbl/day [units] at different refineries – then capital savings for the alliance partners could hit 27% . . . such a hydrotreater could provide higher reliability than a stand-alone unit at any single refinery, capture feedstock quality synergies among refineries, and allow operating cost allocations based on delivered feedstock quality. . ."

- *Four New 100 K Bbl/day Joint Hydrotreating Projects Could Cut Costs of Making ULSD*, Diesel Fuel News, Vol. 5, No. 22, 29 October 2001

"Up to four new 100 K Bbl/day joint hydrotreating projects that would charge various refiners a tolling fee for converting low-quality, cracked [i.e., high sulfur] distillate streams to . . . ULSD could help cut refiner costs and improve the diesel supply situation for 2006. . . .

Many refiners and petrochemical producers . . . participate in . . . joint supply projects . . . in order to cut costs and avoid over-investment in proprietary process units. . . .

Now, . . . a concept is starting to emerge for up to four 100 K Bbl/day distillate hydrotreating projects in locations including Corpus Christi, Houston, Port Arthur or Lake Charles . . .

[Economic] feasibility . . . for high-pressure hydrotreating of low-quality feedstocks starts at around 50 K Bbl/day . . . That's a lot more cracked-stock feed than is found at many individual refineries pondering ULSD investment. In other cases, some refiners might be able to convert a portion of their distillate streams to ULSD, but not their remaining cracked streams. . . .

Under the proposed concept, refiners would sign multi-year take-or-pay tolling agreements to convert these problem feeds to ULSD, with no up-front capital risk . . ."

5.3 MAGNITUDE OF POTENTIAL ECONOMIES OF SCALE

A few examples, all based on **Exhibit 5.1**, may serve to illustrate the magnitude of the economies of scale in ULSD production that would be offered by the various arrangements discussed above.

Exhibit 5.1 shows estimated capital charge (in ¢/gal) as a function of ULSD process capacity (in K Bbl/day), for capacities ranging from 5 K Bbl/day to 100 K Bbl/day. The exhibit contains two curves:

- *Series Retrofitting* applies to retrofitting EPA diesel capacity to ULSD capacity of equal or greater volume.

- *Grassroots Plant* applies to construction of an all-new unit – such as a merchant ULSD plant – to produce ULSD from high-sulfur diesel fuel or low-quality distillate blendstocks.

The capital charges are in year 2000 dollars and apply to a U.S. Gulf Coast location.

Exhibit 5.1 is a hypothetical investment curve intended to illustrate the economies of scale phenomenon. The curves are derived from our analysis of refinery-by-refinery costs of ULSD production (discussed in Section 4.2). The economic factors and assumptions underlying Exhibit 5.1 (e.g., unit investment requirements, rate of return on capital, etc.) are laid out in [Refs. 4 and 16].

Consider a hypothetical refinery with EPA diesel capacity of 10 K Bbl/day. Exhibit 5.1 indicates that (1) retro-fitting that capacity to produce ULSD would incur a capital charge of roughly 4¼¢/gal and (2) participating instead in a 100 K Bbl/day grass-roots merchant plant would incur a capital charge of roughly 1¾¢/gal – reducing the refinery's ULSD production cost by about 2½¢/gal.

Now suppose that refinery entered into a tolling arrangement with a larger refinery that has EPA diesel capacity of 50 K Bbl/day. Retrofitting that unit to 60 K Bbl/day of ULSD capacity (enough to handle both refineries' volume) would incur a capital charge of about 2¢/gal – reducing the smaller refinery's ULSD production cost by about 2¼¢/gal (and the larger refinery's cost by about ¼¢/gal). (In this situation, the smaller refinery (which now produces EPA diesel) probably would supply EPA diesel, or blendstocks of comparable sulfur content, to the larger refinery.)

If such cost savings – in the range of 2–2½¢/gal – could be realized by the refineries that we identified as having high ULSD production costs (> 5¢/gal) (Section 4.2 and Exhibit 4.2), about 90% of their cumulative ULSD production – all but 20 K Bbl/day – would fall below our 5¢/gal threshold.

5.4 Implications for ULSD Supply

Joint production arrangements aimed at achieving economies of scale are common in the refining industry, and such arrangements are now under consideration for ULSD production. By their nature, such arrangements would offer the greatest cost reductions to the refineries with the highest costs of ULSD production (usually the smallest refineries) and the greatest disincentives to produce ULSD.

Notably, the proposed locations of the ventures discussed in Section 5.2 are in refining districts that, according to our economic analysis (Section 4.2), contain clusters of high-cost refineries.

Joint production arrangements could make it economic for certain refineries to expand their production of highway diesel fuel (i.e., produce more ULSD than their current production of EPA diesel). For example, large refineries in PADD 3 could use such arrangements to "over-produce" ULSD and send the additional volumes of ULSD to PADDs 1 and 2 (perhaps to compensate for refineries in those areas that chose to downgrade). Or, refineries that don't produce EPA diesel now could use joint production arrangements to become suppliers of ULSD in the future. For example, a merchant plant producing ULSD from run-of-the-refinery blendstocks would incur lower costs than if it produced ULSD from low-quality cracked stocks, as at least one of the ventures discussed in Section 5.2 is considering.

These are illustrations; not forecasts. Each proposed joint production arrangement would have unique opportunities, constraints, techno-economics, and economies of scale. Our simple analysis cannot capture such diversity of outcomes; it can however serve to highlight that joint production agreements could call out additional supplies of ULSD and thereby reduce the likelihood of a shortfall in supply.

6. Economics of Downgrading Distillate to Non-highway Markets

This section describes our analysis of the economic implications of diverting high-sulfur distillate streams from highway diesel production to various non-highway distillate fuel markets, in the transition period. The analysis addresses (1) the prospective magnitude of on-purpose downgrading that distillate fuel markets could accommodate without significant structural change (e.g., new pipeline and terminal facilities, new end uses, etc.) and (2) the implications of on-purpose downgrading on the price of high-sulfur diesel fuel.

Section 3.6 dealt with downgrading prospects and economics in PADD 4. This discussion focuses on downgrading in PADDs 1, 2, and 3.

The discussion covers five topics.

1. Rationale for the analysis
2. Overall distillate supply/demand balances, by PADD
3. Opportunities for downgrading in PADDs 1, 2, and 3
4. Estimated costs of downgrading
5. Implications for ULSD production in PADDs 1, 2, and 3

6.1 Rationale for the Analysis

In Section 4.2, we identified a set of refineries in PADDs 1, 2, and 3 that now produce EPA diesel and are likely to incur relatively high costs in producing ULSD. These refineries currently produce about 290 K Bbl/day of EPA diesel and could produce a comparable volume of ULSD. In Section 4.3, we noted that a sub-set of these refineries, with about 120–140 K Bbl/day of that capacity, would likely face strong competition from lower-cost sources of ULSD supply in the long run.

These refineries – and indeed others that now produce EPA diesel – could respond to the ULSD program by choosing not to produce ULSD at all or to produce less ULSD than their former out-turn of EPA diesel. A refinery making this choice would have to downgrade part or all of its EPA diesel volume – in the form of either (1) mixtures of distillate blendstocks (diesel fuel components) that could be sold directly as high-sulfur diesel or (2) cracked distillate blendstocks (coker distillate and/or light cycle stock), whose high sulfur content and low cetane call for further processing or blending to make salable off-highway product.

The CRA/BOB and EIA analyses dealt solely with refining techno-economics and the *supply* of ULSD. They reflect the *implicit assumptions* that (1) domestic or foreign outlets exist for whatever distillate volumes the U.S. refining sector might downgrade to non-highway diesel and (2) down-grading would not depress non-highway distillate prices.

Refiners rightly are concerned about being high-cost suppliers in the long run. But, they also must be concerned about having only the limited option in the long run of selling into a depressed, over-supplied market. Downgrading would be attractive only to the extent that markets could absorb the downgraded volumes with relatively small price effects; downgrading would be unattractive if it caused prices to decline significantly. The latter circumstance would create incentives for refineries to avoid downgrading and to pursue options for producing ULSD instead.

The analysis discussed here in Section 6 deals with distillate fuel markets and the *demand* for distillate fuels. In particular, the analysis explores the market options that would exist for absorbing the high-sulfur distillate that high-cost refineries might choose to downgrade. From that perspective, we examine the volumes of downgrading that relevant distillate markets could accommodate and estimated the effects of downgrading on the price of non-highway diesel fuels.

6.2 OVERALL DISTILLATE SUPPLY AND DEMAND, BY PADD

Exhibit 6.1 summarizes the distillate product supply/demand balance, by PADD, averaged over calendar years 1999 and 2000. The exhibit also shows an aggregate supply/demand balance for PADDs 1–3, for the same period. We derived the supply figures from [Ref. 16] and the sales (demand) figures from [Ref. 17].

One of the most notable characteristics of the current distillate supply/demand balance is the apparent "over-supply" of EPA diesel fuel. In PADDs 1–3, EPA diesel constitutes 65% of the supply of distillate fuel, whereas highway consumption constitutes only 57% of total diesel fuel consumption. So, about 8% of EPA diesel supply in PADDs 1–3 (or 190 K Bbl/day at present) is already sold as high-sulfur diesel in off-highway markets – most likely because of limitations in the product distribution system that would cost more to remedy than the revenue loss (< 3¢/gal) incurred in the downgrading. (This phenomenon is even more pronounced in PADD 4, as discussed in Section 3.2.)

Exhibit 6.2 shows the inter-PADD transfer volumes of EPA diesel and non-highway diesel fuel in 2000. PADD 3, which accounts for more than 50% of distillate fuels production in the PADD 1–3 aggregate, sends significant volumes of EPA diesel and high-sulfur diesel to PADD 1 (394 K Bbl/day) and PADD 2 (189 K Bbl/day) and smaller volumes to PADDs 4 and 5.

Aside from the large inter-PADD transfer from PADD 3, PADD 1 imports about 230 K Bbl/day of diesel fuel (split evenly between EPA diesel and high-sulfur diesel). These imports are the balancing mechanism for distillate supply and demand in PADDs 1–3.

About 90% of imports come from three sources: Canada (Atlantic province refineries), the Virgin Islands (the Hovensa LLC refinery in St. Croix), and Venezuela. These off-shore sources are long-standing, continuing suppliers of refined products to PADD 1. The location, ownership, and other market alternatives of these refineries make them natural suppliers to PADD 1 – not easily-displaced marginal players. Of the group, the Venezuelan refineries are likely to be least difficult to displace, because they appear to have better market alternatives than the Canadian and Virgin Islands refineries.

Finally, PADD 3 exports EPA diesel (about 35 K Bbl/day) and high-sulfur diesel (about 65–70 K Bbl/day) mostly to Mexico, Central America, and the Caribbean. **Exhibit 6.3** shows U.S. exports of EPA diesel and high-sulfur diesel fuels in 2000; **Exhibit 6.4** shows the indicated regional destinations of combined diesel volumes in 2000.

6.3 OUTLETS FOR DOWNGRADING IN PADDS 1, 2, AND 3

Non-highway distillate fuels (diesel fuel and heating oil) are consumed in a number of distinct end-use sectors within each PADD. EIA, for example, reports distillate fuel use in ten distinct end-use sectors.

Exhibit 6.5 shows estimates of non-highway distillate fuel consumption, by end-use sector and by PADD, for 2000, based on average annual growth rates from 1995 through 1999. This exhibit summarizes information presented in a report prepared for EPA by Muse, Stancil & Co., *Alternate Markets for Highway Diesel Fuel Components*, September 2000 [Ref. 9]. According to [Ref. 9], highway diesel consumption in PADDs 1–3 has grown at an annual rate of 5.7%, while total non-highway diesel consumption in PADDs 1–3 has been static. Each PADD has unique profiles of demand and growth rate by sector. Considerable variation exists across the non-highway end-use sectors. Some, such as industrial and off-highway, are growing; others, such as residential, commercial, farm, and railroad, are shrinking.

The consumption volumes shown in Exhibit 6.5 for the various sector/PADD combinations are rough indicators of the size of the domestic markets that could potentially absorb on-purpose downgrade volumes in the transition period. The following comments on these markets summarize information presented in [Ref. 9].

PADD 1 is by far the largest domestic market for heating oil, but demand for heating oil in PADD 1 is declining. Heating oil markets in the other PADDs are small (and in general are declining).

The concentration of heating oil demand in PADD 1 reflects the limited availability of natural gas in the Northeast, particularly New England.

At present, PADD 1 accounts for nearly 85% of residential and commercial consumption of distillate fuels in PADDs 1–3, in the form of heating oil. Within PADD 1, the residential and commercial sectors account for about 2/3 of all non-highway diesel consumption. Demand in these sectors is declining.

- PADD 2 consumption is distributed across the various end-use sectors; the two largest sectors – railroad and farm – account for about 45% of total non-highway consumption. Demand in these sectors is also in decline.
- PADD 3 consumption is relatively small and is distributed across the various end-use sectors; the two largest sectors – vessel bunkering and railroad – account for about 40% of total non-highway consumption.

- The railroad, vessel bunkering, residential, commercial, and industrial sectors could best accommodate additional volumes of low-quality (i.e., cracked) distillate blendstocks.

  Railroad and marine diesels have minimal cetane specifications; heating oil for the residential, commercial, and industrial sectors has no cetane specification.

- Distillate fuel demand has grown in the vessel bunkering sector, but this sector has limited capacity to absorb distillate volumes diverted from highway markets.

  In the production of bunker fuel, distillate is blended into residual fuel oil for viscosity and specific gravity control, with the volume of distillate not exceeding that needed to meet specifications. So, this sector's capacity is limited by the growth rate of bunker fuel consumption.

- Distillate fuel demand has grown rapidly in the electric utility sector, but from a very small volume base (currently about 50 K Bbl/day in PADDs 1–3). This sector has limited capacity to absorb distillate volume diverted from highway markets.

  Diesel fuel cannot compete with coal as a fuel for base load power generation, by far the largest segment of electric power supply. Electric utilities use diesel fuel mainly as a back-up to natural gas for fueling gas turbines for peak power generation. Diesel fuel use in peaker operations is limited by emissions permitting in many instances.

In summary, heating oil for the residential, commercial, and industrial sectors in PADD 1 is the largest single market for high-sulfur diesel fuel, and hence is the most prospective outlet for distillate streams that might be downgraded on purpose. This market is geographically concentrated, inaccessible to many refineries in PADDs 1–3, declining in volume, and the recipient of significant volumes of imports from well-positioned suppliers.

Exports are another possible outlet for downgrade volumes. As noted in Section 6.2, PADD 3 now exports about 100 K Bbl/day of diesel fuel to Mexico, Central America, the Caribbean, and South America, about two-thirds of which is high-sulfur diesel. Diesel consumption in this region is growing rapidly, but a number of countries in the region, most notably Mexico, are contemplating new, more stringent sulfur standards for diesel fuel.

Finally, the apparent "over-production" of EPA diesel (discussed in Section 6.2) constitutes another potential outlet for downgraded high-sulfur distillates. At least in principle, the PADD 1–3 refining sector could reduce production of highway diesel fuel by up to 190 K Bbl/day – the volume of "over-production" – without causing shortfalls in diesel fuel supply for highway use or creating surpluses in off-highway uses. Accomplishing this downgrading would require expenditures to eliminate (to the extent possible) the limitations in the distribution system that lead to the downgrading that now occurs. More realistically, changes in the distribution system likely would be made to accommodate some fraction, but not all, of any on-purpose downgrading in response to the ULSD rule.

6.4 Economics of On-Purpose Downgrading in PADDs 1, 2, and 3

Consider a refinery that responded to the ULSD program (at least in the transition period) by reducing or eliminating its out-turn of highway diesel fuel. Even with possible changes in its crude slate and conversion unit operations, the refinery could not stop producing distillate components that (after desulfurization) would have gone into ULSD. Rather, it would have to find new outlets for these streams, from among the following candidates.

- Providing incremental feedstock to refinery conversion units (hydrocrackers or FCC units with feed pre-treating)
- Replacing low-sulfur (highway) diesel volumes with high-sulfur volumes in existing high-sulfur distillate markets, through improved segregation of high-sulfur and low-sulfur distillates in the distribution system
- Displacing imports of high-sulfur distillate (in PADD 1 only)
- Increasing exports of high-sulfur distillate to other countries (in PADD 3 only)
- Displacing high-sulfur distillate received from other PADDs
- Increasing or initiating transfers of high-sulfur distillate to other PADDs
- Meeting demand growth in local high-sulfur distillate markets

The Muse, Stancil report [Ref. 9] provides a detailed discussion of the prospects for diverting volumes of high sulfur distillate to each of these alternative uses, in each PADD.

In addition to diverting distillate volumes to these alternative uses, refineries could continue producing some EPA diesel volumes until 2010, under provisions of the Temporary Compliance Option.

6.4.1 Muse, Stancil Estimates of Downgrade Volumes With Small Price Effects

As part of their analysis, Muse, Stancil estimated the distillate volumes that could be diverted to each alternative outlet in each PADD, with (in their view) *small attendant reductions in high-sulfur distillate prices* under normal market conditions. Their estimates provide a useful point of departure for this analysis.

Exhibit 6.6 summarizes the Muse, Stancil estimates, which are based on (1) the projected market volumes shown in Exhibit 6.5 and (2) technical, economic, and structural factors in the refining and distribution system. **Exhibit 6.6** also shows our re-statement of these estimates, incorporating the adjustments discussed below.

- *Refinery conversion units* (line item 1 in Exhibit 6.6) – Conversion units do not totally destroy distillate feed material; that is, they do not convert all of the distillate to lighter material, outside the distillate boiling range. Rather, a typical product yield pattern for distillate hydrocracking includes about 45 vol% of a stream called "hydrocracked distillate" or "hydrocracked jet" – a low-sulfur, high-quality distillate blendstock. Thus, for example, hydrocracking ≈ 25 K Bbl/day of high-sulfur distillate (as indicated in the table above) would yield about 10 K Bbl/day of low-sulfur hydrocracked distillate, leading to a net loss in distillate volume of only 15 K Bbl/day. We adjusted the Muse, Stancil estimates accordingly.

- *Displacement of low-sulfur diesel from high-sulfur markets* (line item 2 in Exhibit 6.6) – We made no adjustments to this line item. It represents the purposeful reduction of the apparent "over-production" of highway diesel fuel, discussed above. To the extent that it would occur, displacing ULSD with high-sulfur volumes in high-sulfur distillate markets, through more efficient segregation in the distribution system, would (1) accomplish the purpose of downgrading with (at worst) no increase in refining cost, but some increase in logistics costs, and (2) reduce the market call for ULSD in step with the reduction in refinery out-turn of ULSD.

- *Displacement of high-sulfur distillate imports in PADD 1* (line item 3 in Exhibit 6.6) – As discussed in [Ref. 9], Muse, Stancil's estimate of import displacement in PADD 1 reflected two key elements: (1) an estimate that imports of high-sulfur distillate would double between 2000 and 2007 and (2) an assumption that the main exporters to PADD 1 – Canada, the Virgin Islands, and Venezuela – would maintain their current share of exports to PADD 1 (≈ 88%) during this period.

  In our view, the Muse, Stancil estimate is likely to be an artifact of their estimating methodology; imports to PADD 1 are unlikely to grow that fast.[13] If imports were to grow that fast, the main exporters probably would be unable to expand fast enough to maintain their current export share; exports from more remote suppliers would have to take up the slack. But remote suppliers could be displaced by PADD 1 or PADD 3 refiners more easily than the near-by, main exporters.

  To recognize these uncertainties, we assumed import displacement in PADD 1 could range from 50–80 K Bbl/day (versus the Muse, Stancil estimate of 50 K Bbl/day).

- *Exports of high-sulfur distillate to other countries* (line item 4 in Exhibit 6.6) – Current net exports of diesel fuel from PADD 3 to Mexico, Central America, South America, the Caribbean, and South America are about 100 K Bbl/day (as discussed earlier). Muse, Stancil did not make a quantitative estimate of the additional volume of high-sulfur distillate streams that PADD 3 refineries could export – indicating only that "moderate amounts" could be diverted in this way.

  For purposes of this analysis, we assumed that PADD 3 refiners could increase their export volumes by about 50% – meaning an additional export volume of 40–60 K Bbl/day.

- *Demand growth in local markets* (line item 6 in Exhibit 6.6) – As shown in Exhibit 6.5, most markets for non-highway diesel fuel contracted between 1995 and 1999. They are projected to remain essentially static (at best) in the future. Hence, Muse, Stancil envisioned no prospective outlets for diversion of high-sulfur distillate streams to meet demand growth in local high-sulfur distillate markets. Accordingly, we dropped this item from further consideration.

13 The Department of Energy's *Annual Energy Outlook 2001* projects U.S. imports of refined products to increase by 27% between 2000 and 2007.

Finally, Exhibit 6.6 shows what we call the **Off-Shore Downgrade Volume**. This is the sum of the estimated downgrade volumes that would increase the supply of high-sulfur diesel in the aggregate market of Mexico, Central America, the Caribbean, and South America Basin (in brief, "Latin America") – the sum of import displacement in PADD 1 and export volumes from PADD 3(line items 3 and 4 in Exhibit 6.6). As explained below, such supply increases would depress prices for high-sulfur diesel in the importing countries.

In summary, the results of the Muse, Stancil analysis (as adjusted) suggest that existing markets for high-sulfur distillate fuels could accommodate – with minimal reductions in high-sulfur distillate prices – the downgrading of about 165–215 K Bbl/day of distillate produced in PADDs 1, 2, and 3. About 2/3 of this downgrade volume would be import displacements and increases in exports – both tending to increase the supply of high-sulfur diesel in the area noted above.

6.4.2 Muse, Stancil Estimate of the Price Effects of On-Purpose Downgrading

Muse, Stancil estimated that on-purpose downgrading in PADDs 1, 2, and 3 would depress the prices of high-sulfur distillate in those PADDs by amounts that depend on the share of current EPA diesel production that would be downgraded, as shown in the table below.[14]

Total Downgrade Volume		Estimated Price Reduction (¢/gal)		
(% of EPA Diesel Production)	(K Bbl/day)	PADD 1	PADD 2	PADD 3
5%	≈ 100	1.5	0.5	2.5
10%	≈ 200	2.0	12.0	3.0
15%	≈ 300	2.0	14.0	3.0

The small price effect at the 5% downgrade volume reflects exploitation of low-cost opportunities to displace low-sulfur diesel volumes sold in high-sulfur markets (line item 3 in Exhibit 6.6). The large price depressions in PADD 2 at the 10% and 15% downgrade volumes reflect the cost of shipping the additional downgrade volumes by rail or barge from PADD 2 to the U.S. Gulf Coast.

Because of PADD 2's unfavorable economics, one can reasonably assume that most on-purpose downgrading in excess of about 100 K Bbl/day (total) would occur in PADDs 1 and 3. Hence, for all practical purposes, the Muse, Stancil analysis leads to an estimate that on-purpose downgrading of up to 300 K Bbl/day would depress the price of high-sulfur distillate by 2–3¢/gal (all else equal). This price effect corresponds to the cost of shipping high-sulfur distillate from PADD 3 to Caribbean destinations and transporting high-sulfur distillate from PADD 3 to PADD 1.

[14] [Ref. 9] states that these estimates (1) are relative to the five-year average price differentials between EPA diesel and high-sulfur diesel in the respective PADDs (as reported in [Ref. 9]); (2) assume no change in the price of highway (EPA) diesel as a consequence of the downgrading; and (3) reflect mainly the costs of shipping high-sulfur distillate from PADD 3 to Caribbean destinations and transporting high-sulfur distillate from PADD 3 to PADD 1.

6.4.3 MathPro Inc. Estimate of the Price Effects of On-Purpose Downgrading

The Muse, Stancil analysis considers the responses of distillate markets only in the U.S. But, as discussed above, downgrading would tend to increase the supply of high-sulfur diesel in Latin American markets (as defined above). In our view, a full assessment of the economic implications of downgrading must include consideration of the likely price effects of this supply increase in the Latin American markets.

Such price effects would depend primarily on (1) the magnitude of the additional supply relative to the demand for diesel fuel in the Latin American markets, in the transition period,[15] (2) the price elasticity of demand for high-sulfur diesel fuel in these markets, and (3) the response of the local refining sectors to these additional volumes. (We considered only the first two in this analysis.)

Recall that Exhibits 6.3 and 6.4 show U.S. exports of diesel fuel in 2000, by PADD and by destination country, respectively. Currently, U.S. refineries export about 115 K Bbl/day of diesel fuel (more than 90% of which comes from PADD 3), of which about 75 K Bbl/day is high-sulfur diesel.

Of those exports, about 65 K Bbl/day go to Mexico, 28 K Bbl/day to the Caribbean and Central America, 17 K Bbl/day to Europe, and 6 K Bbl/day to South America. These figures are drawn from an EIA publication [Ref. 16] that does not distinguish between low-sulfur and high-sulfur diesel fuels.

By the time of the ULSD program's transition period, European outlets for high-sulfur distillate material are not likely to exist. The European Parliament is now considering a directive that would, among other things, make non-road diesel fuel in the EU subject to on-road diesel specifications – 50 ppm sulfur cap in 2005 and 10 ppm sulfur cap in 2008. Hence, we confined this analysis to the Latin American export markets.

Exhibit 6.7 shows projected demand for diesel fuel in Mexico, the Caribbean, Central America, and relevant portions of South America in 2007. These projections are based on data obtained from the World Bank. Projected total demand in 2007 in Mexico, the Caribbean, and Central America would be 500 K Bbl/day and 625 K Bbl/day, respectively, under the World Bank's *low growth* and *high growth* scenarios. The corresponding demand projections for South America are 1250 K Bbl/day and 1450 K Bbl/day. The World Bank demand projections do not distinguish between high-sulfur and low-sulfur diesel fuels. For purposes of this analysis, we assumed that diesel specifications in 2007 in Mexico, the Caribbean, and Central America would be such that high-sulfur diesel could satisfy all diesel fuel demands in these countries. However, the downgrade volumes exported to these markets could be EPA diesel as well. Were Mexico to adopt a ULSD standard, most of the potential market for downgraded volumes would evaporate.

Off-shore downgrade volumes of 90–140 K Bbl/day (Exhibit 6.6) would be 15–30% of estimated diesel fuel demand in Mexico, the Caribbean, and Central America in 2007, or 5–7% of estimated diesel fuel demand in the total Latin American region. The potential downgrade volume generated by

[15] This demand will be a function of the growth rate in demand for high-sulfur diesel and the specifications (especially the sulfur specification) for high-sulfur diesel in the consuming countries by 2007.

all of the high-cost refineries that we identified, about 290 K Bbl/day (see Section 4.2), would be about 15% of estimated demand in the expanded region. Absorbing off-shore downgrade volumes of these magnitudes would trigger a reduction in high-sulfur diesel prices in the importing countries and/or decreased supply of high-sulfur diesel fuel by the local refineries serving these countries.

We approximated the reduction in high-sulfur diesel prices in the importing countries for four levels of on-purpose downgrading by refineries in PADDs 1–3: 100, 150, 200, and 300 K Bbl/day. Exhibit 6.6 indicates that these downgrade volumes would generate, respectively, 25, 75, 125, and 225 K Bbl/day of off-shore downgrade volume (after accounting for additional feedstock to refinery conversion units and displacement of low-sulfur diesel from high-sulfur markets).

For this purpose, we used the standard relationship between changes in market price, changes in volume, and price elasticity, with the following parameters.

- Baseline CIF spot price of high-sulfur distillate: 75¢/gal in the importing countries
- Baseline demand for high-sulfur distillate: 1900 Bbl/day in the importing countries (average of the high-growth and low-growth estimates shown in Exhibit 6.7)
- Price elasticity of demand: –0.35 (i.e., a 10% change in price corresponds to a 3.5% change in the quantity demanded, in the opposite direction)

The price elasticity of demand, –0.35, is the CRA/BOB estimate of the "medium-term" price elasticity of demand for highway diesel in the U.S. [Ref. 6]. Absent a more relevant estimate, we took the liberty of using this value to denote the price elasticity of demand for high-sulfur diesel in the importing countries, if they were to face increased U.S. exports of high-sulfur distillate in the transition period.

The table below shows the estimated price effects in Latin American markets.

Downgrade Volume (K Bbl / Day)		Estimated Price Reduction (¢/gal)
Total Volume	Off-Shore Volume	
100	25	2¾
150	75	7¾
200	125	12½
300	225	20½

That is, on-purpose downgrading of 100 to 300 K Bbl/day would involve off-shore downgrading of 25 to 225 K Bbl/day[16], which in turn would depress the price of high-sulfur distillate by an estimated 3 to 20¢/gal (on top of the 2 to 3¢/gal estimated by Muse, Stancil).

Hence, we estimate that on-purpose downgrading in the range of 100 to 300 K Bbl/day would decrease the refinery gate price of high-sulfur diesel fuel by about 5 to 23¢/gal, depending on the downgrade volume. This estimate is the sum of:

- The cost of shipping high-sulfur distillate from PADD 3 to Caribbean destinations and transporting high-sulfur distillate from PADD 3 to PADD 1, estimated by Muse, Stancil to be 2–3¢/gal (Section 6.4.2); and

- The change in the equilibrium, or market-clearing, price of high-sulfur distillate that would be induced by off-shore downgrading of 25 to 225 K Bbl/day, estimated here to be ≈ 3 to 20¢/gal.

The indicated price effect of 5 to 23¢/gal is volume dependent: the larger the downgrade volume, the larger the price depression. In particular, for a downgrade volume of 120–140 K Bbl/day (the estimate developed in Section 4), the indicated price depression would be ≈ 7 to 10¢/gal.

The price effect could be mitigated to some extent if refineries in the Latin American region reduced their out-turns of diesel fuel to accommodate the increased supplies from the United States. Whatever its magnitude, the price effect would (1) be in addition to the normal refinery-gate price spread between highway and non-highway diesel fuel – based on refining economics and (2) be felt by *all* refiners in PADDs 1, 2, and 3 (the PADDs that were the sources of the downgraded volumes).

6.5 Implications for ULSD Supply in PADDs 1, 2, and 3

Our analysis of on-purpose downgrading from the viewpoint of distillate markets and the *demand* for distillate fuels indicates that few U.S. refiners are likely to find this option attractive.

- Geography, operational factors, and the slow growth or actual decline in demand for high-sulfur diesel in most U.S. market sectors dictate that only three outlets could in principle accommodate large volumes of on-purpose downgrading. They are:
  - Using high-sulfur distillate to displace highway diesel fuel sold in off-highway markets, with the largest potential in PADD 2,
  - Increasing exports from PADD 3 to markets in Mexico, the Caribbean, Central America, and South America, and
  - Displacing imports in PADD 1, first imports from remote suppliers, then imports from Venezuela.

[16] The balance – 75 K Bbl/day – would be consumed as feedstock to refinery conversion units or displacement of ULSD from high-sulfur diesel markets, as shown in Exhibit 6.6.

Only the latter two, the off-shore downgrading routes, would reduce the effective domestic supply of highway diesel fuel.

- Off-shore downgrading would (all else equal) increase – barrel-for-barrel – the total supply of high-sulfur diesel in Mexico, Central America, the Caribbean, and eastern portions of South America.

- Off-shore downgrading would incur transportation costs and (more importantly) would depress market-clearing prices for high-sulfur distillate in the importing countries and in the U.S.

- We estimate that downgrading in the range of 100 to 300 K Bbl/day would decrease the refinery gate price of high-sulfur diesel fuel in PADDs 1–3 by about 5 to 23¢/gal; the larger the downgrade volume, the larger the price effect.

In summary, market forces in the domestic and off-shore markets for high-sulfur distillate material would reduce prices for high-sulfur distillate, for even moderate volumes of downgrading. Refineries considering downgrading rather than investing in ULSD production would have to weigh the desirability of having only the limited option of selling into depressed, over-supplied markets. A refiner facing the prospect of such markets for high-sulfur distillate would have a strong incentive to produce ULSD, either by investing directly in production capacity or by participating in a joint production arrangement.

7. Features of the ULSD Rule Aimed at Promoting the Transition to ULSD

As part of its regulatory impact analysis for the ULSD program, EPA conducted an extensive and useful analysis of the prospects for adequate supplies of ULSD in the transition period [Ref. 3]. (EPA commissioned the Muse, Stancil study discussed in Section 6 to support part of its analysis). In their analysis, EPA addressed a number of issues, including some that we addressed in this study.

EPA concluded that adequate supplies of ULSD were likely to be available in the transition period. Nonetheless, they incorporated some special features in the final ULSD rulemaking to promote ULSD production in the transition period.

This section briefly discusses some of these features and their possible implications for ULSD supply in the transition period.

7.1 Special Features of the ULSD Program[17]

Four special features offer "regulatory flexibility" in the early years of the ULSD program:

- The Temporary Compliance Option (TCO), available to all refiners;
- The Small Refiner Options, available to companies that meet certain corporate qualifications;
- Two-year extension of the Geographical Phase-In Area (GPA) program, covering refineries in the PADD 4 states plus North Dakota, New Mexico, and parts of Alaska; and
- A general hardship program, available on a case-by-case basis.

A fifth element, a reporting program starting in 2003, will collect and disseminate information on the refining industry's progress in complying with the ULSD program. EPA will produce an annual report on the refining industry's overall progress toward compliance, based on information collected in this reporting program.

We analyzed the GPA program as part of our discussion of prospective ULSD supply in PADD 4 (Section 3.6), because this program offers concrete economic benefits to an identifiable set of refineries. We did not consider the general hardship program, because we did not have the information necessary to identify specific refineries that would apply or qualify for these programs.

The rest of this section focuses on the TCO and, to a lesser extent, the Small Refiner Options and the reporting program. Except for this brief discussion, we did not consider these features in this study. Our objective in this study was to assess the likely effectiveness of the naturally prevailing techno-economic driving forces – not regulatory programs – for calling out investments in ULSD in time for the transition period. The TCO and Small Refiner Options are, in effect, backstops for these driving

[17] None of these features were in the proposed ULSD rule at the time of the CRA/BOB analysis; all were in the final rule at the time of the EIA analysis and are considered in that analysis.

forces, not impediments to them. The reporting program could promote ULSD supply in the transition period, for reasons discussed in Section 8.3.

7.2 Overview of the Temporary Compliance Option

EPA included the TCO in the ULSD rule to address concerns about shortfalls of ULSD supply in the transition period. It allows for some phase-in of ULSD production and supply, between 1 June 2006 and 31 May 2010.

Under the TCO, refiners may produce a highway diesel out-turn comprising as little as 80% ULSD and as much as 20% EPA diesel (< 500 ppm sulfur), from 1 June 2006 through the end of 2009. During this period, a refiner may produce a highway diesel pool containing more than 20% EPA diesel if the refiner has a sufficient number of credits.

As the last statement implies, the TCO includes a credit averaging, banking, and trading (ABT) program. A refinery producing more than 80% of its highway diesel out-turn as ULSD earns sulfur credits (one credit for each gallon of ULSD produced in excess of 80% of the refinery's total highway diesel pool). These credits may be sold to other refineries in the same PADD that do not physically meet the 80% ULSD requirement. The ABT program is regional; that is, credits may be used only in the PADD in which they were generated.

Credits may be generated from 1 June 2006 through 31 December 2009. In addition, credits may be generated during the year starting 1 June 2005 for any volume of ULSD production, provided that the ULSD is segregated.

Credits may be used for highway diesel produced from 1 June 2006 through 31 May 2010. Between 1 January and 31 May 2010, a refinery may use only credits that it had banked at the end of 2009. (Any remaining credits expire after 31 May 2010).

EPA diesel and ULSD must be segregated during the TCO period, from the refinery to the pump.

7.3 Overview of the Small Refiner Options

EPA defines a small refiner (not refiner<u>y</u>) as an organization having a maximum of 1500 employees and a maximum crude running capacity of 155,000 Bbl/day without merger or acquisition. A small refiner under this definition may choose from three options for compliance with the ULSD program:

1. Continue producing EPA diesel (< 500 ppm sulfur) until 31 May 2010 without having to acquire credits, provided that the refiner can reasonably ensure the availability of sufficient ULSD in the market area(s) that it serves.

2. Generate and sell TCO credits for all ULSD produced through 31 May 2010, with no need to retain any credits for the refiner's own use.

3. Extend the compliance date for the Tier 2 *gasoline* sulfur standard by three years (to 1 January 2011) if – starting 1 June 2006 – the refiner produces a highway diesel pool that (i) is 100% ULSD and (ii) has volume $\geq$ 85% of its average annual volume in 1998-1999.

Options 1 and 2 may be used together; option 3 must be used alone.

7.4 Overview of the Reporting Program

EPA required refiners and importers who expect to supply ULSD to register with EPA by 31 December 2001. Prospective suppliers must file annual pre-compliance reports, on or before 1 June of 2003, 2004, and 2005; these reports are to contain (i) estimated production volumes of ULSD and EPA diesel at each refinery and (ii) projected generation and consumption of credits by each refinery. The reports are to include other information, including planned time lines for compliance.

For each reporting year, EPA is to produce a report summarizing information from the pre-compliance reports, in aggregate form (without disclosing refinery-specific information). Presumably, these reports will contain aggregate projections of credit generation and consumption.

7.5 Implications for ULSD Supply in the Transition Period

Collectively, the features of the ULSD rule discussed above could promote adequate ULSD supplies in the transition period in at least two ways.

- Reducing the regulatory call for ULSD production
- Increasing information available to refiners for investment planning

The TCO and Small Refiner Options will reduce the regulatory call for ULSD – that is, the regulatory requirement for refinery production of ULSD – in the transition period by ≈ 400–500 K Bbl/day in PADDs 1–3. This volume is larger than the supply shortfall predicted by the CRA/BOB analysis.

The TCO alone will reduce the regulatory call for ULSD production by more than 400 K Bbl/day by 2006, after giving effect to forecast growth in supply and demand. (Refinery out-turn of EPA diesel in PADDs 1–3 was nearly 2000 K Bbl/day in 2000, as shown in Exhibit 6.1.) EPA has estimated [Ref. 3] that its Small Refiner Option 1 (discussed above) could further reduce the regulatory call for ULSD in the transition period, by about 5% (i.e., more than 100 K Bbl/day), some significant portion of which would be in PADDs 1–3.

EPA asserts that nearly half of U.S. refineries that now produce EPA diesel could take advantage of the TCO and thereby defer investment in ULSD capacity by four years. Deferring investments would (1) yield direct operating cost savings over the four year period and (2) increase the likelihood of capturing the economic benefits of new desulfurization technologies that could come into commercial use prior to 2010.

Nonetheless, some refining industry members and others assert that reducing the regulatory call for ULSD supplies will have little effect on ULSD supply in the transition period. In this view, the TCO will see only limited use, because of physical constraints in the diesel fuel distribution system. Using the TCO would force segregation of three grades of diesel fuel – ULSD, EPA diesel, and high-sulfur diesel – in a distribution system containing many elements (pipelines, terminals, retail outlets) designed to handle only two grades. Operators of these facilities would be reluctant to make the needed investments for handling three grades, because the investments would be stranded after four years. EPA, as well as other industry members and observers, take issue with this line of reasoning, in part because they believe that the distribution system will deal with the three-grade issue.

As noted above, assessing the likely value of the regulatory flexibility in the ULSD rule – e.g., the TCO and the Small Refiner Options – was beyond the scope of this study. Such an assessment would entail detailed analysis of the distribution system.

In our view, the TCO in particular is likely to promote adequate ULSD supplies in the transition period, if for no other reason than its credit trading program (outlined in Section 7.2).

The credit trading program will induce at least some refiners to explore, in the course of making their ULSD investment decisions, the prospects for generating or buying credits. These explorations, coupled with EPA's pre-compliance reporting, will augment the information that refiners normally gather for investment planning. Consequently, refiners should have an unusually detailed and accurate picture of the industry's response to the ULSD rule – in time to influence investment decisions bearing on the transition period. The positive implications of such information for ULSD supply in the transition period are discussed in Section 8.3.

8. Concluding Comments: Prospects for ULSD Supply

8.1 Analyzing Possibilities versus Predicting Outcomes

The CRA/BOB and EIA studies embody novel, detailed, and comprehensive techno-economic analyses; they shed light on important issues in the refining sector. But, the conclusions they reach are predictions – based solely on considerations of refinery techno-economics – of the investment decisions that each U.S. refinery will make in response to the ULSD program, in the time interval relevant to the transition period.

In our view, attempting to predict, at arms length, investment decisions of individual enterprises in a complex business and regulatory situation is not likely to be a fruitful endeavor – and the more so when the predictions are based solely on techno-economic considerations, however well analyzed. Whether refiners choose to invest in ULSD production will depend not just on the refining techno-economics of sulfur control in individual refineries – and certainly not just on a "go/no-go" criterion based on estimated average ULSD production cost – but on the interplay of techno-economic, geographic, strategic, supply/demand, regulatory outlook, and other factors.

Unlike the CRA/BOB and EIA analyses, ours offers no predictions regarding the investment decisions of individual refiners with respect to ULSD production. Rather, we sought to (1) delineate key techno-economic factors (both inside and outside refinery battery limits, but primarily outside) that influence decisions on investing for ULSD production, (2) develop first-order estimates of their effects, and (3) indicate how these factors influence the likelihood of the refining industry as a whole making the investments needed to assure adequate supplies of ULSD in the transition period.

8.2 Prospects for ULSD Supply in the Transition Period

The CRA/BOB study predicted a national shortfall in ULSD supply of 320 K Bbl/day (relative to estimated year 2007 highway diesel production capacity, after giving effect to capacity creep and demand growth). The EIA study projected comparable shortfalls in year 2007 production in PADDs 1–4 for some combinations of its supply and demand scenarios. Our analysis, discussed in the four preceding sections, suggests that the economic driving forces for investment in ULSD capacity are sufficient to make it likely that ULSD supply will be adequate in the transition period.

The key assumption in the CRA/BOB and EIA analyses is that no high-cost refineries would invest in ULSD capacity. Their decisions not to invest would cause the forecast shortfalls in ULSD supply. By contrast, our analysis indicates that many high-cost refineries will have strong economic incentives to invest in ULSD capacity and therefore are likely to do so. Some of the remaining high-cost refineries could still choose to produce ULSD via joint production arrangements. Further, some refineries that do not now produce EPA diesel are likely to have incentives to produce ULSD.

The incentives for ULSD production arise mainly from the factors considered in our analysis:

- The unique nature of the diesel fuel market in PADD 4
- The location and competitive position of high-cost refineries in PADDs 1, 2, and 3
- Prospective ULSD production arrangements that capture economies of scale
- The market economics of downgrading distillate material from highway to non-highway diesel

Following is a brief summary of our findings regarding each of these factors.

8.2.1 PADD 4 Refineries Are Likely to Produce ULSD

The PADD 4 refineries now produce about 120 K Bbl/day of highway diesel fuel. PADD 4 is a unique situation, by virtue of its physical isolation from the other PADDs. PADD 4's isolation provides physical and economic barriers that afford protection to PADD 4 refineries from competition from lower-cost refineries in PADDs 2 and 3. Its isolation limits opportunities for downgrading highway diesel to high-sulfur diesel markets within the PADD or outside of it, as an alternative to producing ULSD. In addition, the Geographical Phase-In Area provision of the ULSD rule offers significant additional economic incentives for PADD 4 refineries to produce ULSD.

Our analysis of diesel fuel supply in PADD 4 (Section 3) led to the finding that PADD 4 refineries are likely to upgrade all of their EPA diesel capacity to ULSD capacity, in time for the transition period. (At least three PADD 4 refineries have already announced their intention to produce ULSD by 2006.)

PADD 4 refineries are unlikely to contribute to shortages of ULSD in the transition period, should any occur. This finding addresses ≈ 50 K Bbl/day of the total ULSD shortfall forecast in the CRA/BOB study and as much as 120 K Bbl/day of the shortfall forecast in the EIA study.

8.2.2 High-Cost Refineries in PADDs 1–3 That Operate in Niche Markets Are Likely to Produce ULSD

The twenty-eight high-cost refineries that we identified in PADDs 1–3 account for about 290 K Bbl/day of highway diesel fuel production. A significant fraction of these refineries operate in niche markets – markets in which they would face limited competition from supplies of ULSD having lower delivered costs (refining cost plus transportation), absent significant structural changes in the refining and distribution systems. High-cost refineries in this circumstance would be more likely to produce ULSD than those who were not.

Our assessment of the competitive position of high-cost refineries (Section 4.3) indicated that those in niche markets in PADDs 1–3 account for about 150–170 K Bbl/day of EPA diesel fuel supply. Most of these niche market refineries would have only high-cost means of exporting high-sulfur diesel or distillate streams in the future, as alternatives to producing ULSD. In summary, the niche market refineries in PADDs 1–3 are in a competitive position analogous to that of the PADD 4 refineries.

Hence, we conclude that high-cost refineries in PADDs 1–3 that operate in niche markets are unlikely to contribute to shortages of ULSD in the transition period, should any occur. We estimate that this finding addresses another 150–170 K Bbl/day of the total potential ULSD shortfall forecast in the CRA/BOB and EIA studies.

We estimate that high-cost refineries in PADDs 1–3 that face strong competition from lower-cost suppliers account for potential ULSD capacity of 120–140 K Bbl/day. These refineries have difficult choices to make regarding ULSD production and may be influenced by the considerations discussed below.

8.2.3 Capturing Economies of Scale Could Improve Economics of High-Cost Producers

High-cost refineries that are at a competitive disadvantage could overcome it by participating in joint production arrangements (merchant ULSD plants, tolling arrangements, or opportunity capacity) that capture economies of scale – a possibility that the CRA/BOB and EIA analyses did not consider. Such arrangements would reduce the participating refineries' cost of ULSD production and (in some situations) obviate the need for them to invest in ULSD capacity. These economic benefits hold out the prospect of making ULSD production economic for high-cost refineries that otherwise might choose not to produce ULSD.

Our analysis of the benefits of economies of scale (Section 5) suggests that refineries, especially small refineries, with high costs of ULSD production could reduce their costs significantly by participating in a joint production arrangement involving a large-scale (50–100 K Bbl/day) merchant ULSD plant. Several joint production arrangements now under consideration would involve large-scale ULSD plants located in areas close to a number of the high-cost refineries that we identified.

One cannot forecast the extent to which joint production arrangements may encompass high-cost refineries with adverse competitive positions in PADDs 1–3 or refineries that do not now produce highway diesel fuel. But, present indications suggest that economies of scale ventures are likely to contribute to ULSD supply, a factor to be considered in assessing prospects for ULSD supply.

8.2.4 Downgrading Significant Volumes of Distillate Material from Highway to Non-Highway Markets Is Likely To Be Uneconomic

A refinery choosing to curtail or eliminate highway diesel production would have to downgrade part or all of its EPA diesel volume – in the form of either (1) EPA diesel itself, (2) mixtures of distillate blendstocks (diesel fuel components) that could be sold directly as high-sulfur diesel or (3) cracked distillate blendstocks (coker distillate and/or light cycle stock), whose properties would call for further processing or blending to make salable off-highway product. The CRA/BOB and EIA analyses *assumed* that (1) domestic or foreign outlets would exist for whatever distillate volumes might be downgraded to non-highway diesel and (2) on-purpose downgrading would not depress non-highway distillate prices, regardless of the extent to which it were practiced.

Our analysis of the potential for and economic implications of downgrading (Section 6) indicated that the U.S. refining sector is unlikely to find on-purpose downgrading attractive for more than small volumes. In particular, on-purpose downgrading would be unattractive at an aggregate volume of

120–140 K Bbl/day – the prospective ULSD capacity in the high-cost refineries with adverse competitive positions, described above.

Geography, operational factors, and slow growth or actual decline in demand for high-sulfur diesel in most U.S. market sectors dictate that only three outlets could accommodate large volumes of on-purpose downgrading:

- Displacing highway diesel fuel now sold in off-highway markets, with the largest potential in PADD 2,
- Increasing exports from PADD 3 to markets in Mexico, the Caribbean, Central America, and South America, and
- Displacing imports in PADD 1, first imports from remote suppliers, then imports from Venezuela.

The displacement route for downgrading would not reduce the supply of ULSD for highway use. Only the off-shore downgrading routes would reduce the effective supply of ULSD in the U.S.

Off-shore downgrading would incur transportation costs. Moreover, it would increase – barrel-for-barrel – the total supply of high-sulfur diesel in Latin American markets (all else equal). Hence, it would depress market-clearing prices for high-sulfur distillate in the importing countries and in the U.S. We estimate that downgrading in the range of 100 to 300 K Bbl/day would decrease the refinery gate price of high-sulfur diesel fuel by about 5 to 20¢/gal or more in PADDs 1–3; the larger the downgrade volume, the larger the price effect.

Our analysis indicates that market forces in the domestic and off-shore markets for high-sulfur distillate material would make the prospect of widespread downgrading of distillate volumes unattractive to the refining sector. The more downgrading were practiced, the more unattractive it would be. This market response would give high-cost refiners in PADDs 1, 2, and 3 a strong incentive to invest in ULSD capacity (or enter into processing agreements) rather than accept the lower prices for high-sulfur distillate that would result from even moderate volumes of downgrading.

The price-depressing effects of widespread downgrading would be felt throughout PADDs 1–3, creating economic incentives for investments to upgrade high-sulfur distillate capacity (in addition to EPA diesel capacity) to ULSD production. Such upgrading would either increase domestic supply of ULSD (reducing the call for imports) or off-set corresponding volumes of on-purpose downgrading by other refiners.

8.3 Marginal Supply Curves and Investment Planning

The CRA/BOB and EIA analyses assume that each refinery would respond to the ULSD rule solely on the basis of its own cost of ULSD production, without regard to (among other things) the situations, prospects, and decisions of other refineries with which it interacts (or could interact). That is, in making ULSD investment decisions, each refiner would be "myopic" – oblivious to the rest of the refining industry.

For example, in the CRA/BOB and EIA framework, a large, low-cost refinery would upgrade its EPA diesel facilities to produce only the same volume of ULSD – but not more – even though one or more higher-cost competitors in its highway diesel markets had chosen not to produce ULSD. Similarly, the higher-cost competitors would not participate in any joint production arrangements.

However, in practice, refiners tend to be "informed", not myopic, regarding the rest of their industry. Refiners exhibit "informed" decision-making many ways. They trade and exchange refined products with competitors to reduce costs in product distribution. (Industry observers estimate that such transactions involve nearly half of total refined product volume.). Tolling arrangements and merchant plants are commonplace. During the lead phase-out period, refiners made extensive use of the lead credit trading and banking program.

Refiners continually gather information on the operations, performance, costs, and planned investments of their competitors – from industry surveys and reporting systems, trade publications, industry sources, personal contacts, etc. They use this information in shaping their own operations and investment planning in general.[18] In planning for the ULSD rule in particular, refiners are likely to have even more information than usual, because of the TCO's credit trading program and EPA's pre-compliance reporting (as discussed in Section 7.5).

From an analytical standpoint, informed decision-making means that a given refinery need not have a fixed position on a marginal cost curve and the curve itself need not have an immutable shape.

For example, suppose a high-cost refinery enters into a tolling arrangement with a large, low-cost refinery, thereby reducing the cost of ULSD production for both refineries (Section 4.3). Such an arrangement would change the position of both refineries on a marginal cost curve and, as a consequence, change the "shape" of the marginal cost curve itself.

To the extent that refiners make informed decisions, refiners' responses to the ULSD rule cannot be predicted by appealing to marginal cost curves and arbitrary cost thresholds for investment.

Ultimately, the marginal cost curve for ULSD supply will be determined by the set of decisions that U.S. refiners make – not the other way around. In reality, the CRA/BOB and EIA analyses generated not "marginal cost curves" for the transition period but rather graphical orderings of refinery-specific ULSD costs under myopic decision-making.

8.4 OTHER ISSUES

8.4.1 Bounds on the Scope of the Study

We did not consider the effects of a prospective new federal sulfur standard for *non-highway* diesel fuel. Stringent sulfur control of non-highway diesel fuel would (1) alter the techno-economics of the ULSD program for highway diesel fuel, in both refining and distribution, and (2) likely influence the refining sector's technical and temporal response to diesel fuel sulfur control. However, the nature of

[18] Informed investment planning does not necessarily achieve its intended results. Refiners are informed; not omniscient.

the linkages between sulfur control for highway and for non-highway diesel fuel will depend on the specifics of the non-highway rule – most notably the target sulfur level, the time-table, and the affected categories of non-highway diesel fuel. As of this writing, EPA has not proposed a new rule for non-highway sulfur control.

We did not examine company-specific strategic factors that could influence the ULSD investment decisions of individual refiners – e.g., financial considerations (such as availability of capital), corporate strategies, etc. Nor did we examine the capacity of the engineering, procurement, and construction industry to build all of the necessary ULSD production capacity in time for the transition period. In general, these issues have not been subjects of controversy. They were beyond the scope of not only this study but also the earlier studies of prospective ULSD costs and supplies.

Finally, aside from the brief analysis described in Section 4, we did not estimate refining costs of ULSD production in the transition period or thereafter, nor did we forecast or project ULSD prices. In prior studies, notably [Refs. 4 and 11], we estimated the likely refining costs of producing ULSD to various sulfur standards, including the 15 ppm cap specified by EPA. Those analyses covered a range of likely technical approaches to diesel fuel sulfur control. Further analysis of ULSD production costs, beyond that described in Section 4, was not warranted in this study.

8.4.2 Information Underlying the Analysis

Our techno-economic analysis to estimate refinery-specific costs of ULSD production (Section 4) relied on information in the public domain. We did not have information on certain refinery-specific technical factors (e.g., properties of the crude oil slate, quality of the refinery's distillate pool, details of the technology used for distillate desulfurization, etc.) that was available to CRA/BOB and the EIA studies. For this reason, our analysis yielded somewhat smaller refinery-to-refinery variations in ULSD production costs; that is, our estimated marginal cost curves (Exhibit 4.1) are somewhat "flatter" than those generated in the CRA/BOB and EIA studies.

Not having access to refinery-specific technical information may seem an important limitation, because all the primary analyses of ULSD production economics are rich in technical detail. However, this analysis focuses on the prospects for adequate ULSD supply, not the cost of ULSD production. We estimated refinery-specific costs of ULSD production *solely* to identify the refineries likely to have the highest costs. Had we used the CRA/BOB or EIA marginal cost curves, our findings would have been essentially the same with respect to PADD 4, existence of refineries with niche markets in PADDs 1–3, economies of scale projects, and the market consequences of on-purpose down-grading to high-sulfur diesel markets.

Finally, we did not attempt to project supply/demand balances for highway diesel fuel in 2006 and 2007 in our analysis of distillate markets (Section 6). Rather, we (1) relied on supply and consumption data for 2000 and (2) assumed that growth in demand for highway and non-highway diesel would be met by capacity creep in U.S. refineries and some growth in imports. Using a projected supply/demand balance for 2006/2007 would not have changed the thrust or main findings of the analysis.

9. References

1. *Control of Air Pollution from New Motor Vehicles: Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements: Final Rule*; Federal Register, 40 CFR Parts 69, 80, and 86; January 18, 2001

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3. Regulatory Impact Analysis: *Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*, EPA-20-R-00-26 (Chapter V); Environmental Protection Agency; December 2000

4. *Refining Economics of Diesel Fuel Standards: Supplemental Analysis of 15 ppm Sulfur Cap*; MathPro Inc.; August 2000

5. *U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels* (Chapter 3); National Petroleum Council; June 2000

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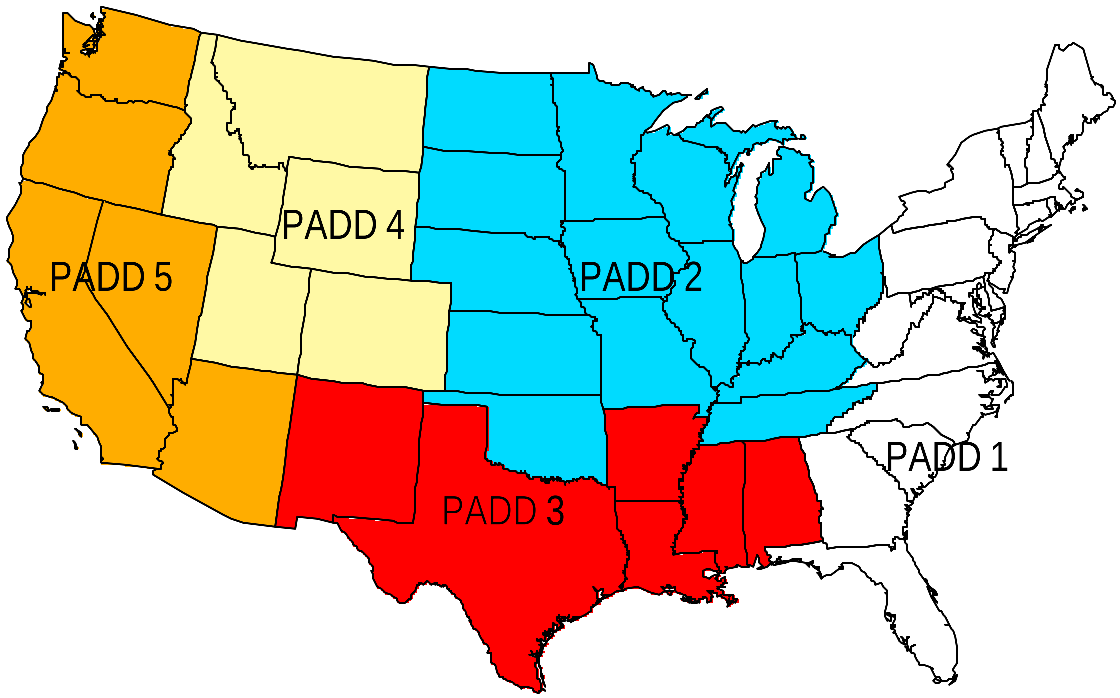
Petroleum Administration for Defense Districts
(PADDs)



Appendix: Estimating Average Refining Margins by PADD

The procedure for estimating differences in average annual refining margins between PADD 4 and PADDs 2 and 3, shown in Exhibit 3.6, has five steps.

1. Develop data on the volume of refinery inputs and refined product outputs for each PADD.
2. Develop data on prices for refinery inputs and refined product outputs for each PADD.
3. Calculate total refinery revenues and input costs for each PADD.
4. Calculate average "gross refining margin" for each PADD.
5. Calculate the difference in refining margins between PADD 4 and PADDs 2 and 3.

Following is a brief description of the analysis.

A.1 Volume of Refinery Inputs and Refined Product Outputs

For each year of interest, we drew refinery input and output volumes from tables in the corresponding edition of EIA's *Petroleum Supply Annual* (PSA).

- Table 16: Refinery inputs of crude oil, natural gas liquids, and other liquids (oxygenates, unfinished oils, motor gasoline blendstocks, etc.) by PADD
- Table 17: Net production of finished petroleum products by PADD
- Tables 22-25: Imports, by PADD, of crude oil from the following groups of countries and individual countries: Arab OPEC, Other OPEC, Canada, Mexico, and Other non-OPEC

A.2 Prices for Refinery Inputs and Refinery Outputs (Refined Products)

Data are available on refinery crude oil acquisition costs at the national level, but not the PADD level. For each year of interest, we estimated refinery crude oil acquisition costs at the PADD level by using data from the corresponding edition of EIA's *Petroleum Marketing Annual* (PMA) on landed costs of imported crude oil (Table 25) and first purchase prices of domestic crude oil (Table 21).

Landed costs of crude oil are reported on a national level, disaggregated by selected countries or groups of countries. We tabulated reported landed costs (or calculated landed costs) for the following groups of countries and individual countries: Arab OPEC, Other OPEC, Canada, Mexico, and Other non-OPEC. We then adjusted these landed costs by the difference between reported landed costs for all imported crude oil and reported refiner acquisition costs (33¢/bbl in 1999 and 42¢/bbl in 2000). We used the same adjusted landed crude oil costs for each PADD. However, because the mix of imported oil differs across PADDs, the calculated refiner acquisition cost for imported crude oil differs across PADDs.

First purchases of domestic crude oil are reported at the PADD level. However, the national average first purchase prices of domestic crude are substantially lower than reported refiner acquisition costs for domestic crude – by about $2.31/bbl in 1999 and $2.38/bbl in 2000. We added these differentials to the first purchase prices reported for each PADD, to estimate PADD-level refiner acquisition costs for domestic crude oil.

We developed annual average Gulf Coast prices, for 1996 and 1997, for refinery inputs of n-butane, iso-butane, ethanol, methanol, MTBE, and toluene, based on "first-of-the-month" prices reported in *Octane Week*. For other PADDs, including PADD 4, we adjusted the Gulf Coast prices to account for transport costs and other factors influencing supply. We estimated the acquisition cost of unfinished oils as a function of estimated crude oil acquisition costs (i.e., 1.1 * crude cost).

Spot, or refinery gate, prices for refined products are not publicly available in PADD 4. Hence, we used "refiner sales for resale" prices reported for each PADD in the 1996 and 1997 editions of the PMA to represent refinery gate prices on sales of major refined products. We considered propane (38), motor gasoline (35), aviation gas (36), kerosene jet fuel (36), kerosene (36), No. 2 distillate (weighted average of No. 2 fuel oil and high and low sulfur diesel fuel) (37), and residual fuel oil (42). (Numbers in parentheses denote the PMA table number.)

Price data are not publicly available on a PADD level for a variety of small-volume refined products reported in the PSA. We estimated PADD-level prices for these minor products as:

- price of asphalt = price of residual oil;
- prices of naphtha and special naphthas = crude oil price;
- other oils to petrochemicals = crude oil price + $2/bbl;
- lubricants and waxes = crude oil price + $6.75/bbl;
- petroleum coke = $0/bbl; and
- miscellaneous products = 1.3 * crude oil price.

Given the relatively small volume of these products, modifying the pricing assumptions has little effect on *relative* refinery margins.

A.3 Revenues, Costs, Refining Margins, and Differential Refining Margins

For each year of interest and each PADD, we calculated refinery revenues and input costs as the dot product between prices and output/input volumes. Then, for each PADD, we calculated gross refinery margins as the difference between calculated revenues and input costs, divided by the crude run. (Note that input costs do not include purchased energy costs, other refinery operating costs, labor costs, administration costs, marketing costs, or capital charges.)

Finally, we calculated the differential margins between PADD 4 and PADDs 2 and 3 by subtracting the estimated gross refinery margins in PADD 2 and PADD 3 from the corresponding values for PADD 4.

Exhibit 3.1: PADD 4 Refining Capacity and Crude Oil Imports, by Refinery -- 2000

(barrels per calendar day)

Process/ Crude Oil Imports	Colorado		Montana				Utah					Wyoming				Total
	Commerce City Conoco	Denver Ultramar	Laurel Cenex	Billings Conoco	Billings Exxon	Great Falls Montana	Salt Lake City BP	Salt Lake City Chevron	Woods Cross Silver Eagle	North Salt Lake Flying J	Woods Cross Phillips 66	Cheyenne Frontier	Evansville Little Amer.	Sinclair Sinclair*	Newcastle Wyoming	
Complexity	6.3	6.0	9.0	11.6	9.0	9.6	5.5	8.0		7.6	8.7	9.3	7.5	7.4	7.9	**8.1**
Crude Distillation	57,500	28,000	46,000	55,100	58,000	7,000	53,000	45,000	idle	25,000	25,000	40,500	22,000	54,000	12,500	**528,600**
Vacuum Distillation	25,000	9,500	23,500	26,600	27,500	3,350		25,600		5,000	5,500	23,500	7,800	6,500	1,500	**190,850**
Coking				16,470	8,000			7,200				10,000				**41,670**
Cat Cracking	19,000	8,000	12,700	18,450	20,000	2,300	19,400	13,000		5,000	7,680	12,000	13,300	20,000	6,000	**176,830**
Hydrocracking					5,000											**5,000**
Cat Reforming	9,600	9,000	11,000	13,500	12,000	1,000	10,600	7,000		5,500	7,200	7,800	5,700	14,200	3,500	**117,600**
Desulfurization																
FCC Feed	12,000		15,000	*19,800*		2,900								10,000		**59,700**
Reformer Feed	9,600	9,000	13,000	10,800	12,500	1,000	10,600	7,300		7,000		8,000	5,700	14,200	3,500	**112,200**
Naphtha & Isom Feed											12,000		3,500			**15,500**
Distillate	12,500		14,100	22,500	24,000	2,850		16,700		7,000	1,700	16,600		22,000	4,000	**143,950**
Other					7,000											**7,000**
Other Processes																
Alkylation			3,500	6,480	3,500	675	4,900	4,500		1,400	2,400	4,200		4,000	1,500	**37,055**
Butane Isomerization			2,500	3,420				1,000		2,000		1,500				**10,420**
Pen/hex Isomerization						675				1,750	2,600					**5,025**
Cat. Polymerization	2,600	900				400								700		**4,600**
Solvent Deasphalting**			4,000								5,040					**9,040**
H2 (MMcf/d)																
Production			12	20	22							6				**60**
Recycle			12	11	5											**28**
Crude Oil Imports																
% Sulfur	0.23		2.16	2.52	2.16	1.78	0.26	0.40		0.19		1.61				**2.03**
API Gravity	31.5		24.9	28.0	27.6	26.1	34.9	33.8		31.7		21.5				**27.4**
Specific Gravity	0.868		0.904	0.887	0.889	0.898	0.850	0.856		0.867		0.925				**0.891**
Volume (K bbl/d)	5		32	58	25	5	1	9		3		9				**147**
% of Crude Dist.	9%		70%	105%	43%	71%	2%	20%		12%		22%				**28%**

* 2000 OGJ data for the Sinclair refinery are in error; 1999 OGJ data used instead.

** Solvent deasphalting capacity from Jan 2001 EIA/DOE data.

Notes: Silver Eagle refinery in Utah did not operate in 2000.

Imports of crude oil differ from data reported in EIA/DOE *Petroleum Supply Annual*; those data are tabulated by PADD of entry, not by the refinery/PADD in which the imported oil is processed.

Sources: Refining Process Capacity: *OGJ*, December 18,2000, p. 110-119; and *Petroleum Refining Capacity Data,* Jan. 2001, EIA/DOE.

Exhibit 3.2: Inputs and Operations for PADD 4 Refineries 1996 - 2000

(K Bbl/CD)

Inputs/Operations	Year 1996	1997	1998	1999	2000
Refinery Net Inputs	498	505	504	524	541
Crude Oil	470	479	480	498	506
Natural Gas Liquids	15	15	15	16	19
Pentanes Plus	4	3	6	6	7
Liquified Petroleum Gases	11	11	9	10	11
Ethane					
Propane					
Normal Butane	7	7	6	6	6
Isobutane	4	4	3	5	5
Other Liquids	13	11	10	9	16
H2 & H2 feeds	0	0	0	0	1
Oxygenates	2	2	3	3	4
Naphthas					
Unfinished Oils	4	1	1	3	4
Residuum					
Gasoline Blend. Comp.	7	8	5	4	8
Fuel (foeb)					
Refinery Operations					
Atmospheric Distillation					
Gross Input	473	483	486	505	513
Operable Capacity	514	520	524	528	542
Utilization Rate (%)	92.2	92.9	92.7	95.7	94.7
Fresh Feed Input to Downstream Units					
Catalytic Cracking	150	155	147	145	144
Catalytic Hydrocracking	4	3	4	5	4
Delayed and Fluid Coking	36	40	41	39	41
Crude Oil Qualities					
Sulfur Content (wt %)	1.31	1.38	1.35	1.37	1.40
API Gravity (degrees)	33.6	33.1	33.2	34.1	33.2
Specific Gravity	0.857	0.860	0.859	0.854	0.859

Source: Derived from Table 16, *Petroleum Supply Annual*, 1996 - 2000," DOE/EIA.

Exhibit 3.3 Outputs for PADD 4 Refineries, 1996 - 2000

(K Bbl/CD)

Products	Year				
	1996	**1997**	**1998**	**1999**	**2000**
Refinery Outputs	511	519	497	541	558
Refinery Gases	6	6	4	6	7
Ethane/Ethylene			0		
Propane/Propylene	9	9	8	9	9
Normal Butane/Butylene	(2)	(2)	(2)	(1)	(0)
Isobutane/Isobutylene	(1)	(1)	(3)	(2)	(1)
Finished Petroleum Products	505	512	493	535	551
Motor gasoline	251	254	257	262	271
Reformulated					
Oxygenated	17	19	17	14	21
Conventional	233	235	239	248	250
Aviation Gasoline	1	0	0	0	1
Jet Fuel	28	26		27	29
Naphtha-Type	1				
Kerosene-Type	26	26	24	27	29
Kerosene	3	2	3	2	1
Distillate Fuel Oil	138	138	137	144	148
0.05 % sulfur & under	110	112	111	119	121
Greater than 0.05 % sulfur	28	26	26	24	28
Residual Fuel Oil	13	13	12	12	10
Less than 0.31 % sulfur	3	3	2	2	1
0.31 to 1.00 % sulfur	3	3	3	3	2
Greater than 1.00 % sulfur	7	7	7	7	7
Naphtha to Petrochemical					(0)
Other Oils to Petrochemical	1	1	1	1	1
Special Naphthas		(0)		(0)	(0)
Lubricants					
Waxes	3	3	4	4	3
Petroleum Coke	13	15	16	17	17
Marketable	7	8	10	10	10
Catalyst	6	6	7	7	7
Asphalt and Road Oil	36	40	41	44	48
Still Gas	19	19	20	20	20
Miscellaneous Products	2	2	2	2	2

Source: Derived from Table 17, *Petroleum Supply Annual* , 1996 - 2000," DOE/EIA.

Exhibit 3.4: Pipelines Transporting Refined Products to and from PADD 4

Pipeline	Origin	Destination
To PADD 4		
Chase	PADD 2 -- El Dorado, Kansas	Colorado
Diamond Shamrock	PADD 3 -- McKee, Texas	Colorado
Phillips	PADD 3 -- Borger, Texas	Colorado
From PADD 4		
Cenex	Billings, Montana	PADD 2 -- North Dakota
Cheyene	Cheyene, Wyoming	PADD 2 -- Nebraska
Wyco	Casper, Wyoming	PADD 2 -- South Dakota
Chevron	Salt Lake City, Utah	PADD 5 -- Eastern Oregon & Washington
Yellowstone	Great Falls, Montana	PADD 5 -- Eastern Washington

Sources: Personal communications and *1995 International Petroleum Encyclopedia.*

Table 3.5: Diesel Fuel Sales & Supply in PADD 4 -- 1996 - 2000
(K bbl/d)

Type of Diesel Fuel	Year 1996	1997	1998	1999	2000	Average
Sales*	**154**	**162**	**152**	**163**	**171**	**160**
On-Road	71	81	84	96	100	86
All other	83	81	68	67	70	74
Supply						
<= 0.05% Sulfur	**121**	**128**	**123**	**136**	**140**	**130**
Refinery Production	110	112	111	119	120	114
Inter-PADD Transfers						
From: PADD 2	20	23	24	28	32	25
PADD 3	1	1	2	2	2	2
To: PADD 2	11	8	10	9	10	10
PADD 5	0	1	5	7	7	4
Imports	2	2	2	3	3	2
Export						
Stock Change	0	0	1	1	0	0
> 0.05% Sulfur	**33**	**33**	**29**	**27**	**31**	**31**
Refinery Production	28	26	26	24	27	26
Inter-PADD Transfers						
From: PADD 2	0	0				0
PADD 3						
To: PADD 2						
PADD 5	0	0	0	0	0	0
Imports	5	7	3	3	4	4
Exports		0	0			0
Stock Change	0	0			0	0
Total	**154**	**162**	**152**	**163**	**171**	**160**
Refinery Production	138	138	137	143	147	141
Inter-PADD Transfers						
From: PADD 2	20	23	24	28	32	25
PADD 3	1	1	2	2	2	2
To: PADD 2	11	8	10	9	10	10
PADD 5	1	1	5	7	7	4
Imports	7	9	5	6	7	7
Exports						0
Stock Change	0	0	1	1	0	0

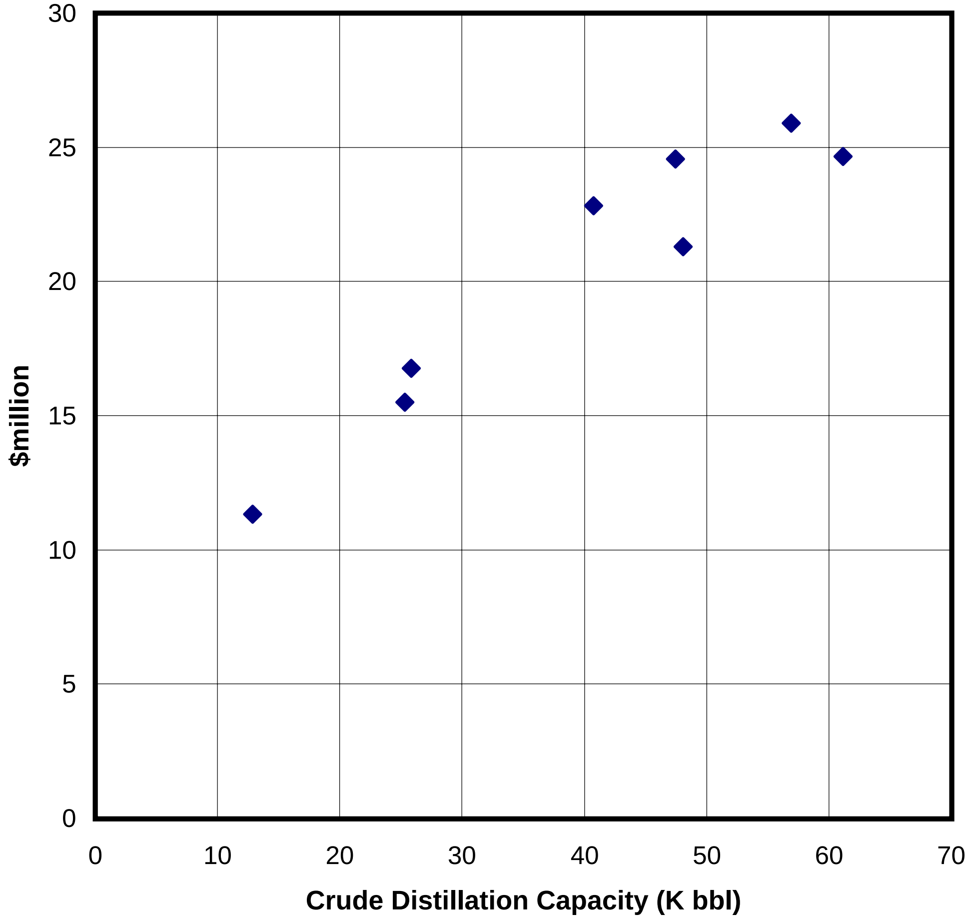
* Sales volumes adjusted to match supply volumes.
Note: Year 2000 imports for PADD 4 modified to equal DOE import volumes shown in Table 5.
Zero indicates less than 500 bbl/d.
Sources: Sales: Derived from Table 16, *Fuel Oil and Kerosene Sales* , 1996 - 1999, EIA/DOE.
Supply: Tables 11 & 32, *Petroleum Supply Annual, Vol 1* , 1996 - 2000, EIA/DOE.

Exhibit 3.6: Estimated Difference in Gross Refining Margins between PADD 4 and PADDs 2 and 3, 1996 - 2000
($/bbl Crude Throughput)

Year	PADD 2	PADD 3
1996	1.28	2.75
1997	1.75	3.00
1998	0.90	1.92
1999	1.55	1.80
2000	0.59	2.38

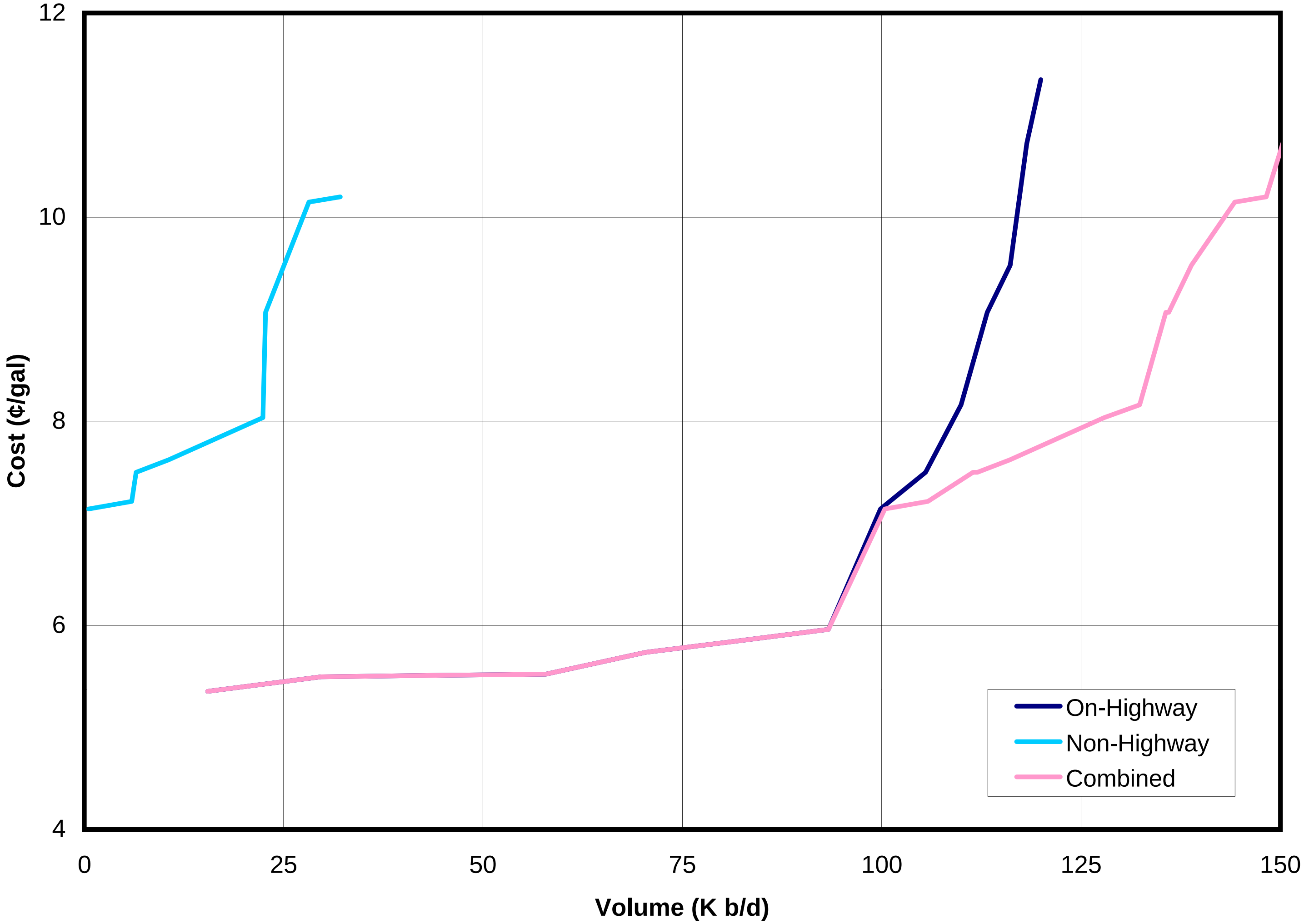
Source: Derived from *Petroleum Supply Annual* and *Petroleum Marketing Annual*, 1996 - 2000, EIA/DOE.

Exhibit 3.7: Estimated Distribution of ULSD Investment Costs in PADD 4, $million



Note: Includes investment by some refineries to expand production of ULSD to include currently produced volumes of off-road diesel.

Exhibit 3.8: PADD 4 -- Estimated Cost of Producing ULSD*



* Refects average cost for each refinery of producing ULSD at current on-road diesel volumes and of converting current production of off-road (all-other) diesel to ULSD.

Exhibit 3.9: PADD 4 -- Estimated Distribution of ULSD Costs, $/barrel of Crude Run

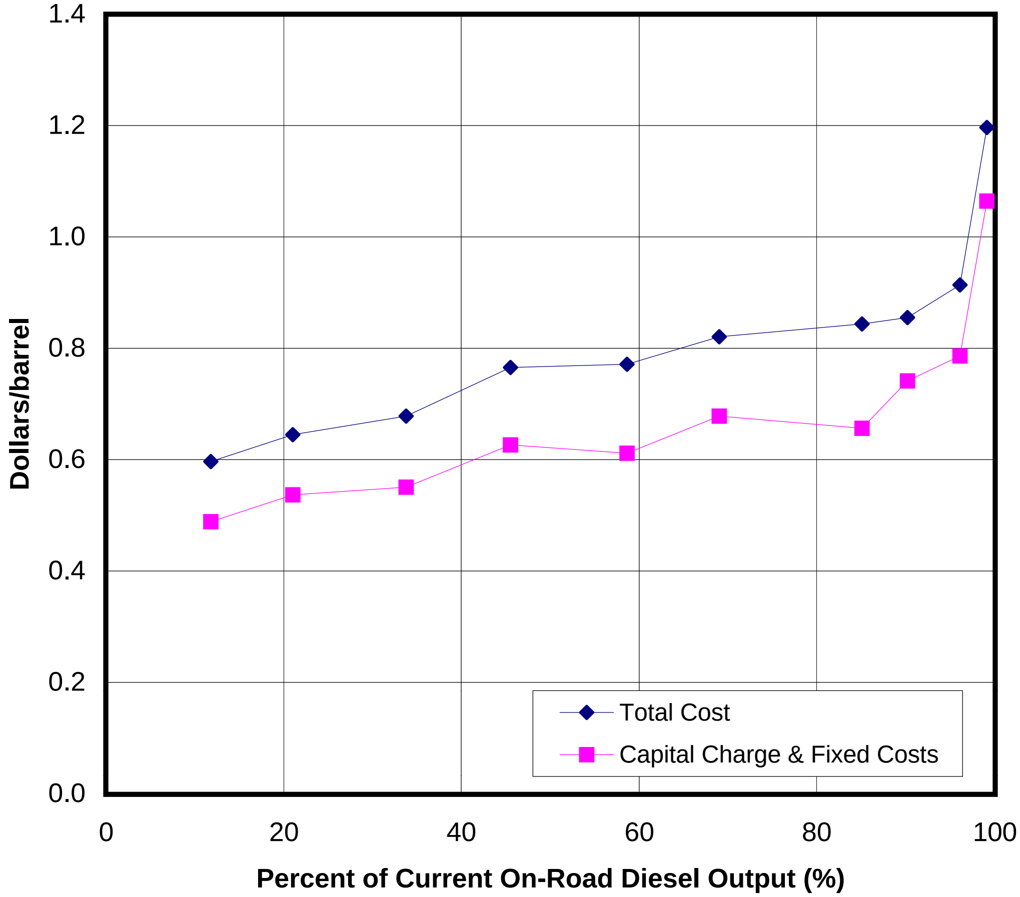
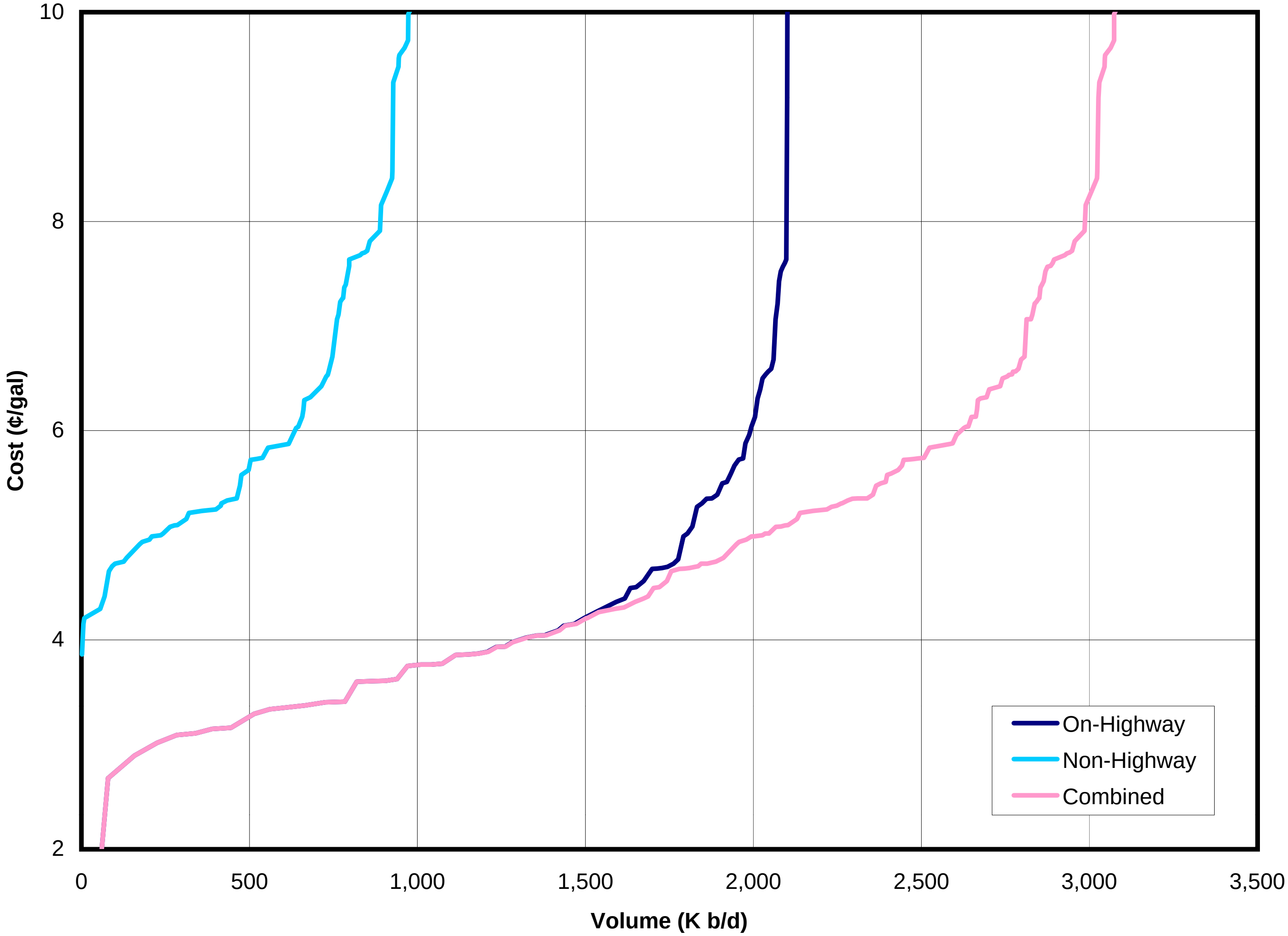


Exhibit 4.1: PADDs 1-4 -- Refinery Cost Curves for ULSD

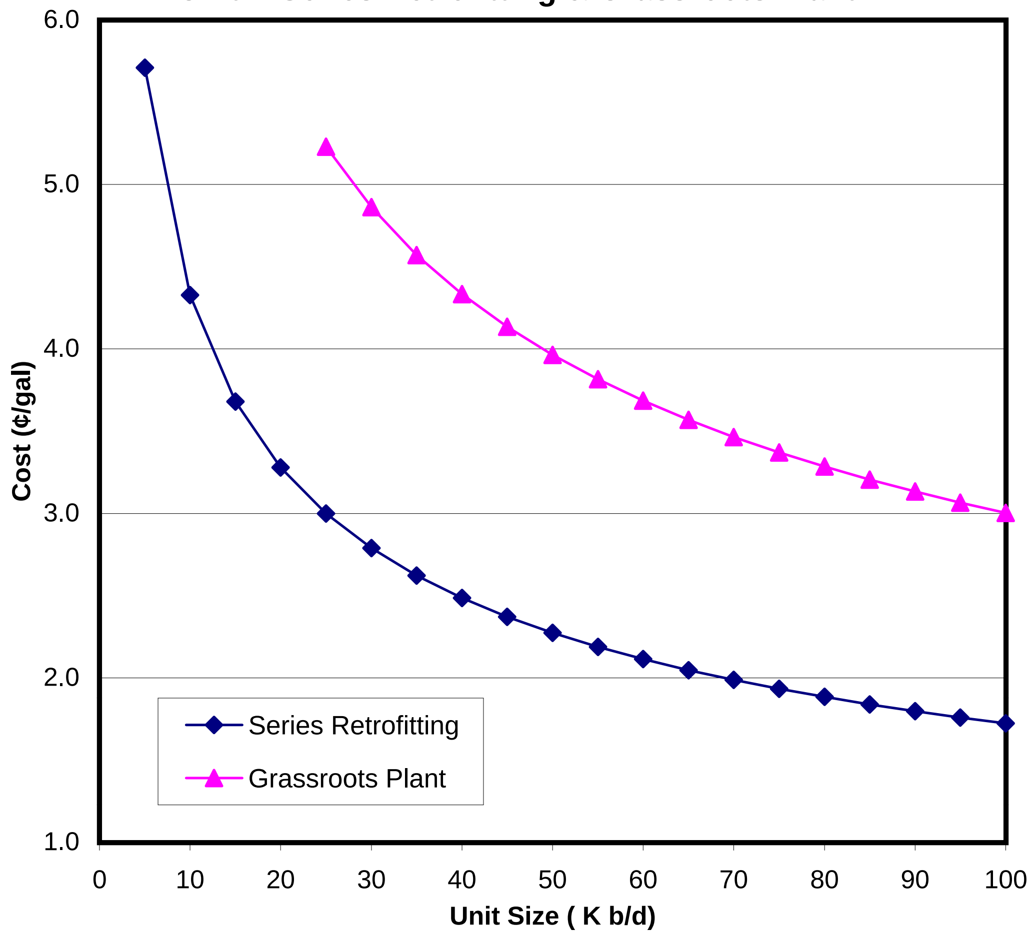


* Reflects average cost for each refinery of producing ULSD at current on-road diesel volumes and of converting current production of off-road diesel (all other) diesel to ULSD.

Exhibit 4.2: High Cost (> 5 ¢/gal) ULSD Refineries in PADDs 1 to 3

Region	Refinery	Volume (K b/d)	Investment $MM	Avg. Cost (¢/gal)
PADDs 1-3		**210.5**	**267.4**	**6.0**
PADD 1		**43.5**	**94.3**	**6.6**
East Coast	1A-1	9.4	20.0	6.5
	1A-2	9.1	19.7	6.6
	1A-3	6.1	15.5	7.6
Appalachian No. 1	1B-1	16.7	28.3	5.4
	1B-2	1.3	6.2	13.1
	1B-3	0.8	4.7	15.6
PADD 2		**99.0**	**89.0**	**5.7**
Indiana, Illinois, Kentucky	2A-1	16.3	25.6	5.1
	2A-2	14.3	26.3	5.3
	2A-3	12.1	21.5	5.6
	2A-4	7.1	15.6	6.7
Minn., Wis., N. & S. Dakota	2B-1	14.5	23.9	5.3
	2B-2	7.5	16.1	6.6
	2B-3	5.1	12.7	7.5
Oklahoma, Kansas, Missouri	2C-1	13.9	23.3	5.3
	2C-2	8.1	16.9	6.4
PADD 3		**68.1**	**84.2**	**6.1**
Texas Inland	3A-1	14.6	22.9	5.1
	3A-2	10.4	18.8	5.7
Texas Gulf	-	-	-	-
Louisiana Gulf Coast	3C-1	7.4	13.8	5.9
	3C-2	6.8	13.2	6.0
North Lousisiana	3D-1	7.6	15.5	6.3
	3D-2	6.9	14.7	6.5
	3D-3	5.4	12.7	7.1
New Mexico	3E-1	4.7	11.6	7.4
	3E-2	4.3	11.4	7.6

Exhibit 5.1: Illustration of How Capital Charges plus Fixed Costs Vary with Size of Distillate Hydrotreating Unit -- Series Retrofitting & Grassroots Plant



Note: Cost curves assume low sulfur feeds (EPA diesel) for series retrofitting and high sulfur feeds for grassroots plant.

Exhibit 6.1: Summary of Distillate Sales and Supply -- Average of 1999 and 2000

(K bbl/d)

	PADD					PADDs 1-3	
	1	2	3	4	5	Volume	% Share
Sales*	**1,340**	**1,091**	**620**	**167**	**429**	**3,050**	**100**
On-Highway	654	691	381	95	281	1,726	57
Non-Highway	686	399	239	71	148	1,324	43
Supply							
<= 0.05% Sulfur	**734**	**825**	**425**	**138**	**368**	**1,983**	**65**
Refinery Production	217	630	1,071	120	353	1,917	63
Net Inter-PADD Transfers	394	189	-615	16	15	-32	-1
Net Imports	114	4	-30	3	2	89	3
Canada	34	4	0	3	6	38	
Virgin Islands	47				2	47	
Venezuela	15					15	
Other	17	0	-30	0	-5	-12	
Stock Change	-9	-2	2	1	2	-10	
> 0.05% Sulfur	**606**	**266**	**195**	**29**	**61**	**1,067**	**35**
Refinery Production	229	219	523	26	104	970	32
Net Inter-PADD Transfers	223	43	-267		3	-2	0
Net Imports	116	2	-62	3	-47	56	2
Canada	31	1	0	4	1	31	
Virgin Islands	29				0	29	
Venezuela	42					42	
Other	15	1	-62	0	-48	-47	
Stock Change	-39	-3	-2		-2	-43	
Total	**1,340**	**1,091**	**620**	**167**	**429**	**3,050**	**100**
Refinery Production	445	849	1,593	145	457	2,887	95
Net Inter-PADD Transfers	617	232	-882	16	18	-33	-1
Net Imports	230	6	-92	6	-45	144	5
Canada	65	5	0	7	6	70	
Virgin Islands	76				2	76	
Venezuela	57					57	
Other	32	1	-92	0	-53	-59	
Stock Change	-48	-5	0	1	1	-53	

* Adjusted to equal reported supply.
Source: Sales: Derived from Table 16, *Fuel Oil and Kerosene Sales* , 1999, EIA/DOE.
Supply: Derived from Tables 4-13, *Petroleum Supply Annual, Vol 1* , 1999 & 2000, EIA/DOE.

Exhibit 6.2: Movements of Diesel Fuel between PADDs, 2000
(K b/d)

PADD of Destination	PADD of Origin 1	2	3	4	5
On-Highway					
1		8	473		
2	69		160	10	
3		18			
4		32	2		
5			9	7	
Non-Highway					
1		5	236		
2	19		30		
3		3			
4					
5			1	0	

Source: Derived from Table 32, *Petroleum Supply Annual, 2000* , EIA/DOE.

Exhibit 6.3: U.S. Exports of Diesel Fuel, by PADD -- 2000 (K b/d)

PADD	< .05 % Sulfur	> .05 % Sulfur	Total
1	4	6	10
2	1	-	1
3	36	69	105
4	0	0	0
5	7	50	57
Total	**48**	**125**	**173**
1 - 3	**41**	**75**	**116**

Source: Tables 5-13, *Petroleum Supply Annual, 2000* , EIA/DOE.

Exhibit 6.4: Estimated PADD 1-3 Exports of Diesel Fuel, by Region -- 2000
(K b/d)

Region	Volume
Mexico	65
Carib. & Central. Amer.	28
South America	6
Europe	17
Other	0
Total	**116**

Source: Derived from Table 28, *Petroleum Supply Annual, 2000* , EIA/DOE.

Exhibit 6.5: Estimated Diesel Fuel Supply and Use in 2000, by PADD and Type of Use (K b/d), and Average Annual Growth Rates, 1996-1999

	PADD					PADDs 1-3		
	1	2	3	4	5	Volume	% Share	1-5
Diesel Fuel Supply	***1,360***	***1,100***	***648***	***172***	***442***	***3,108***	***100***	**3,722**
On-Highway Use*	**668**	**716**	**384**	**101**	**312**	**1,768**	**57**	**2,030**
Non-Highway Use*	**692**	**384**	**264**	**71**	**130**	**1,340**	**43**	**1,542**
Residential	341	40	0	3	9	381	12	393
Commercial	134	34	14	8	13	182	6	203
Industrial	49	45	27	13	13	121	4	147
Off-Road	44	39	33	13	17	116	4	146
Railroad	30	75	48	18	19	153	5	190
Marine	32	38	57	0	15	127	4	142
Farm	31	92	40	13	21	163	5	197
Military	5	2	9	0	4	15	0	20
Oil Company	1	2	33	1	4	36	1	41
Electric Utility	26	16	3	1	15	46	1	62
Average Annual Growth Rates (%)								
On-Highway Use	**4.9**	**4.5**	**9.1**	**5.8**	**1.2**	**5.6**		**5.4**
Non-Highway Use	**-0.1**	**-1.2**	**-0.6**	**2.3**	**3.0**	**-0.5**		**-0.1**
Residential	-1.2	-9.4	-19.0	3.7	0.1	-2.1		-2.0
Commercial	-2.1	-1.4	0.4	4.3	1.3	-1.8		-1.3
Industrial	3.1	4.2	0.3	7.8	1.8	2.9		3.2
Off-Road	3.7	1.2	7.1	7.9	3.3	3.8		4.1
Railroad	-0.9	-4.0	-1.1	-3.7	3.0	-2.5		-2.1
Marine	1.5	8.3	2.2	34.9	-0.9	3.9		3.3
Farm	2.4	-2.8	-4.0	2.0	7.3	-2.1		-0.8
Military	-17.8	0.7	-4.4	12.2	-1.9	-7.5		-6.1
Oil Company	15.5	16.6	7.0	14.5	6.0	7.6		7.7
Electric Utility	-6.3	-2.7	0.8	5.1	20.7	-4.5		1.9

Note: DOE projects on-highway use to grow at an annual rate of 2.5% from 2000 to 2007.

* Normalized so sum of diesel use equals supply.

Sources: 2000 Diesel Supply: Tables 3-13, *Petroleum Supply Annual, 2000* , EIA/DOE.

2000 Use: Derived from Table 16, Fuel Oil and Kerosene Sales, 1999, EIA/DOE.

Growth rates: Tables III-1 to5, *Alternative Markets for Highway Diesel Fuel Components* ,

Muse, Stancil & Co., September 2000.

Exhibit 6.6: Prospective Volumes of On-Purpose Downgrading of EPA Diesel at Lowest Cost, 2007
(K b/d)

	PADD			
	1	**2**	**3**	**Total**
Muse, Stancil Estimates	**50 - 60**	**46 - 52**	**25+**	**-**
1. Feedstock to refinery conversion units	0	<6	<20	<26
2. Displacement of low-sulfur diesel from high-sulfur markets	< 10	46	<5	46 - 51
3. Displacement of imports	50	0	0	50
4. Exports to other countries	0	0	"moderate"	"moderate"
5. Net transfers to other PADDs	0	0	0	0
6. Demand growth in local high-sulfur markets	0	0	0	0
MathPro Estimates Adapted from Muse, Stancil	**60 - 90**	**50**	**55 - 75**	**165 - 215**
1. Feedstock to refinery conversion units	0	5	10	15
2. Displacement of low-sulfur diesel from high-sulfur markets	10	45	5	60
3. Displacement of imports	50 - 80	0	0	50 - 80
4. Exports to other countries	0	0	40 - 60	40 - 60
5. Net transfers to other PADDs	0	0	0	0
Off-shore downgrade volume	**50 - 80**	**0**	**40 - 60**	**90 - 140**

Exhibit 6.7: Estimated Diesel Fuel Use in Nearby Export Markets, Export Markets, 1998 & 2007

(K b/d)

Country/ Region	1998	2007	
		Low Growth	High Growth
Atlantic Basin	**437**	**521**	**700**
Mexico	286	331	434
Central America	67	88	125
Caribbean	84	102	141
South America*	**996**	**1,199**	**1,413**
Total	**1,433**	**1,720**	**2,113**

* Excludes Chile

Source: Derived from World Bank data and projections.