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### Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>$ MM</td>
<td>US Dollars, Millions</td>
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<tr>
<td>$, USD</td>
<td>United States Dollar</td>
</tr>
<tr>
<td>ADB</td>
<td>Asian Development Bank</td>
</tr>
<tr>
<td>AEAI</td>
<td>Advanced Engineering Associates International, Inc.</td>
</tr>
<tr>
<td>Afs</td>
<td>Afghani (Afghan Currency Unit, 49 Afs = 1 USD)</td>
</tr>
<tr>
<td>AOFP</td>
<td>Absolute Open Flow Potential</td>
</tr>
<tr>
<td>ASME</td>
<td>American Society for Mechanical Engineers</td>
</tr>
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<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>ATM</td>
<td>Atmospheres</td>
</tr>
<tr>
<td>Bank</td>
<td>The World Bank</td>
</tr>
<tr>
<td>BBL</td>
<td>Barrel</td>
</tr>
<tr>
<td>BCF</td>
<td>Billion Cubic Feet</td>
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<tr>
<td>BCM</td>
<td>Billion Cubic Meters</td>
</tr>
<tr>
<td>BOPD</td>
<td>Barrels of Oil per Day</td>
</tr>
<tr>
<td>BPD</td>
<td>Barrels per Day</td>
</tr>
<tr>
<td>BPSD</td>
<td>Barrels per Stream Day</td>
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<tr>
<td>BTU</td>
<td>British Thermal Unit</td>
</tr>
<tr>
<td>Consultant</td>
<td>Hill International, Inc.</td>
</tr>
<tr>
<td>CSO</td>
<td>Central Statistics Office</td>
</tr>
<tr>
<td>DABM</td>
<td>Da Afghanistan Breshna Moassesa (Afghanistan Electricity Utility)</td>
</tr>
<tr>
<td>DAP</td>
<td>DiAmmonium Phosphate</td>
</tr>
<tr>
<td>DEG</td>
<td>DiEthyleneGlycol</td>
</tr>
<tr>
<td>EPC</td>
<td>Engineering, Procurement and Construction</td>
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<td>FSU</td>
<td>Former Soviet Union</td>
</tr>
<tr>
<td>GT</td>
<td>Gas Turbine</td>
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<td>GTZ</td>
<td>Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Assistance)</td>
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<tr>
<td>GW</td>
<td>Gigawatt</td>
</tr>
<tr>
<td>GWh</td>
<td>Gigawatt-Hour</td>
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<tr>
<td>Hill</td>
<td>Hill International Inc.</td>
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<td>HPP</td>
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</tr>
<tr>
<td>HSFO</td>
<td>High Sulfur Fuel Oil</td>
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<tr>
<td>IBRD</td>
<td>The International Bank for Reconstruction and Development (World Bank)</td>
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<td>ICB</td>
<td>International Competitive Bidding</td>
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<td>IFI</td>
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<td>IOC</td>
<td>International Oil Company</td>
</tr>
<tr>
<td>IRR</td>
<td>Internal Rate of Return</td>
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<td>Full Form</td>
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</tr>
<tr>
<td>ISBL</td>
<td>Inside Battery Limits</td>
</tr>
<tr>
<td>KfW</td>
<td>Kreditanstalt für Wiederaufbau</td>
</tr>
<tr>
<td>KG</td>
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</tr>
<tr>
<td>kW</td>
<td>Kilowatt</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt-hour</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>M³</td>
<td>Cubic Meters</td>
</tr>
<tr>
<td>MMBO</td>
<td>Million Barrels of Oil</td>
</tr>
<tr>
<td>MMBTU</td>
<td>Million British Thermal Units</td>
</tr>
<tr>
<td>MMCF</td>
<td>Million Cubic Feet</td>
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<tr>
<td>MMCM</td>
<td>Million Cubic Meters</td>
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<tr>
<td>MMI</td>
<td>Ministry of Mines and Industry</td>
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<tr>
<td>MMSCF</td>
<td>Million Standard Cubic Feet</td>
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<td>NGO</td>
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<td>p.a.</td>
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<tr>
<td>p.u.</td>
<td>Per unit</td>
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<td>PF D</td>
<td>Process Flow Diagram</td>
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<tr>
<td>PPA</td>
<td>Power Purchase Agreement</td>
</tr>
<tr>
<td>PPM</td>
<td>Parts Per Million</td>
</tr>
<tr>
<td>PRRP</td>
<td>Priority Reform and Restructuring Program</td>
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<tr>
<td>PSI</td>
<td>Pounds per Square Inch</td>
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<td>SCFD</td>
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<tr>
<td>SCMD</td>
<td>Standard Cubic Meter per Day</td>
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<td>Technical Assistance</td>
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<td>Turkmenistan-Afghanistan-Pakistan Gas Pipeline</td>
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<td>Total Installed Cost</td>
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<td>Ton of Oil Equivalent</td>
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<td>TOR</td>
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<tr>
<td>TPY</td>
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<td>USAID</td>
<td>United States Agency for International Development</td>
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<tr>
<td>USD / USc</td>
<td>United States Dollars / cents</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>USTDA</td>
<td>United States Trade and Development Agency</td>
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<tr>
<td>WACC</td>
<td>Weighted Average Cost of Capital</td>
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Table of Conversions

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<td>1 atmosphere</td>
<td>10,333 kgs/sq meter</td>
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<td>1 atmosphere</td>
<td>14.70 pounds per square inch</td>
</tr>
<tr>
<td>1 Bar</td>
<td>0.987 atmospheres</td>
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<tr>
<td>1 Barrel (bbl)</td>
<td>159 liters or 35 imperial gallons</td>
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<tr>
<td>1 BCF</td>
<td>$10^9$ Cubic Feet</td>
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<td>1 BCM</td>
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<td>1 Cubic Meter Diesel</td>
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<td>1 MMBTU</td>
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<tr>
<td>1 MMBTU</td>
<td>0.0283366 MCM = 1 MSCF of Natural Gas</td>
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<tr>
<td>1 MMCF</td>
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<td>1 Normal Cubic Meter per day (NM3/d)</td>
<td>37.33 standard cubic feet per day (SCFD)</td>
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<td>1 Standard Cubic Foot (SCF)</td>
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<td>1.199 MCM Natural Gas</td>
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<tr>
<td>1 USD</td>
<td>49 new Afghanis</td>
</tr>
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The Afghan Calendar

Afghanistan uses the Persian Calendar, which is a solar calendar with a starting point that matches that of the Islamic calendar. Its origin can be traced back to the 11th century when a group of astronomers (including the well-known poet Omar Khayyam) created what is known as the Jalaali calendar.

The current calendar has been used in Iran since 1925 and in Afghanistan since 1957. However, Afghanistan used the Islamic calendar in the years 1999-2002.

As in the Islamic calendar, years are counted since Mohammed's emigration to Medina in AD 622. At vernal equinox of that year, AP 1 started (AP = Anno Persico/Anno Persarum = Persian year).

Note that contrary to the Islamic calendar, the Persian calendar counts solar years. In the year AD 2003 we have therefore witnessed the start of Persian year 1382, but the start of Islamic year 1424.

The Afghan Year is calculated by subtracting 621 or 622 from the Gregorian year. The year 1382 corresponds to the Gregorian 2003-2004 (March 20 – March 21).
1.0 Executive Summary

This task report presents an analysis of Afghanistan’s oil supply and demand, analyzes several potential standalone refinery and combination refinery and power plant projects, and presents the related financial and economic requirements for the efficient exploitation and development of the country’s crude oil resources.

The report begins by presenting an overview and analysis of Afghanistan’s oil reserves, develops several production forecast scenarios in order to establish a reliable supply pattern, and analyzes twenty (20) different cases for crude oil disposition. It should be noted that the Consultant has significantly expanded the scope of work called for in the TOR, which called for the analysis of a 5,000 BPD refinery. During the course of the study, it was felt that a more comprehensive analysis was necessary in order to properly present recommendations for crude oil disposition. The additional effort did not result in any increases to the lump-sum fixed price contract, despite significantly higher man-hours and expenditure on part of the Consultant.

1.1 Introduction

In early 1956, the first wildcat well in Afghanistan was drilled into the Angot structure near Sar-I-Pul, to a depth of 817 meters, and had oil shows in two zones. A second well was drilled in 1957 to a depth of 1,120 meters, and penetrated several oil bearing structures. Subsequent drilling found additional oil reserves in a total of six small fields. Of the six oil discoveries, only the Angot field has been produced to date.

The production of oil, through 1979, was limited to small quantities for local use as unrefined fuel. Subsequently, this Angot oil was processed at a small topping plant in Sheberghan, and supplied some ‘refined’ fuel for the central heating boilers in the cities of Sheberghan, Mazar-E-Sharif and Kabul. However, after the departure of the Soviets in 1989, and the several wars and political disturbances that followed, the topping refining plant was destroyed and plans for a 10,000 bbl/day refinery in Sheberghan were never realized.

Currently, refining of crude oil is through a very primitive artisanal method consisting of heating the oil in several horizontal long retorts. A large rectangular pit is dug next to the well and segmented into compartments with vertical plastic sheeting which serves as a semi-permeable membrane. The upstream compartment is filled with water and the next compartment is filled with produced crude oil. The horizontal force of the water serves to slowly push the crude oil through the membrane away from the water compartment. In the process of passing through his membrane, the crude oil separates into its constituent components based on the direct relationship between molecular size and travel time through the membrane with the lighter products passing through first and floating to the top in a form of gravity separation. This process is repeated several times until at the last chamber, product separation has been reasonably complete. A pit is dug adjacent to the end of the “refinery pit” and delivery port holes have been placed in the downstream wall of the last “refinery pit”. The highest port delivers gasoline, the middle one kerosene and the lowest diesel. At the end of the batch process, after all products have been captured, the residual soaked sand within the pit is recovered and used as boiler or heating fuel.
1.2 Oil Supply Estimates and Production Forecast

There are six discovered oil fields in Afghanistan: Angot, Ak-Darya, Kashkari, Bazar-Kami, Ali Gul and Zamradsay. Of the six oil discoveries, only the Angot field has produced to date.

The total oil-in-place for all six fields is estimated at 48.1 Million Tons (318 MBBO), with approximately 18.5 Million tons (122 MBBO) of this being remaining recoverable (C1+C2)\(^1\).

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Remaining Oil in Place</th>
<th>Recoverable Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MMTons</td>
<td>MMBO</td>
</tr>
<tr>
<td>Angot</td>
<td>3.4</td>
<td>22.4</td>
</tr>
<tr>
<td>Ak-Darya</td>
<td>4.7</td>
<td>31.0</td>
</tr>
<tr>
<td>Kashkari</td>
<td>19.6</td>
<td>129.4</td>
</tr>
<tr>
<td>Bazar-Kami</td>
<td>1.1</td>
<td>7.3</td>
</tr>
<tr>
<td>Ali Gul</td>
<td>5.8</td>
<td>38.3</td>
</tr>
<tr>
<td>Zamradsay</td>
<td>13.5</td>
<td>89.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48.1</strong></td>
<td><strong>317.5</strong></td>
</tr>
</tbody>
</table>


The estimated 20-year production forecast for all five fields involves drilling 187 new wells, 110 during the first 10 years and 77 during the second decade. The average combined production rate for all five fields is estimated at 14,800 BOPD, and is shown in Figure 1-1 below.

\(^1\) The Soviet C1 classification approximately corresponds to SPE classification “Proved Undeveloped, overlapping into Probable”. The Soviet C2 classification approximately corresponds to SPE classification “Probable, overlapping into Possible”.

Figure 1-1: Production Forecast for Five Afghan Oil Fields
Source: Gustavson Report
These reserves, if confirmed, would be sufficient to supply a 10,000 BOPD refining facility for 20 years, but would require the drilling of about 187 new wells over the next 20 years.

Although as accurate as possible given the available information, the reserves and production figures contain a significant degree of uncertainty which can only be resolved by observing well flows as each of the wells are brought on stream. The development scenarios in this task report assume that all production will be via newly drilled wells in the discovered, undeveloped fields.

1.3 Crude Gathering System

Costs for crude oil gathering and related facilities associated with the six oil fields, to collect oil from existing wells, process the oil to remove gas and water and transfer the oil to a refinery located adjacent to the largest Kashkari field, are estimated at $34.1 million, not including contingency, owner’s cost, cost for land, taxes, rights of way, and well development.²

1.4 Refinery Location

The location for the proposed refinery was chosen to be near the largest production field, Kashkari. A sensitivity analysis for location change is included in the report. The net increase in capital costs associated with changing the location of the refinery adjacent to the alternate location at Sheberghan town is estimated at $10.4 million, all of which is due to the additional facilities that would be required at the crude loading and unloading stations if the refinery were to be situated within the Sheberghan city limits rather than close to the production field.

Additional qualitative reasons for recommending that the refinery be located in the field, close to the producing wells, include: (i) elimination of crude oil truck traffic within the city limits, which, with the poor quality of roads will necessitate immediate road improvement expenditures; (ii) environmental pollution problems that the heavy truck traffic would cause and the high probability of a crude oil traffic accident in the city which could result in high environmental clean-up costs; (iii) security - a refinery located in the city is considered less secured and more vulnerable to vandalism and attacks in light of the current security situation in the country; and (iv) the need for the construction of another crude oil storage farm facility around the refinery, a case that will not be necessary for a field-located refinery because the crude oil production storage facilities will be available to serve the needs of the refinery.

The alternative of supplying the refinery with crude through a pipeline was also considered but it was deemed a less reliable source for supply due to security reasons and also because of the high up-front cost required for building such a crude oil pipeline.

1.5 Refinery Cases Analyzed

The Consultant developed and analyzed various combinations of the five base cases listed below:

**Case 1: Maximum Power Generation** - A power plant directly consuming 10,000 BPSD of crude oil.

² Drilling and well development costs are not part of the scope of this report and are being addressed by Gustavson Associates under their activity.
Case 2A: **Atmospheric Crude and Vacuum Distillation** - A 10,000 BPSD simple topping refinery and a power plant.

Case 2B: **Atmospheric Crude and Vacuum Distillation** - A 5,000 BPSD simple topping refinery and a power plant.

Case 3A: **Integrated Refinery (10,000 BPSD)** - A 10,000 BPSD refinery to meet transportation fuel specifications and a power plant.

Case 3B: **Integrated Refinery (15,000 BPSD)** - Identical to case 3A, with a 15,000 BPSD capacity.

The report for each case provides process configurations, block flow diagrams, plot plan requirements, utilities systems, offsites and infrastructure, capital cost estimates, operating costs, production volumes and electricity generated. All cost information was based upon U.S. Gulf Coast mid-2004 pricing, and Afghan pricing adjustment factors were considered. Estimates are at a conceptual estimate level, with a +/- 30% tolerance.

The different capacities of the refineries studied were 5000 bpd, 10,000 bpd and 15,000 bpd. From a demand perspective, the 15,000 bpd case better matches the current requirements for products in Afghanistan. From a reservoir management perspective, The 10,000 bpd option better matches the producibility of crude reserves to reliably sustain a refinery for 15 years, using crude from selected reservoirs, without resorting to an aggressive field development and production plan.

Crude quality is the most important variable in defining a refinery configuration. For this study, we were only able to obtain a small crude sample from the Angot field (23.6 API and 2.65% wt Sulfur). It is recommended that a full assay be performed on the Kashkari and other crudes, once the shut-in wells have been reopened, as the actual crude yields would need to be estimated from actual crude assays and would affect the economics.

The information on Kashkari and other fields’ reserves indicates oil quality ranging from 33.99 API to 21.47 API and Sulfur levels from 0.93% to 2.99% wt. Given these large variations, we used the crude analysis performed on the Angot crude, and included in our estimates a factor of 5-15% incremental investment to process lighter crudes and higher sulfur crudes.

The product yields in the analyses were based on Angot crude yields. Due to the heavy nature of the crude oil, simple crude distillation yields a significant (64.2%) amount of high sulfur fuel oil (HSFO). HSFO is valued at approximately 75% of the value of crude internationally, thus refineries which produce large quantities of residue need to convert it to more valuable products. Given the small size of the refinery it was considered that a sophisticated conversion processing approach using coking or hydrocracking of the residue would add significant investment and not be economically attractive given the incremental margins.

Afghanistan does not currently have power stations that can use the HSFO, and so a large percentage of the refinery’s product would have to be exported under this scenario. There is very little use for HSFO in neighboring countries, so this nets a very low value for fuel oil.

We have therefore recommended maximized disposition of residue in Afghanistan as follows:
1. Produce asphalt from the bottom of the vacuum tower in cases 2A and 2B. This would be done primarily during the summer, so this operation is termed the ‘summer case’. The operation when asphalt is not produced is termed the ‘winter case’. When the asphalt is not produced as a product, it becomes part of the fuel oil for the power plant. The fuel oil to the power plant is a blend of the naphtha and the vacuum gas oils in the summer case, and a blend of the naphtha, vacuum gas oils, and the vacuum bottoms in the winter case. Asphalt production frees distillate from fuel oil and the resulting product is more valuable than fuel oil in our price scenario by about 30%, given the low net back obtained from fuel oil when exported to Pakistan.

2. Use all non-converted residues as fuel for a power plant located adjacent to the refinery. Given the urgent and acute need for power in Afghanistan, we believe that local use of HSFO is a far better option than exporting the product. Therefore, all cases studied in this report consider an integrated power plant in addition to the refinery. The economic analysis considers both the standalone and integrated cases.

3. We considered visbreaking as the lowest cost conversion process to convert residue into more valuable transportation fuels. We included visbreaking in cases 3A and 3B to reduce fuel oil production from 64.2% to 39.5%. The configuration of the refinery in this case is more complex, as we need to hydrotreat the distillate cuts in order to meet product specifications.

1.6 Crude Pricing

The consultants have used a base case average crude oil price projection corresponding to the “World Bank Average” ("WBA") crude basket (which was approximately equivalent to WTI minus $1 per bbl in 2003) averaged over the last five years, equal to 25.80$/bbl. The derived equivalent price of Afghan crude oil for this base case is equivalent to $17.57/bbl at the refinery gate. Given that no samples of Afghan crude other than Angot are currently available due to inaccessibility of wells, the consultant considers this is a reasonable approximation of the value of Afghan crude based on published historical data for similar quality crudes.

In addition to the base crude case described above, a protracted high crude oil price scenario using recent (May 2004) crude oil prices corresponding to a steady WBA price of $34.80$/bbl was considered. The price of the exported Afghani crude oil for this case is equivalent to $26.57/bbl at the refinery gate.

<table>
<thead>
<tr>
<th>Crude</th>
<th>Base Price</th>
<th>High Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank Average Oil Price</td>
<td>25.80</td>
<td>34.80</td>
</tr>
<tr>
<td>Differential (WB-Arabian Heavy)</td>
<td>-3.70</td>
<td>-3.70</td>
</tr>
<tr>
<td>Arabian Heavy 27º</td>
<td>22.10</td>
<td>31.10</td>
</tr>
<tr>
<td>Differential (to 23º Angot)</td>
<td>-1.50</td>
<td>-1.50</td>
</tr>
<tr>
<td>Afghan Crude at Seidy refinery</td>
<td>20.60</td>
<td>29.60</td>
</tr>
<tr>
<td>Differential (Transportation)</td>
<td>-3.03</td>
<td>-3.03</td>
</tr>
<tr>
<td>Afghan Crude at Sheberghan</td>
<td>17.57</td>
<td>26.57</td>
</tr>
</tbody>
</table>

Figure 1-2 below shows the various crude oil price projections for both the base case and high price scenarios.
1.7 Petroleum Product Pricing and Demand

The World Bank’s historical correlation between products and crude oil was used as the conversion factor to determine forecast petroleum product prices, applied to the WBA crude price. Transportation costs\(^3\) to Sheberghan were then factored in to obtain what would represent projected prices at the new refinery gate in Sheberghan. For export of fuel oil from Sheberghan to Pakistan, we have assumed international fuel oil prices in Islamabad less transportation costs to Sheberghan, based on the assumption that Turkmenistan, Uzbekistan and Iran would not provide a market for HSFO.

In order to confirm the validity of this projection, the projected product price differentials were then applied to the High Price Scenario, the appropriate transportation costs applied, and the resulting projected prices were compared to current Afghanistan market prices for petroleum products. The results were within +/- 10% of product prices obtained from the Consultant’s product price surveys in Kabul, Mazar-E-Sharif and Sheberghan\(^4\). The only substantial exception to this rule is jet fuel, which is currently selling in Kabul for almost $500 per ton, significantly higher than gasoline at an average of $430 per ton, and not in line with the historical correlations (or conventional market pricing).

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\(^3\) Transportation costs within Afghanistan were determined from an in-country survey of transportation companies and individual transporters. The routes in the survey included Sheberghan-Mazar, Mazar-Kabul, Kabul-Pakistan Border, Sheberghan-Heart, Heart-Pakistan Border, Sheberghan-Turkmenistan Border, and Heart-Iran Border. Although the prices varied among suppliers, they generally were in the range of USD 0.07 per kilometer-ton.

\(^4\) A product price survey was performed to determine both wholesale and retail prices of petroleum products in Kabul, Sheberghan and Mazar-E-Sharif. It was interesting to note that products varied not only by type, but also by origin; that is, diesel fuels of different origins had slightly different prices, even though the provenance was not easily established, nor the quality of the fuel easily determined.
The results of the survey of Afghanistan product prices, together with a comparison to the projected sales price of products from the financial model under the High Price (equivalent to current oil prices) is shown in tables 1-C and 1-D below.

**Table 1-C: Survey of Afghanistan Petroleum Product Prices (USD)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Diesel</th>
<th>Kerosene</th>
<th>Petrol (Gasoline)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran/Afghanistan Border</td>
<td>340</td>
<td>0.29</td>
<td>430 0.32</td>
</tr>
<tr>
<td>Turkmenistan/Afghanistan</td>
<td>330</td>
<td>0.28</td>
<td>450 0.33</td>
</tr>
<tr>
<td>Pakistan/Afghanistan Border</td>
<td>316</td>
<td>0.27</td>
<td>451 0.33</td>
</tr>
<tr>
<td>GTZ data - Kabul</td>
<td>320</td>
<td>0.27</td>
<td>461 0.34</td>
</tr>
<tr>
<td>GTZ data - Sheberghan</td>
<td>340</td>
<td>0.29</td>
<td>460 0.34</td>
</tr>
</tbody>
</table>

**Table 1-D: Comparison of Model Prices (High Price) vs. Actual Afghanistan Prices**

<table>
<thead>
<tr>
<th>Product</th>
<th>Projected Model Prices</th>
<th>Kabul Prices</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>$426.93</td>
<td>$460.00</td>
<td>7.2%</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>$380.14</td>
<td>$500.00</td>
<td>24.0%</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>$344.43</td>
<td>$340.00</td>
<td>-1.3%</td>
</tr>
<tr>
<td>Kerosene</td>
<td>$335.63</td>
<td>$300.00</td>
<td>-11.9%</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>$213.31</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Asphalt</td>
<td>$258.67</td>
<td>$240.00</td>
<td>-7.8%</td>
</tr>
<tr>
<td>High Octane</td>
<td>$537.37</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
The Consultant used several sources to obtain demand information for primary refinery products. Through interviews with wholesale importers, donor organizations, published research and other available data, the annual demand for petroleum products was established at approximately 17,000 BPD, or 940,000 TPY of crude oil. (Interviews with the Ministry of Mines and Energy, and the Ministry of Planning place demand at approximately 600,000-800,000 TPY (10,800-14,500 BPD)). The Draft Norconsult study, using CSO figures, estimates and projects demand at 985,000 TPY (17,500 BPD) of products.

The Consultant was not able to obtain good regional demand numbers. We have assumed, therefore, that urban fuel demand has a direct correlation to urban population.

The Consultant has used the demand figures from the CSO and assumed that the slate of products will also remain similar.

1.8 Results of the Economic Analysis

The summary of investment costs for each of the cases considered is shown in table 1-E on the following page. The additional costs for meeting World Bank Environmental Guidelines have been included in the financial analyses, and are shown here as a separate line item.

The key assumptions behind the methodology used to compare the eighteen refinery and integrated refinery/power plant cases are listed below:

1. The export price for crude oil at Sheberghan was calculated to be $17.57 /bbl for the base case and $26.57 /bbl for the high crude price scenario.
2. The sale price of electricity was assumed to be 7 cents per KWh. The benchmark price in northern Afghanistan is 2-3 cents per kwh, which is the current price of imported power (2.3 cents/kwh) and the estimated price of electricity generated from the gas-fired power plant planned in Sherberghan would be about 3 cents /kwh. Because the power from crude oil will be competing with imported power as well as power generated by the gas-fired power plant, this price assumption makes the power from crude oil uneconomic and makes it at best a long-term project (if and when all other cheap sources of power including coal, are exhausted).
3. A discount rate of 11.5% for all cases
4. All projections and DCF calculations were performed assuming a 15-year life.
5. The net back price for crude oil at the refinery gate was calculated in order to cover all operating costs and the cost of capital.
6. The net back price of crude oil was compared with the value of the crude exported to determine if it is higher or lower than this export value. The difference is the value created or destroyed by the refinery or power plant as compared to exporting the crude oil.
7. Capital Investment costs were assumed to be equal to US Gulf Coast (with contingency of about 30%). Although location factors could have been considered, there is no reliable data source for determining such
location factors for Afghanistan, and just applying a higher location factor would only serve to make the investments less feasible.

The project economic model’s results are depicted in Table 1-F.
Table 1-E – Summary of Refinery Investment Costs

<table>
<thead>
<tr>
<th>Case</th>
<th>1 Power Plant</th>
<th>2a 10,000 bpd with Asphalt</th>
<th>2a 10,000 bpd without Asphalt</th>
<th>2b 5,000 Bpd</th>
<th>3a 10,000 bpd refinery</th>
<th>3b 15,000 bpd refinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity, BPSD</td>
<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
<td>5,000</td>
<td>10,000</td>
<td>15,000</td>
</tr>
<tr>
<td>Power Plant Capacity, MW</td>
<td>226</td>
<td>141</td>
<td>141</td>
<td>71</td>
<td>93</td>
<td>140</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet Fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide-Cut Diesel / Diesel Fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.0</td>
<td>10,000</td>
<td>10,000</td>
<td>5,000</td>
<td>10,074</td>
<td>15,112</td>
</tr>
<tr>
<td>Export Power, MW</td>
<td>203.6</td>
<td>130.9</td>
<td>130.9</td>
<td>65.4</td>
<td>77.6</td>
<td>115.9</td>
</tr>
<tr>
<td><strong>Investment Costs:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery</td>
<td>1,600</td>
<td>(Desalting)</td>
<td>41,900</td>
<td>22,700</td>
<td>34,500</td>
<td>107,000</td>
</tr>
<tr>
<td>Power Plant</td>
<td>153,700</td>
<td>113,200</td>
<td>113,200</td>
<td>62,700</td>
<td>73,400</td>
<td>110,500</td>
</tr>
<tr>
<td>Cooling Water System</td>
<td>900</td>
<td>1,100</td>
<td>900</td>
<td>600</td>
<td>2,000</td>
<td>2,900</td>
</tr>
<tr>
<td>Tank Farm Storage</td>
<td>7,800</td>
<td>27,200</td>
<td>21,400</td>
<td>13,600</td>
<td>41,900</td>
<td>54,800</td>
</tr>
<tr>
<td>Offsites</td>
<td>31,100</td>
<td>40,900</td>
<td>33,300</td>
<td>28,600</td>
<td>59,300</td>
<td>74,900</td>
</tr>
<tr>
<td><strong>Total Refinery and Offsites</strong></td>
<td>1,600</td>
<td>90,400</td>
<td>57,500</td>
<td>62,800</td>
<td>193,400</td>
<td>244,900</td>
</tr>
<tr>
<td><strong>Total Power Plant and Offsites</strong></td>
<td>193,500</td>
<td>133,900</td>
<td>133,900</td>
<td>77,200</td>
<td>90,100</td>
<td>131,100</td>
</tr>
<tr>
<td>Environmental Costs to meet WBEAG - Refinery</td>
<td>0</td>
<td>3,000</td>
<td>3,000</td>
<td>2,000</td>
<td>8,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Environmental Costs to meet WBEAG – Power Plant</td>
<td>47,000</td>
<td>38,000</td>
<td>38,000</td>
<td>17,600</td>
<td>25,000</td>
<td>36,000</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td>242,100</td>
<td>265,300</td>
<td>232,400</td>
<td>159,600</td>
<td>316,500</td>
<td>421,000</td>
</tr>
</tbody>
</table>

*Source: Refinery Analysis*
### Table 1-F – Summary of Financial and Economic Analysis (All Figures in USD Thousands)

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2A</th>
<th>2B</th>
<th>3A</th>
<th>3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Power Plant</td>
<td>Refinery</td>
<td>Refinery + Power Plant</td>
<td>Refinery + No Asphalt</td>
<td>Refinery Power Plant</td>
</tr>
<tr>
<td>Capacity, BPSD</td>
<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Power Plant Capacity, MW</td>
<td>226</td>
<td>0</td>
<td>141</td>
<td>141</td>
<td>0</td>
</tr>
<tr>
<td>Export Power, MW</td>
<td>204</td>
<td>0</td>
<td>131</td>
<td>131</td>
<td>0</td>
</tr>
<tr>
<td>Investment, $MM</td>
<td>242</td>
<td>104</td>
<td>265</td>
<td>233</td>
<td>76</td>
</tr>
<tr>
<td>Annual Operating Costs, $MM</td>
<td>11</td>
<td>7</td>
<td>15</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Annual Cost of Natural Gas, $MM</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

#### 1) Base Case Pricing Scenario

| Crude Oil price, $/BBL | 25.80 |
| Afghans Mix, $/BBL (Seidi) | 20.60 |
| Afghans Mix, $/BBL (Refinery Gate Sheberghan) | 17.57 |
| Netback at refinery, $/BBL | 20.39 | 14.34 | 17.57 |
| Project IRR (15-year period) | 19.2% | -2.6% | 14.1% |
| Values required to obtain netback equal to Afghan Mix at Refinery Gate | 304 | 34 | 263 |
| Investment, $MM | 6.43 | N/A | 7.04 |
| Price of electricity, $ cent/Kwh | N/A | 8.10 | N/A |

#### 2) Current Pricing Scenario

| Crude Oil price, $/BBL | 34.80 |
| Afghans Mix, $/BBL (Seidi) | 29.60 |
| Afghans Mix, $/BBL (Refinery Gate Sheberghan) | 26.57 |
| Netback at refinery, $/BBL | 20.39 | 22.66 | 23.05 |
| Project IRR (15-year period) | 1.2% | -8.5% | 7.1% |
| Values required to obtain netback equal to Afghan Mix at Refinery Gate | 107 | 19 | 173 |
| Investment, $MM | 8.25 | N/A | 8.32 |
| Price of electricity, $ cent/Kwh | N/A | 9.39 | N/A |
The model’s results indicate that besides the Power Plant only option, which has the highest return of 19.2% IRR, Case 2A is the most likely economic and financially viable option. This is the case for the construction of a 10,000 BOPD simple refinery (topping plant) with or without asphalt capability:

- For Case 2A without the vacuum distillation unit, the refinery cost including all offsites is $57.5 M, the 141 MW (131 MW Net Export) power plant cost is $133.9 MM, for a combined cost of $191.4 MM, which would increase to $232.4 MM with the addition of WBEAG environmental mitigation costs.

- For Case 2A with the vacuum distillation unit, the refinery cost including all offsites is $90.4 M, the 141 MW (131 MW Net Export) power plant cost is $133.9 MM, for a combined cost of $224.3 MM, which would increase to $265.3 MM with the addition of WBEAG environmental mitigation costs.

Highlights of the results of the financial and economic analysis to support this recommendation are as follows:

For the base price scenario, 17.57 $/BBL export price:

- The best net back option is $19.29 /bbl corresponding to a simple 10,000 BPD refinery integrated with a power plant that consumes the produced fuel oil (case 2A, integrated refinery and power plant) without asphalt production capabilities. The next best net back option is the same case 2A with the vacuum distillation tower for asphalt production, at $17.46 /bbl.

- None of the standalone refineries can pay the export crude value. The best case is 2A (Simple 10,000 BPD refinery) which can pay $14.34 /bbl for the crude oil.

For the high price scenario, 26.57 $/BBL export price:

- None of the cases can pay the export crude oil value under the high price scenario.

1.9 Product Mix

Cases 2A and 3B were evaluated against the current Afghan demand for petroleum products. In all cases, current demand was significantly higher than the refinery supply. It should be kept in mind that the current levels of product consumption are distorted by the high volume of diesel fuel being imported for power generation. It is anticipated that gas-fired generators will somewhat decrease this volume in the future.
Table 1-G – Refinery Production Compared to Afghan Product Demand

<table>
<thead>
<tr>
<th></th>
<th>Refinery Supply by Case</th>
<th>Refinery Supply by Case</th>
<th>Refinery Supply by Case</th>
<th>Refinery Supply by Case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Projected Product Demand</td>
<td>Refinery (Summer)</td>
<td>Refinery (Winter)</td>
<td>Refinery (Summer)</td>
</tr>
<tr>
<td>Capacity, BPSD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Products (BBL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td>2200</td>
<td>2550</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>3700</td>
<td>4700</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>Kerosene &amp; Jet Fuel</td>
<td>2800</td>
<td>3700</td>
<td>5200</td>
<td></td>
</tr>
<tr>
<td>Wide-Cut Diesel / Diesel Fuel / Fuel Oil</td>
<td>15,600</td>
<td>23,900</td>
<td>36,800</td>
<td>7,220</td>
</tr>
<tr>
<td>Asphalt</td>
<td>4,000</td>
<td>4,500</td>
<td>5,000</td>
<td>2,780</td>
</tr>
<tr>
<td>Total</td>
<td>28,300</td>
<td>39,350</td>
<td>56,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

Source: Securing Afghanistan’s Future; Consultant’s Projections and Refinery Analysis

1.10 Product Pricing

In some sense, the issue of government product pricing policy has already been resolved in Afghanistan through a reasonably well-functioning market for refined oil products. The current system, a combination of both normal product imports and a “grey market” of small scale subsidized oil imports from Iran and Turkmenistan, yields prices that offer little scope for arbitrage within the country. The consultants recommend that the government not attempt to control or otherwise manipulate the prices paid for refined oil products.

1.11 Environmental

Several refinery options have been presented in this report. The Consultant recommends that the Government considers a refinery option, such as case 2a, as a means of utilizing its crude oil reserves, because of the overall positive impact on the environment as compared to the current situation:

- Reducing the overall transportation requirements of products within Afghanistan.
- Providing a substantial portion of the consumed products with a clear specification, setting a national standard for what product qualities should be, and raising the standard of quality for the consumer.
- Reducing a large number of the small generators that use nafta or diesel for small electricity demands, by having a thermal power plant that is part of a national power grid.
- Eliminating primitive crude oil refining techniques (artisanal refining) that are conducive to water and soil pollution and a safety hazard.

5 The slight imbalance is due to additional input of natural gas to the hydrogen plant, less vented carbon dioxide.
• Limiting any emissions to the refinery site, which is almost uninhabited, versus the current practice of transferring the emissions to the consumer.

1.12 Conclusions and Recommendations

On the basis of the above analysis, a new refinery unit, in particular, either standalone or in conjunction with Power Plant is very difficult to justify using economic criteria acceptable to foreign investors. Furthermore, given recent trends in IFI financing, concessionary financing from these sources for this type of investment is probably not likely.

While Afghanistan, as a devastated, landlocked country with few developed natural resources, importing close to a million tons per year of fuel (representing foreign exchange payments of over $300,000,000 per year) does not fall into any traditional categories, and may require unique consideration assistance needs to be provided in determining the likely options for the utilization of its crude.

Various crude oil disposition options were considered, including:

(1) Leave the crude oil in the Ground, and continue to have it pilfered, refined primitively and burnt, at a loss to the country.

(2) Burn the Crude in a Power Plant at an investment of $242 MM for a 204 MW plant at a 10,000 bpd rate, although this power plant may be downsized to a lower daily processing rate at a reduced investment cost. However, this is not as economic as producing the power from gas;

(3) Export the Crude, either selling it or paying a refining fee and receive refined products, or barter it for other products, e.g. urea. All of these export options, however, have a high risk of security and pilferage. The shortcomings of this option are the need to develop crude transportation infrastructure, provide adequate security against pilferage of refined products; and

(4) Build a Refinery or Refinery/Power Plant Combination, as discussed above. Among the various refining options considered, this last option, consisting of a 10,000 BOPD refinery with Power plant combination seems the most viable option because the power plant provides the option for the disposition of fuel oil that would be produced as part of the refinery slate. However, such a refinery is small and does not benefit from economy of scale; and at an estimated cost of $ 224 million ($ 90.4 million for the refinery and $ 134 million for a 140 MW power plant), such a refinery can only be economically feasible assuming a low cost of crude ($ 17/barrel), a high cost of power generation (at about $0.07/kwh) and significant government subsidy in form of low cost of capital. Furthermore, even at a high electricity price of $0.07/kwh at the power plant gate, the economics of this project are at best marginal. As such, this can only be a long term project, and economically viable only (if and when all other cheap sources of power including coal, are exhausted).

(5) In addition, further work needs to be done to firm up the reserve of crude. In this regard a refinery investment is not considered a priority in the short-term. Its viability could however be re-evaluated in the future when there are confirmed increases in oil reserves/production to justify a more economic size. While the country continues to import products, the
consultant recommends that the government establish a regulating and monitoring agency to ensure the quality and standard of products being imported.

However, if at a later date, options other than leaving the crude in the ground be considered, the Consultant has prepared the following list of recommendations that can be implemented prior to committing the substantial funds required for a refinery or refinery/power plant combination.

1.12.1 Verify Oil Quality and Reserves

- Given the uncertainty surrounding reserves and qualities of the crudes, a parallel effort to more accurately define the reserves and production capabilities should be undertaken. All fields with wells should have the wells flows observed and more accurate flow and pressure data taken. Crude assays of all crudes should be obtained to determine if the configuration selected in this report could be improved for more value creation. The Consultant believes that the refinery returns could improve using the lighter crudes (27+ API in the case of Kashkari) versus Angot (23.6 API).

1.12.2 Consider crude production and export strategy

- A crude production and export strategy should be evaluated to determine if the crude could be exported as a means of generating revenue from this resource. A crude processing agreement could be considered with the Seidy refinery in Turkmenistan. This will define more clearly the actual international price of the crude oil, and the real value of segregating different oils for export or domestic use. Barter for either refined products or alternates such as fertilizer is an ideal way of realizing immediate value for the crude and reducing the amount of foreign exchange paid out for imports.

1.12.3 Update Refinery sizing and configuration study

- With new reserves and production information, the refinery capacity, configuration and economics should be updated to confirm the validity of the recommendations outlined here.

1.12.4 Analyze ways of reducing transportation costs

- Road transportation costs in Afghanistan are currently very high, due partly to the poor state of the road infrastructure as well as to security concerns. Transportation cost as a percentage of cargo value for petroleum product transportation is substantially higher than in neighboring countries, resulting in abnormally high premiums for refined products transportation.
- The cost and modes of transportation from Sar-i-Pul to the Seidy Refinery should be analyzed in more detail. Given the partial rail link between the
refinery and the town of Kerki near the Afghan border, consideration should be given as to whether extending the rail link to Sheberghan and the Sar-I-Pul area can be economically justified. The Consultant estimates that at a rough cost of US $1 MM per mile of railway, the additional investment of approximately $140 MM may not justify a reduction of $2-$3 per barrel in the cost of transport (equivalent to US $10.9-$16.4 MM per annum assuming return trips carrying 15,000 BPD each way) to Seidy. However, opportunities may exist in involving the Turkmen refinery or government in the project, using lower cost Turkmen or Uzbek rail contractors (or other regional contractors), or increasing the economic value of the railway by adding on the benefits of transporting other cargo across the route.

1.12.5 Analyze cost reduction options, including pre-owned units

The consultant recommends that additional methods and approaches to achieving the lowest capital cost possible and improved logistics for equipment installation for each case be explored.

- **Refinery Process Units:** Maximally utilize modularization techniques for plant construction. Also, strongly consider purchasing pre-owned equipment, which can then be modularized into small modules for ease of transport and installation.

- **Power Plant:** Evaluate utilizing gas turbines (Diesel) instead of steam turbines to burn the heavy crude and residual oil streams to produce electricity. A few vendors have given preliminary feedback that this may be possible. The TIC is approximately $600,000 to $700,000 /Megawatt for a power plant based upon gas turbine technology versus $900,000 to $1,000,000 /Megawatt for a conventional steam based electrical plant.

- **Investigate Pre-Owned Plants:** There are significant cost advantages to slightly used plants or plant elements. Such relocations are routinely done and guarantee and performance concerns addressed in various ways. Refer to the article entitled "Effective Relocation of Existing Refining Units", by G. Grame and D. Posey which is included in Appendix E of this report.
2.0 Terms of Reference

The key sub tasks under the TOR for this activity are as follows:

- Estimate the current and potential future reserves and production of crude oil from the northern Afghanistan oil fields, and define the potential supply capabilities that should justify the refinery design basis;

- Evaluate the pattern for the supply/demand of refined petroleum products in Afghanistan;

- Analyze potential locations for the refinery taking into consideration cost minimization of all aspects of the Total Cost Chain from well-head to final consumer delivery, and recommend an optimum location for the refinery;

- Prepare a conceptual refinery processing scheme including crude oil gathering and delivery to the refinery and allowing for supporting off-sites and provision for product storage and dispatch, in line with the consumption pattern and state of refined products in Afghanistan, with a particular focus on the Northern Region, where it is likely that all such refinery products would be consumed;

- Prepare capital and operating cost estimates for the refinery and crude oil gathering and delivery facilities based on the conceptual design;

- On the basis of the above analysis, prepare overall economics to justify the construction of the refinery, with a capacity of about 5,000 BOPD, and compare the cost of locally refined petroleum products relative to imported products into Afghanistan;

- Design an appropriate pricing policy for the petroleum products to ensure viability of the refinery;

- Identify potential sources of financing and provide an analysis of alternative options of financing the project by the private sector;

- Provide a preliminary environmental assessment of the operation of the refinery, taking into account the environmental and social impact of current operations that the refinery would replace; and

- Provide a report that summarizes the results of the analysis of the above tasks including the recommended options of the next steps needed to implement and fund the project.

A copy of the Bank TOR is included in this Section.
AFGHANISTAN
EVALUATION OF INVESTMENT OPTIONS FOR THE DEVELOPMENT OF OIL AND GAS INFRASTRUCTURE
(Trust Fund # 030397)

B. Terms of reference for the construction of a small sized crude oil refinery (Capacity <5000BOPD)

Background

B1. Crude oil produced at the Angot field in the northern Sar-I-Pol province was initially processed at a small topping plant in Shebergan, and supplied ‘refined’ fuel for the central heating boilers in the cities of Shebergan, Mazar-I-Sharif and Kabul. However, after the departure of the Soviets in 1989, and the several wars and political disturbances that followed, the level of oil and gas production has declined, the facilities were not maintained (in some cases parts of some of the facilities were destroyed), and efforts towards further oil and gas exploration and development work as well as plans to build a 10,000 barrels/day (1360 metric tons/day) refinery near Shebergan were halted. The topping refining plant was destroyed during the wars and currently, refining of crude oil is through a very primitive method consisting of heating the oil in several horizontal 15 meters long retorts. Currently, major source of supply of petroleum products is through imports from surrounding countries of Tajikistan and Pakistan. The importation is handled by several small local entrepreneurs under minimum or no government control, monitoring (for quality) and management.

B 2. In order to standardize the quality of refined products in the country and also reduce dependence on imports, the government would like to centralize and upgrade the crude processing efforts through the construction of a small refinery of capacity 1000-5000 barrels per day (or equivalent to 136-700 metric tons/day) by the private sector.

Objective of Study

B 3. The objective of the study is to evaluate the economic and financial justification for constructing an adequately sized refinery to satisfy the demand for refined petroleum products in Afghanistan.

Scope of the study

B 4 The scope and components of the study include:

- Review of the current and future potential of oil production in the Northern Region of Afghanistan;

- Definition of the optimum size, location, configuration and cost of an adequately sized refinery based on current and future supply/demand of refined products in Afghanistan;

- Justification of the rationale for constructing the refinery by comparing the cost of the locally refined products with imports;

- Development of a strategy for the construction, financing and management of the refinery by the private sector, if proven to be viable.
Proposed Methodology:

B 5. The consultant would be expected to:

(i) estimate the current and potential future reserves and production of crude oil from the northern Afghanistan oil fields, and define the potential supply capabilities that should justify the refinery design basis;

(ii) evaluate the pattern for the supply/demand of refined petroleum products in Afghanistan;

(iii) analyze potential locations for the refinery taking into consideration cost minimization of all aspects of the Total Cost Chain from well-head to final consumer delivery, and recommend an optimum location for the refinery;

(iv) prepare a conceptual refinery processing scheme including crude oil gathering and delivery to the refinery and allowing for all supporting off-sites and provision for product storage and dispatch, in line with the consumption pattern and slate of refined products in Afghanistan;

(v) prepare capital and operating cost estimates for the refinery and crude oil gathering and delivery facilities based on the conceptual design;

(vi) on the basis of the above analysis, prepare overall economics to justify the construction of the refinery, with a capacity of about 5000BOPD, and compare the cost of locally refined petroleum products relative to imported products into Afghanistan;

(vii) design an appropriate pricing policy for the petroleum products to ensure viability of the refinery;

(viii) identify potential sources of financing and provide an analysis of alternative options of financing the project by the private sector;

(ix) provide a preliminary environmental assessment of the operation of the refinery, taking into account the environmental and social impact of current operations that the refinery would replace; and

(x) provide a report that summarizes the results of the analysis of the above tasks including the recommended options of the next steps needed to implement and fund the project.
### 3.0 Oil Supply

#### 3.1 Afghan Oil Reserves

In early 1956, the first wildcat well in Afghanistan was drilled into the Angot structure near Sar-I-Pul, to a depth of 817 meters, and had oil shows in two zones. A second well was drilled in 1957 to a depth of 1,120 meters, and penetrated several oil bearing structures. Subsequent drilling found additional oil reserves in a total of six small fields. Of the six oil discoveries, only the Angot field has been produced to date.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Oil in Place MMTons</th>
<th>Oil in Place MMBO</th>
<th>Recoverable Reserves MMTons</th>
<th>Recoverable Reserves MMBO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angot</td>
<td>3.4</td>
<td>22.4</td>
<td>2.2</td>
<td>14.2</td>
</tr>
<tr>
<td>Ak-Darya</td>
<td>4.7</td>
<td>31.0</td>
<td>2.0</td>
<td>13.2</td>
</tr>
<tr>
<td>Kashkari</td>
<td>19.6</td>
<td>129.4</td>
<td>6.8</td>
<td>45.0</td>
</tr>
<tr>
<td>Bazar-Kami</td>
<td>1.1</td>
<td>7.3</td>
<td>0.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Ali Gul</td>
<td>5.8</td>
<td>38.3</td>
<td>2.0</td>
<td>13.2</td>
</tr>
<tr>
<td>Zamradsay</td>
<td>13.5</td>
<td>89.1</td>
<td>5.0</td>
<td>33.0</td>
</tr>
</tbody>
</table>

**Total**

<table>
<thead>
<tr>
<th>Oil in Place MMTons</th>
<th>Oil in Place MMBO</th>
<th>Recoverable Reserves MMTons</th>
<th>Recoverable Reserves MMBO</th>
</tr>
</thead>
<tbody>
<tr>
<td>48.1</td>
<td>317.5</td>
<td>18.5</td>
<td>122.0</td>
</tr>
</tbody>
</table>

*Source: ADB Report, Gustavson Report*

Currently, the total oil-in-place for all six fields is estimated at 48.1 Million Tons (318 MMBO), with approximately 18.5 (122 MMBO) Million tons of this being remaining recoverable (C1+C2).
The production of oil, through 1979, was limited to small quantities for local use as unrefined fuel. Subsequently, this Angot oil was processed at a small topping plant in Sheberghan, and supplied some ‘refined’ fuel for the central heating boilers in the cities of Sheberghan, Mazar-E-Sharif and Kabul. However, after the departure of the Soviets in 1989, and the several wars and political disturbances that followed, the topping refining plant was destroyed and plans for a 10,000 bbl/day refinery in Sheberghan were never realized. Currently, refining of crude oil is through a very primitive artisanal method consisting of heating the oil in several horizontal long retorts (see inset).

3.1.1 Producing fields

Angot – The field area is 3.3x1.8km in area and lies 65 km SE of Sheberghan. Overlying the basement is a Cretaceous sandstone reservoir, in which the producing horizon is at a depth of 1035-1092m. The reservoir has 21% porosity, and an oil saturation of 0.97%. The currently producing reservoir pressure is 1.39 atm and its temperature is 53C. The oil is heavy with a density is 0.914, and a sulfur content of 2.86%. Angot was originally productive from several horizons, but is now only producing from the shallow horizons because of higher pressures in the deeper levels.

3.1.2 Non producing fields

The oils from these fields are similar in their chemical nature and are related to the natural gas deposits which have been discovered within the sedimentary basin; the fields are located along the southern basin margin. In general, the oil is heavy, low gravity and has migrated SE, out of the Caspian trough, towards the mountains.
### Table 3-B: Summary of Afghan Oil Reserves

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ak-Darya</td>
<td>Discovered in 1974 at TD of 5,000'; APIs 21.5, 26.5, and 38.5</td>
</tr>
<tr>
<td>Kashkari</td>
<td>Discovered in 1976, close to the Angot field. Ten wells have been drilled to depths ranging from 1427 to 1865 meters. There are four limestone reservoirs of Albian and Hauterivian age (Cretaceous). APIs 27.7 and 33.9</td>
</tr>
<tr>
<td>Bazar Kami</td>
<td>Discovered in 1977 at a TD of 3182'; API 33.8</td>
</tr>
<tr>
<td>Zamradsay</td>
<td>Discovered in 1978 at a TD of 2,500'; API 28</td>
</tr>
<tr>
<td>Ali Gul</td>
<td>Discovered in 1977 at a TD of 3182'; API 33.8</td>
</tr>
</tbody>
</table>

Source: ADB Report, Sproule Associates Report

### 3.1.3 Kashkari Oil Field

Of the six discovered fields, the Kashkari field is the largest, with over 19 million metric tons of oil in place believed to be present. As with the non-produced gas fields, there are no production records in any of the oil fields, including the Kashkari field. The only production data acquired were the initial production test data. In addition to this were the Soviet estimates of the estimated original oil in place and recovery factors for each of the productive reservoirs.

The Kashkari oil field is located south of the town of Sar-i-Pul, was discovered in 1976 and is a relatively narrow elongate anticline occupying an area of 12.5 square kilometers. A total of 10 wells have been drilled on the structure, all of which were drilled to the Hauterivian reservoir horizon. Of these, six wells encountered recoverable oil in the primary Cretaceous age Hauterivian reservoir and in the shallower Albian reservoir, also of Cretaceous age. Four of the wells were apparently below the oil/water contact.

A Soviet constructed map and cross section of the oil field are shown on the following page in Figure 3-2.

Estimates of the field’s reserves are 19.6 million tons of oil in-place with 6.82 million tons recoverable. Oil production from the field has been limited, it is reported that oil production was interrupted in 1980 and thereafter only small quantities have been produced, but no production data is available. The field is shut-in, and although some oil characteristics are available, no proper oil assay exists. The MMI estimates that obtaining a crude sample large enough for a proper assay (20-25 liters) would take a minimum of 2-3 months, and involve consider work on one or more of the wells. It is also believed that if the well is reopened, it may fall into the hands of local warlords who are likely to take it over for their own exploitation.

Although Kashkari crude could not be utilized for the refinery cases in this report, it is expected that its characteristics will increase the yield of the lighter ends, thus having a positive effect on the economics.
Figure 3-2: Soviet Field Map and Cross-Section for Kashkari Oil Field

Source: Gustavson Report
3.2 Productivity and Reserve Calculation Methodology

The Kashkari field, which is the largest of the six oil fields, seems ideal to serve as a primary source of feedstock for a small refinery. It also appears to have the best potential product spread of all the oils discovered to date.

Utilizing all of the available data, well productivities have been developed for each reservoir within the field. This has been accomplished by assuming a reasonable exponential decline of reservoir pressure, based on available well test data. Initial oil flow rates have been estimated based on production tests made while the field was being explored during the Soviet era. From these estimated initial well production rates, recoverable reserves have been calculated, making use of the assumed production decline curves.

It is important to realize that, although as accurate as possible, given the available information, these results contain a significant degree of uncertainty which can only be resolved by observing well flows as each of the wells are brought on stream.

All development scenarios described below assume that the existing wells, which were drilled more than twenty-five years ago, are to be abandoned and that all production will be via newly drilled wells. Based on an efficient well spacing of 80 acres per well, 14 wells would be required to produce the deeper Hauterivian reservoir, and 24 wells to produce the shallower Albian horizons. The total number of production wells would therefore be 38. For a smaller well spacing of 40 acres, which may be desirable for production rate acceleration purposes, such as Case Four, described below, twice as many wells would be required: 48 to produce the three upper horizons, and 28 to produce the lower horizon, for a total well count of 76.

3.2.1 Possible Production Scenarios

Four production scenarios have been developed as a means of optimizing production for the purpose of providing feedstock for a small refinery. The reason that there are four cases which have been investigated is that, due to the uncertainties of field reserves and their deliverability, there is no obvious single answer to an optimized field/refinery project development case. The rational for each of the following cases is explained in more detail below:
3.2.1.1 Case One

This scenario, which is designed to produce the field at its maximum economic rate, results in a strong production peak followed by a relatively rapid decline for natural reasons. The purpose of this case is to maximize early income to Afghanistan and the production must be exported. The production profile is unsuitable for refinery feedstock due to the projected rapid production decline. In other words, this case looks only to maximize the economic return from the field in isolation, without regard to the requirements of a refinery which would utilize its production as feedstock. It therefore serves as a base case against which the economics of refinery construction and operation may be judged.

The production curve for this case is shown below in Figure 3-3, followed by a tabular listing of the production figures in Table 3-C.

![Production Profile for Kashkari Field – Case 1](image)
3.2.1.2 Case Two

This case was developed as a base case for a small refinery, which requires feedstock at a constant throughput rate of 1,300 tons/day for a minimum of 15 years. To accomplish this, production from Kashkari would be utilized for the first seven to eight years, following which field decline would set in. The resulting wedge of missing throughput would be supplied by the addition of less credible re-serves from the other, smaller existing oil fields which would be pipelined or trucked to the refinery. New field discoveries as a result of future exploration efforts for oil, rather than gas, may also supply additional crude oil as feedstock for the refinery. This case thus contains the additional uncertainty that other fields would have to be discovered or proved and developed during the early days of refinery operation.
Figure 3-4: Production Profile for Kashkari Field – Case 2

The production curve for this case is shown above in Figure 3-4, followed by a tabular listing of the production figures in Table 3-D.

Table 3-D: Production Projection for Kashkari Field – Case 2

<table>
<thead>
<tr>
<th>Year</th>
<th>New wells drilled</th>
<th>Total prod. wells</th>
<th>Total average daily prod. TON/D</th>
<th>Total average monthly prod. TON/MON</th>
<th>Total annual prod. MTON</th>
<th>Cum prod. MMTON</th>
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</tr>
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<td>1.88</td>
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<td>41,710</td>
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</table>
3.2.1.3 Case Three

The purpose of this case was to provide a high-confidence level estimate of utilizing only Kashkari production as a single source of refinery feed stock. In this case, a smaller refinery throughput is assumed, compared to that of Case Two. Under Case Three the field will produce constantly at the rate of 1,000 Tons/Day but will be depleted in 10 years. The production curve for this case is shown below in Figure 3-5, followed by a tabular listing of the production figures in Table 3-E.

![Production Profile for Kashkari Field – Case 3](image)

**Table 3-E: Production Projection for Kashkari Field – Case 3**

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<th>Year</th>
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<th>Total prod. wells</th>
<th>Total average daily prod. TON/D</th>
<th>Total average monthly prod. TON/MON</th>
<th>Total annual prod. MTON</th>
<th>Cum prod. MMTON</th>
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<td>559</td>
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<td>6,197</td>
<td>74</td>
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</tr>
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</table>
3.2.1.4 Case Four

The objective of Case Four is to maximize the rate of exploitation of the field in order to supply the refinery with its required feedstock from a single field source. To accomplish this, a larger number of wells, on reduced drainage spacing, will be required. The result will be a constant plateau level of production that will continue through approximately Year 15. Thereafter, the field will rapidly decline.

The economic effect of this case is to shift the value of the field from the operator, who would be required to drill more wells than are actually needed to exploit the reservoir, to the refinery, which is thus assured of continuous throughput of feedstock. Although not common, this approach has been occasionally used in integrated petroleum operations and may still yield an attractive overall return on the project.

The production forecast under these conditions of closer well spacing, is shown in the table 3-F below.

Table 3-F: Production Projection for Kashkari Field – Case 4

<table>
<thead>
<tr>
<th>Year</th>
<th>New wells drilled</th>
<th>Total prod. wells</th>
<th>Total average daily prod. TON/D</th>
<th>Total average monthly prod. TON/MON</th>
<th>Total annual prod. MTON</th>
<th>Cum prod. MMTON</th>
</tr>
</thead>
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<td>959</td>
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<td>0.37</td>
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3.2.2 Reserve and Production Estimates for the Remaining Four Oil Fields

The remaining oil fields, which are considerably smaller than Kashkari, have even less production data from which reserve and productivity estimates may be made. The detailed work on Kashkari has, however, served to validate the Soviet methodologies which have been utilized in determining oil in place and recoverable reserves. Based on the results of this due diligence work as part of the Kashkari investigation, considerable confidence can be placed in the oil-in-place figures which have been attributed to the remaining fields.

From this, approximate ratios of available reserves may be estimated by comparing these other fields to the in place/recoverable reserves ratio that has been established for the Kashkari field. Having said this, there is some danger of circular reasoning in this approach, and hence caution must be used before placing too much reliance of reserve estimations from the other fields. This is due to the nature of the assumptions that were utilized in developing the production scenarios for the Kashkari field.

3.2.3 Summary Production Estimates for Five Oil Fields

The Production Forecast for all five oil fields is shown in Figure 3-6 and depicted in tabular form in Table 3-G below. The forecast shows an average production of approximately 15,000 BPD over a twenty year horizon.
### Table 3-G: Production projection for Five Afghan Oil Fields

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<tr>
<th>Year</th>
<th>New wells drilled</th>
<th>Total prod wells</th>
<th>Total average daily prod STB/D</th>
<th>Total average daily prod MSTB</th>
<th>Total annual prod MMSTB</th>
<th>Cum prod MMSTB</th>
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<td>76.41</td>
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<tr>
<td>2017</td>
<td>7</td>
<td>133</td>
<td>7,020</td>
<td>17,227</td>
<td>6,288</td>
<td>82.70</td>
</tr>
<tr>
<td>2018</td>
<td>10</td>
<td>142</td>
<td>7,008</td>
<td>17,197</td>
<td>6,277</td>
<td>88.98</td>
</tr>
<tr>
<td>2019</td>
<td>44</td>
<td>187</td>
<td>7,017</td>
<td>17,220</td>
<td>6,285</td>
<td>95.26</td>
</tr>
<tr>
<td>2020</td>
<td>0</td>
<td>187</td>
<td>6,238</td>
<td>15,309</td>
<td>5,588</td>
<td>100.85</td>
</tr>
<tr>
<td>2021</td>
<td>0</td>
<td>187</td>
<td>4,825</td>
<td>11,841</td>
<td>4,322</td>
<td>105.17</td>
</tr>
<tr>
<td>2022</td>
<td>0</td>
<td>187</td>
<td>3,801</td>
<td>9,329</td>
<td>3,405</td>
<td>108.58</td>
</tr>
<tr>
<td>2023</td>
<td>0</td>
<td>187</td>
<td>3,039</td>
<td>7,459</td>
<td>2,723</td>
<td>111.30</td>
</tr>
<tr>
<td>2024</td>
<td>0</td>
<td>187</td>
<td>2,458</td>
<td>6,033</td>
<td>2,202</td>
<td>113.50</td>
</tr>
</tbody>
</table>

**Averages -**

- Total prod wells: 14,808
- Total annual prod MSTB: 5,405
3.1 Crude Oil Gathering

The costs and configurations for the Crude Oil Gathering systems have not been included in the financial and economic analyses as they will be required for all of the crude disposition options, including export of crude oil. A preliminary configuration and conceptual estimates are presented here for informational purposes, based on the 10,000 BPD scenario.

We have estimated costs for crude oil gathering and related facilities associated with 6 oil fields in Northern Afghanistan including the largest Kashkari field. These systems collect oil from existing wells, process the oil to remove gas and water and transfer the oil to a 10,000 BPD refinery that is located adjacent to the Kashkari field. The required system facilities are as follows:

1. Gathering network for each of the six (6) oil fields.
2. Separation station (oil, gas and water) for the applicable fields.
3. Pumping for crude oil transfer via pipeline.
5. Water re-injection / disposal.
6. Power requirements for the various facilities.
7. Metering stations for measurement of crude oil production and transfer at each of the six (6) fields.
8. Tankage and loading racks for trucks at the applicable fields.

Various reference documents are included in this Section to describe the basis for the estimate and aid in understanding this description. These documents include:

- Afghanistan Gathering System TIC Estimate Summary (Annex 1)
- Afghanistan Gathering System Facilities Table (Annex 2)
- Simplified Process Flow Sketches (Annexes 3-1, 3-2 and 3-3):
  - Fields #2, #3 and #5
  - Fields #4 and #6 (very similar to Field #1)
  - Flowlines within Field (Initial)

The overall TIC for the facilities described is $34.1MM on a U.S. Gulf Coast basis with an accuracy of +/- 40%. No contingency has been included or other considerations such as owner's cost, cost for land, taxes, rights of way, well development including injection wells, etc. Cross country pipelines are assumed to be by the most direct route and exclude extraordinary installation costs such as rock blasting. No electric power transmission costs are included.

3.1.1 Field and Facility Descriptions:

To determine the cost estimates for the gathering systems, we have developed the equipment requirements and configurations for 6 fields using the following set of assumptions. System sketches are attached that represent the equipment configurations for the six fields. Field no. 1 is the Kashkari field, which is the largest producing field. The total production from all 6 fields is assumed to be 10,000 BPD. The Kashkari production is assumed at 7,000 BPD with the remainder from the other 5 fields. The table in Annex 2 summarizes the
production from each field, the distances of the fields relative to field no. 1, field sizes, oil/water ratio, gas production and other assumptions necessary to develop the estimate.

We have assumed that fields no. 2 and 3 are 2 and 3 kilometers from field no. 1. The pressure from these wells is sufficient to move the crude oil via pipeline from these fields to oil/water/gas separators and tank storage systems at field no. 1. Similarly, we have assumed that field no. 5 is 2 kilometers away from field no. 4 and the crude oil from field no. 5 is pressured to field no. 4 via pipeline. The phase separators and tank storage for fields no. 4 and 5 are located at field no. 4. Refer to the Simplified Flow Sketch (Fields #2, #3 and #5).

Field no. 6 is assumed to be 80 kilometers from field no. 1. Field no. 4 is 25 kilometers from field no. 1. Trucks are utilized to transfer crude directly from these fields to the refinery. Due to these remote locations, truck loading stations have been included for fields no. 4 and 6 and a truck unloading station is included at the refinery.

Fields no. 1, 4 and 6 each include a production separator as well as a test separator. These locations each include tanks for storage of crude. A number of small sized storage tanks are utilized for fields no. 4 and 6 such that these tanks are skid mounted and easily transported and installed at each site. The tank storage for field no. 1 is more significant and one (1) field erected tank is used. Refer to the Simplified Flow Sketch (Fields #4 and #6). The equipment requirements and configuration for this sketch is very similar for field no. 1, with the exception that truck loading is not utilized because the crude is pumped via pipeline from field no. 1 to the refinery.

Pig launchers and receivers are included for pipeline transfers, which apply to pipelines from field no. 5 to no. 4, from fields no. 2 and 3 to field no. 1 and from field no. 1 to the refinery.

Gas is separated from the oil at fields no. 1, 4 and 6. This gas is re-injected into wells utilizing gas re-injection compressors, which utilize gas from the wells to provide the motive force (i.e. electrical power is not required). A natural gas engine/generator is included at fields no 1, 4 and 6 to produce sufficient power that is required at these locations for pumps used for truck loading of crude (fields 4 and 6). For pipeline transfer from field no. 1, electric power from the refinery is assumed to be available. The other fields do not require electricity. The instruments can use gas as the motive force at all locations.

Gas treating is required at all field locations. Simple sulfatreat or iron sponge systems have been assumed. These are very small systems for fields no. 2, 3 and 5 because only gas utilized for instruments requires treating at the locations. Medium gas treating systems are required for fields 4 and 6 with the most significant treating system located at field no. 1.

Each field includes a standard flare. Field no. 1 has the largest flare that also includes a knockout drum. Metering skids are utilized at each field for measurement of crude transfers and tank gauging can be utilized at fields 4 and 6 for transfer verification.
Section 3.0, Annex 1: Gathering System TIC Estimate Summary

Overall TIC Estimate for Afghanistan Oil Production Facilities

<table>
<thead>
<tr>
<th>Size</th>
<th>Bbls</th>
<th>Quantity</th>
<th>$/Bbls</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>2</td>
<td>$800,000</td>
<td>$1,600,000</td>
<td>Field erected</td>
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</tr>
<tr>
<td>500</td>
<td>26</td>
<td>$10,000</td>
<td>$260,000</td>
<td>Skid Mounted (15' x 15')</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$1,860,000</td>
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<table>
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<tr>
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<th>Size</th>
<th>Quantity</th>
<th>$/Size</th>
<th>TIC</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Drums</td>
<td>7.5ft x 22' x 1</td>
<td>1</td>
<td>$100,000</td>
<td>$100,000</td>
<td>Field No. 1 (Qashqary)</td>
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<tr>
<td>48' x 12' x 1</td>
<td>1</td>
<td>$40,000</td>
<td>$40,000</td>
<td>Field No. 4</td>
<td></td>
</tr>
<tr>
<td>3.5 x 20' x 1</td>
<td>1</td>
<td>$25,000</td>
<td>$25,000</td>
<td>Field No. 6</td>
<td></td>
</tr>
<tr>
<td>3' x 8' x 1</td>
<td>6</td>
<td>$20,000</td>
<td>$120,000</td>
<td>Test Separator @ each field</td>
<td></td>
</tr>
<tr>
<td>3' x 6' x 1</td>
<td>3</td>
<td>$45,000</td>
<td>$900,000</td>
<td>3 treaters , fields 1, 4 and 6; use 3x prod separator costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1,275,000</td>
<td></td>
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<table>
<thead>
<tr>
<th>Size</th>
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<th>$/pump</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude Transfer Pumps</td>
<td>Field No. 1</td>
<td>2</td>
<td>$18,000</td>
<td>$36,000</td>
</tr>
<tr>
<td>Water Injection Pumps</td>
<td>Field No. 1</td>
<td>3</td>
<td>$10,000</td>
<td>$60,000</td>
</tr>
<tr>
<td>Water Injection Pumps</td>
<td>Field No. 6</td>
<td>1</td>
<td>$10,000</td>
<td>$20,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$116,000</td>
<td></td>
</tr>
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<tr>
<th>Size</th>
<th>Quantity</th>
<th>$/LF</th>
<th>$/LF</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piping</td>
<td>4'</td>
<td>0.600</td>
<td>$30.48</td>
<td>$292,608</td>
<td>This is for the pipelines from Field No. 2 and 3</td>
</tr>
<tr>
<td>2' pipe within the well fields</td>
<td>2'</td>
<td>60,000</td>
<td>$22.50</td>
<td>$1,000,000</td>
<td>This is for the pipelines within each well field</td>
</tr>
<tr>
<td>6' pipeline between Field No. 1 and 2</td>
<td>6'</td>
<td>6,000</td>
<td>$32.50</td>
<td>$208,000</td>
<td>This is for the pipelines from Field No. 1 and 2</td>
</tr>
<tr>
<td>8' pipeline between Field No. 1 and Refinery</td>
<td>8'</td>
<td>3,200</td>
<td>$36.50</td>
<td>$116,800</td>
<td>This is for the pipelines from Field No. 1 to the Refinery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1,517,408</td>
<td></td>
<td></td>
</tr>
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<table>
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<th>$/EA</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig Launchers/Receivers</td>
<td>Pig Launcher 4&quot;</td>
<td>2</td>
<td>$75,000</td>
<td>$150,000</td>
</tr>
<tr>
<td>Pig Launcher 6&quot;</td>
<td>6&quot;</td>
<td>1</td>
<td>$100,000</td>
<td>$100,000</td>
</tr>
<tr>
<td>Pig Launcher 6&quot;</td>
<td>8&quot;</td>
<td>1</td>
<td>$125,000</td>
<td>$125,000</td>
</tr>
<tr>
<td>Pig Receiver 4&quot;</td>
<td>4&quot;</td>
<td>2</td>
<td>$75,000</td>
<td>$150,000</td>
</tr>
<tr>
<td>Pig Receiver 4&quot;</td>
<td>6&quot;</td>
<td>1</td>
<td>$100,000</td>
<td>$100,000</td>
</tr>
<tr>
<td>Pig Receiver 6&quot;</td>
<td>8&quot;</td>
<td>1</td>
<td>$125,000</td>
<td>$125,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$750,000</td>
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</tr>
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</table>

<table>
<thead>
<tr>
<th>Size</th>
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<th>$/Station</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track Loading Stations</td>
<td>600</td>
<td>1</td>
<td>$1,000,000</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>1200</td>
<td>1</td>
<td>$1,000,000</td>
<td>$1,000,000</td>
<td>Field No. 4 and 5</td>
</tr>
<tr>
<td>1600</td>
<td>2</td>
<td>$1,000,000</td>
<td>$2,000,000</td>
<td>Unloading station at Refinery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$4,000,000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
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<th>$/compr.</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Re-injection Compressors/Pumps</td>
<td>Typical small gas compressors</td>
<td>300hp</td>
<td>2</td>
<td>$75,000</td>
</tr>
<tr>
<td>Gas re-injection compressors</td>
<td>6&quot;</td>
<td>$200,000</td>
<td>$3,600,000</td>
<td>Field No. 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$3,600,000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
<th>Quantity</th>
<th>$/System</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Treating</td>
<td>7 MMSCFD</td>
<td>1</td>
<td>$800,000</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>.01 MMSCFD</td>
<td>1</td>
<td>$25,000</td>
<td>$62,500</td>
<td>Field #2 assumed .01 MMSCFD gas flow rate, recommend SulfaTreat or Iron Sponge</td>
</tr>
<tr>
<td>.03 MMSCFD</td>
<td>1</td>
<td>$25,000</td>
<td>$62,500</td>
<td>Field #3 assumed .01 MMSCFD gas flow rate, recommend SulfaTreat or Iron Sponge</td>
</tr>
<tr>
<td>.12 MMSCFD</td>
<td>1</td>
<td>$500,000</td>
<td>$1,250,000</td>
<td>Field #4 assumed .12 MMSCFD gas flow rate, recommend SulfaTreat or Iron Sponge</td>
</tr>
<tr>
<td>.31 MMSCFD</td>
<td>1</td>
<td>$25,000</td>
<td>$62,500</td>
<td>Field #5 assumed .12 MMSCFD gas flow rate, recommend SulfaTreat or Iron Sponge</td>
</tr>
<tr>
<td>6 MMSCFD</td>
<td>1</td>
<td>$250,000</td>
<td>$625,000</td>
<td>Field #6 assumed .06 MMSCFD gas flow rate, recommend SulfaTreat or Iron Sponge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$4,062,000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
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<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Engine/Generator</td>
<td>125 kW unit</td>
<td>2</td>
<td>$50,000</td>
<td>$300,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
<th>Quantity</th>
<th>$/flare</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flare</td>
<td>Standard flare for well fields 2-6</td>
<td>5</td>
<td>$70,000</td>
<td>$350,000</td>
</tr>
<tr>
<td>Standard flare for well field no. 1</td>
<td>1</td>
<td>$200,000</td>
<td>$600,000</td>
<td>This is a flare and tip for Field 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$600,000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
<th>Quantity</th>
<th>$/Meter</th>
<th>TIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metering Skids</td>
<td>Assume free production meter skids</td>
<td>4&quot;</td>
<td>5</td>
<td>$250,000</td>
</tr>
<tr>
<td>Assume one prod meter skid for field 1</td>
<td>8&quot;</td>
<td>1</td>
<td>$300,000</td>
<td>$300,000</td>
</tr>
<tr>
<td>Assume six test meter skids</td>
<td>2&quot;</td>
<td>6</td>
<td>$200,000</td>
<td>$1,200,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$2,700,000</td>
<td></td>
</tr>
<tr>
<td>Chemical Injection Systems</td>
<td>$2,500,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional Process Heating Systems</td>
<td>$5,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCADA/Instrument &amp; Control Systems</td>
<td>$5,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Grand Total Gathering System | $34,880,908 |     |     |     |
### Section 3.0, Annex 2: Afghanistan Gathering System Facilities Table

| Field | Flow rate (MSCFD) | Dist from #1 Field (Km) | #Wells/ Acreage | Oil/Water Ratio | Associated Wells | Field # / Dist (Km) | Field Flowrate | Water Transport Method | Water Disposition | Gas Disposition | Oil/Water Production Test | Heater | Tankage | Power Generation | Pig Launch | Loading | Truck Loading | Metering | Water Rejection |
|-------|-------------------|--------------------------|-----------------|-----------------|-----------------|------------------|------------------|-------------------|-------------------|----------------|----------------|-------------------|----------|---------|------------------|-----------|---------|----------------|----------|---------------|
| 1     | 700              | 0                        | 25/600          | -               | -               | -                | Reinject         | Reinject          | X                 | X               | X                 | X       | N       | RECEVRS          | UNLDG     | X       | X              |          |             |
| 2     | 500              | 2                        | 2/60            | 40              | 500             | #3/1              | Pipeline         | Pipeline to #1 (3 phase) * | Pipeline to #1 (3 phase) | N           | X               | N                 | N        | X       | N               | X         | X       | N              | X         |             |
| 3     | 700              | 3                        | 3/90            | 20              | 800             | #2/1              | Pipeline         | Pipeline to #1 (3 phase) * | Pipeline to #1 (3 phase) | N           | X               | N                 | N        | X       | N               | X         | X       | N              | X         |             |
| 4     | 500              | 25                       | 3/90            | 40              | 500             | #5/2              | Truck (Combine for #5) | Truck to #1*        | X                 | X               | X                 | X       | N       | X               | X         | X       | X              | X         |             |
| 5     | 700              | 25                       | 4/120           | 20              | 800             | #4/2              | Pipeline         | Pipeline to #4 (3 phase) * | Pipeline to #4 (3 phase) | N           | X               | N                 | N        | X       | N               | X         | X       | N              | X         |             |
| 6     | 600              | 80                       | 3/90            | 20              | 1000            | #1/80              | Truck            | Reinject (30 BPD initial) | Reinject (2400 psig at wellhead) 1MMSCFD Initial 300 HP | Install 500 HP | X           | X               | X       | X       | N               | X         | X       | X              | X         |             |

* As field matures, economics may justify separate water well
Section 3.0, Annex 3: Simplified Process Flow Sketches

Simplified Flow Sketch (Fields #4 and #6)

For 2500 # System

Note: Field #1 is very similar to this system

(pump needed in future for Field #4)
Simplified Flow Sketch (Fields #2, #3 and #5)

For 2500 # System

4” Production Header

2” Test Header

Test Separator

Flow Meter

LC

To Flare

Pig Launcher

Pipeline to “Q”
2 Wells in Field 1150 feet of 2” flowline (assume schedule 80 pipe)

3 Wells in Field 2500 feet of 2” flowline (assume schedule 80 pipe)

4 Wells in Field 3750 feet of 2” flowline (assume schedule 80 pipe)  
(schedule 80 pipe = 2400 psia (approximately))
4.0 Oil Demand

4.1 Demand for Petroleum Products

Afghanistan imports virtually all of its petroleum products. All supplies of gasoline, jet fuel and diesel are provided by neighboring countries, mainly Pakistan, Turkmenistan, and Uzbekistan, and delivered by tanker trucks over narrow, often winding and badly maintained roads. The importation is handled by several small local entrepreneurs under minimum or no government control, quality monitoring and management. There are also large amounts of products, particularly diesel fuel for generators, imported through the various donor and aid agencies. Much of this fuel is imported through Pakistan. Turkmenistan has a petroleum product storage and distribution facility at Tagtabazar near the Afghan border, which supplies northwestern Afghanistan.

Crude oil produced at the Angot field in the northern Sar-I-Pul province was initially processed at a small topping plant in Sheberghan, and supplied ‘refined’ fuel for the central heating boilers in the cities of Sheberghan, Mazar-E-Sharif and Kabul. After the departure of the Soviets in 1989, and the several wars and political disturbances that followed, the level of oil and gas production declined, the facilities were not maintained (in some cases parts of some of the facilities were destroyed), and efforts towards further oil and gas exploration and development work, as well as plans to build a 10,000 barrels/day refinery near Sheberghan were halted. The topping plant was destroyed during the wars, and currently refining of crude oil is through a very primitive method consisting of heating the oil in several horizontal 15 meters long retorts.

The determination of demand for Petroleum products in Afghanistan presents a challenge in that there is a considerable volume of imports that are illegally smuggled into the country from neighboring countries, where government subsidies present a lucrative opportunity for entrepreneurs willing to transport products across the border into Afghanistan.

With this in mind, the Consultant used several sources to obtain demand information for the primary products. Through interviews with wholesale importers, donor organizations, published research and other available data, the annual demand for petroleum products was established at approximately 17,000 BPD, or 940,000 TPY. (Interviews with the Ministry of Mines and Energy, and the Ministry of Planning place demand at approximately 600,000-800,000 TPY (10,800-14,500 BPD).

The Norconsult study, using CSO figures, estimates and projects demand according to the following Table 4-1. Equivalent figures in BPD units are also presented.

Given the supply scenarios presented in the preceding section of this report, and the above demand figures, the Consultant has, in addition to a 5,000 BPD topping plant, analyzed several larger refinery cases at 10,000 and 15,000 BPD, in order to better address the country’s supply and demand balance.
Table 4-A: Afghanistan Projected Demand for Petroleum Products

<table>
<thead>
<tr>
<th>DEMAND FOR PETROLEUM PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric Tons/year</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Gasoline</td>
</tr>
<tr>
<td>Kerosene</td>
</tr>
<tr>
<td>Diesel</td>
</tr>
<tr>
<td>Aviation Fuel</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

Source: Norconsult Power Sector Master Plan

<table>
<thead>
<tr>
<th>BBL/day (365 days/yr)</th>
<th>2004</th>
<th>2005</th>
<th>2007</th>
<th>2010</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>3,500</td>
<td>3,700</td>
<td>4,200</td>
<td>4,700</td>
<td>6,000</td>
</tr>
<tr>
<td>Kerosene</td>
<td>1,500</td>
<td>1,800</td>
<td>1,700</td>
<td>1,800</td>
<td>2,100</td>
</tr>
<tr>
<td>Diesel</td>
<td>14,300</td>
<td>15,800</td>
<td>20,200</td>
<td>23,900</td>
<td>36,800</td>
</tr>
<tr>
<td>Aviation Fuel</td>
<td>1,100</td>
<td>1,200</td>
<td>1,600</td>
<td>1,800</td>
<td>3,100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20,400</strong></td>
<td><strong>22,100</strong></td>
<td><strong>27,700</strong></td>
<td><strong>32,300</strong></td>
<td><strong>48,000</strong></td>
</tr>
</tbody>
</table>

Source: Norconsult Report, CSO

This Demand projection is depicted graphically in Figure 4-2 below.
5.0 Refinery Cases

This section of the report documents the study results for the five primary cases listed below.

Case 1: Maximum Power Generation - A power plant consuming 10,000 BPSD of crude oil.
Case 2A: Atmospheric Crude and Vacuum Distillation - A 10,000 BPSD simple topping refinery and a power plant.
Case 2B: Atmospheric Crude and Vacuum Distillation - A 5,000 BPSD simple topping refinery and a power plant.
Case 3A: Integrated Refinery (10,000 BPSD) - A 10,000 BPSD refinery to meet transportation fuel specifications and a power plant.
Case 3B: Integrated Refinery (15,000 BPSD) - Identical to case 3A, with a 15,000 BPSD capacity.

The report for each case analyzed provides process configurations, block flow diagrams, plot plan requirements, Utilities systems, offsites and infrastructure, capital cost estimates, operating costs, production volumes and electricity generation to perform an economic evaluation for each of these cases. All cost information is based upon U.S. Gulf Coast mid-2004 pricing. Afghan pricing adjustment factors are provided. Estimates are at a conceptual estimate level, with a +/- 30% tolerance.

In total, the information included in this report also allows evaluating various additional cases including:

- Cases 2A and 2B with or without a vacuum unit
- Cases 3A and 3B with or without the visbreaker and/or the vacuum unit
- The power plant can be easily removed from any of the refinery cases
- Stand alone liquid fuel based power plants at various capacities (2 and 3 train plants with 45 and 75 MW turbines)
- For case 3B, a cost estimate is provided for a fuel export option in the case that a power plant is not included with the refinery
- For Case 2A, a sensitivity analysis for location change is included in the report. The analysis is based upon locating the refinery closer to Sheberghan than by the well head.

Capital cost exponent factors have been included for each processing unit, which provide the flexibility to estimate capital costs at increased or decreased plant capacity.

Finally, a site conversion factor has been provided to convert the U.S. Gulf Coast cost estimates to an Afghanistan basis.

Table 5-A shows a summary of capacities, product streams and investments costs for the various refinery and refinery/power plant options evaluated.
## Table 5-A – Refinery Case Overview

<table>
<thead>
<tr>
<th>Case</th>
<th>1 Power Plant</th>
<th>2a 10,000 bpd with Asphalt</th>
<th>2a 10,000 bpd without Asphalt</th>
<th>2b 5,000 Bpd</th>
<th>3a 10,000 bpd refinery</th>
<th>3b 15,000 bpd refinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity, BPSD</td>
<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
<td>5,000</td>
<td>5,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Power Plant Capacity, MW</td>
<td>226</td>
<td>141</td>
<td>141</td>
<td>71</td>
<td>71</td>
<td>93</td>
</tr>
</tbody>
</table>

### Products

<table>
<thead>
<tr>
<th></th>
<th>10,000</th>
<th>10,000</th>
<th>10,000</th>
<th>5,000</th>
<th>5,000</th>
<th>10,000</th>
<th>10,000</th>
<th>15,000</th>
<th>15,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>3,580</td>
<td>3,580</td>
<td>1,790</td>
<td>1,790</td>
<td>3,297</td>
<td>3,964</td>
<td>4,945</td>
<td>5,947</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>3,640</td>
<td>6,420</td>
<td>1,820</td>
<td>3,210</td>
<td>3,350</td>
<td>3,951</td>
<td>3,525</td>
<td>3,927</td>
<td></td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>2,780</td>
<td>0</td>
<td>1,390</td>
<td>0</td>
<td>2,780</td>
<td>4,170</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.0</td>
<td>10,000</td>
<td>10,000</td>
<td>5,000</td>
<td>5,000</td>
<td>10,074</td>
<td>10,217</td>
<td>15,112</td>
<td>15,325</td>
</tr>
</tbody>
</table>

### Export Power, MW

|                    | 203.6  | 130.9  | 130.9  | 65.4  | 65.4  | 77.6   | 77.6   | 115.9  | 115.9  |

### In vestment Costs:

<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery</td>
<td>1,600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Desalting)</td>
<td>41,900</td>
<td>22,700</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Plant</td>
<td>153,700</td>
<td>113,200</td>
<td>113,200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling Water System</td>
<td>900</td>
<td>1,100</td>
<td>900</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tank Farm Storage</td>
<td>7,800</td>
<td>27,200</td>
<td>21,400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offsites</td>
<td>31,100</td>
<td>40,900</td>
<td>33,300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Refinery and Offsites</td>
<td>1,600</td>
<td>90,400</td>
<td>57,500</td>
<td>62,800</td>
<td>193,400</td>
<td>244,900</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Total Power Plant and Offsites

|                        | 193,500| 133,900| 133,900| 77,200| 90,100| 131,100|       |       |       |

### Environmental Costs to meet WBEAG - Refinery

|                        |        |        |        |       |       |       |       |       |       |
| Environmental Costs to meet WBEAG – Power Plant | 47,000 | 38,000 | 38,000 | 17,600| 25,000| 36,000|       |       |       |

### Total Costs

|                        | 242,100| 265,300| 232,400| 159,600| 316,500| 421,000|       |       |       |

*Source: Refinery Analysis*
5.1 SCOPE OF WORK

During the evaluation of the economic and financial justification for constructing a 5000 BPSD refinery facility, as part of an overall study to define the disposition options for land-locked oil reserves in Afghanistan, the consultant found it necessary to extend the scope of work considerably beyond the TOR. Higher demand figures than those initially expected, the current shortage of power generation capacity in Afghanistan, and economic development factors were part of the reasons that the scope of this study was expanded to include the several cases that are described below:

**Case 0: Crude Export (base case).** This case is the do-nothing option, based upon producing and exporting crude oil to Turkmen or Pakistani refineries. This case is not described in this section, but simply evaluated against the other options in the section on economic and financial analysis.

**Case 1: Maximum Power Generation.** This case is based upon producing maximum electricity for export and sale in a stand-alone power plant with a fuel firing rate of 10,000 BPSD of crude oil directly from the wells.

**Cases 2A and 2B: Atmospheric Crude and Vacuum Distillation.** Case 2A is based upon a crude oil feed rate to the refinery of 10,000 BPSD. Case 2B is exactly the same as Case 2A, but with a crude oil feed rate to the refinery of 5,000 BPSD. A simple refinery topping scheme is utilized to maximally produce diesel and asphalt. Asphalt is produced in the summer months only for use in building much needed roads in Afghanistan. The objective for producing diesel is to meet the highest specification possible, but it is not a requirement to meet transportation grade specifications. A power plant option is also included in this case to produce maximum electricity by burning all of the products that cannot meet specifications. During the winter months, the asphalt is also utilized for fuel in the power plant facility. The power plant supplies the necessary power for the refinery and all excess electricity is exported for sale.

The base case for each case in the evaluation is to locate the power plant and/or refinery immediately adjacent to the oil field. Included in the scope for Case 2A is an alternate location analysis, which evaluates the estimated cost for locating the plants adjacent to Sheberghan town.

**Cases 3A and 3B: Integrated Refinery.** These two cases are the same as Case 2, but with incremental investment in additional processing units to meet transportation fuel specifications. Case 3A is based upon a crude oil feed rate to the refinery of 10,000 BPSD. Case 3B is exactly the same as Case 3A, but with a crude oil feed rate to the refinery of 15,000 BPSD. A power plant is also included to produce maximum electricity by burning all the remaining products that cannot meet specifications. The power plant supplies the necessary power for the refinery and all excess electricity is exported for sale.

The scope for case 3B only includes estimating the cost for a fuel export option in the case that a power plant is not approved. This option is essentially a tank and truck loading rack.

This report is based upon the four cases listed above. However, much additional information can be extracted from the report to allow analyzing various alternates. For example, the Total Installed Cost Summary for case 2 includes sufficient information to determine the economics with or without the Vacuum Unit. Likewise, the Total Installed Cost Summary tables have been prepared so as to easily remove the Power plant from any of the refinery cases. For case 3...
(Integrated Refinery), the Total Installed Cost with and without the Visbreaker and/or the Vacuum unit is fairly straightforward to determine.

Capital cost exponent factors have been included for each processing unit and the power plant in report Section 6.0, Cost Estimation. These exponents allow the flexibility to estimate capital costs at increased or decreased plant capacity. Finally, a site conversion factor has been provided in report Section 6.0, Cost Estimation, to convert the U.S. gulf coast estimate to an Afghanistan basis.

**Additional Study Basis information and input:**

**Environmental Regulations:** World Bank Environmental Assessment Guidelines (WBEAG) have been considered for the design of the various cases. Added costs to achieve WBAEG standards have been separately estimated and are included in the Total Installed Cost Summaries for each case within the report.

**Product Specifications:** For cases 3A and 3B, specifications for refinery products are based upon meeting NATO specifications for jet fuel and either ASTM or Pakistani specifications for other products. For Case 2A and 2B, the diesel product meets the Pakistani wide cut diesel specifications. Product specifications for all cases are included in the appendix of this report.

**Crude Assay:** As a stipulation of the study, flexibility has been included in the design of the refining units for higher °API oil and for sulfur removal for higher sulfur content in the crude.

The contents of this report include the following deliverables for each case evaluated:

- Case description
- Block Flow Diagram
- Plot plan requirements
- Production capacity summary
- Operating cost summary
- Total Installed Cost (TIC) summary

The cases were evaluated utilizing a simplified approach to complete the number of cases in the necessary study timeframe and cost. The units for each case were defined based upon similar units as defined by the study. These units were scaled and/or revised to meet the requirements for each case. Utilities and offsites requirements were similarly determined by utilizing ratios.

A crude assay was thought to be available at the outset of the study. However, it was discovered that available distillation information and crude parameters were outdated and contradictory, and not sufficient in order to carry out the refinery study. In late April, a sufficiently large crude sample from Angot field was finally obtained, and after much difficulty, exported to India for a full crude assay. As the results of this assay will not be available until after the submission of this report, and because the oil supply forecasts are heavily dependent on Kashkari field supply, from which a sample is not possible to obtain at this point in time, the Consultant performed a GC distillation on a small sample of Angot crude. API gravity and sulfur as well as additional limited crude properties were also provided from the Angot field and adjusted for the differences between Angot and Kashkari to the extent these were documented. As Kashkari crude (which is in itself a combination of different types of lighter and heavy crude, ranging from 27.6 to 33.8 API Gravity, and varying Sulfur quantities) is a lighter crude than Angot, the economics of all scenarios should be more favorable. A Heavy Arabian crude assay...
was used as a further guide for the distribution of sulfur, metals and the product property determination.

The costs were determined as all-inclusive of a grass-roots facility, U.S. Gulf Coast. Cost estimates were produced by utilizing the estimates for the similar processing units as indicated above and/or by utilizing estimating curves. The estimating accuracy is approximately +/- 30 percent. The cost estimates are broken down to define the separation of ISBL (process) and OSBL (offsites) in the estimates. Exclusions to the estimates are identified and included in report section 6, Cost Estimation.
5.2 Case 1 - Maximum Power Generation

5.2.1 Case Description

In this case, all of the crude oil goes to the power plant to produce electricity. The crude oil feed rate is 10,000 BPSD. There are only two processing steps in addition to the power plant itself.

A desalter removes salt from the crude oil as its name implies. The desalter is normally part of the atmospheric crude distillation unit, but must be a stand-alone unit in this case because there is no crude unit. The salt would increase the corrosion and fouling of the steam boiler tubes if it were left in the fuel oil.

The flue gas from the power plant contains too much sulfur dioxide to meet World Bank Environmental Assessment Guidelines, so a flue gas scrubbing process is applied to remove it. There are also guidelines on nitrogen oxides and particulate matter which the process may have to remove also. This will not be known until a more detailed design stage is reached. Nitrogen oxides are derived from atmospheric nitrogen, and the amount is not a direct function of the fuel oil properties as is the amount of sulfur oxides. The amount generated is a function of the burner design. It is possible that a Selective Catalytic Reduction unit will be required, and this is not included in the current estimate.

The power plant uses conventional steam-turbine driven generators. Three trains keep the plant from losing a large block of power during a shutdown. Each train has a 740,000 Lb/Hr steam boiler and a nominal 75 MW turbine-generator set. Natural gas will be used for startup, and then the fuel will be switched to the fuel oil. A small Diesel-driven generator is part of the facilities to provide cold-start capability without relying on electrical power from the grid.

The tank farm will maintain a 5-day supply crude oil for use as fuel oil in the power plant. This inventory should be sufficient because the plant is located so close to the production fields. The storage at the production facility will act as inventory for the power plant.

The utilities area will produce the utilities such as boiler feed water and instrument air that are required by the power plant. The steam boilers are so intimately connected with the generation of power that they will be thought of more as part of the power plant than as a utility. The maintenance and administration areas complete the facility.

The details of this configuration are presented in the subsequent sections. Although the block flow diagram and plot plan are part of the details, they are shown here as well in order to help provide an overview of the case.
5.2.2 Process Configuration

This section includes the block flow diagram, the plot plan, the utilities system list, and the offsite and infrastructure list.

5.2.2.1 Block Flow Diagram

This section contains the following block flow diagram:

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>400901-C1-B001</td>
<td>Case 1 Maximum Power Generation Block Flow Diagram</td>
</tr>
</tbody>
</table>
5.2.2.2 Plot Plan Requirements

This section contains the following plot plan:

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>400901-C1-A001</td>
<td>Case 1 Maximum Power Generation Plot Plan</td>
</tr>
</tbody>
</table>
CASE 1
MAXIMUM POWER GENERATION
PLOT PLAN
400901-C1-A001

TANK FARM

MAINTENANCE/
ADMINISTRATION/
MISCELLANEOUS
BUILDINGS

UTILITIES

POWER PLANT

325 M

300 M

METERS

DESIGN BY
M. LOCKHART
A. V. CELIS
5-12-04 T. H.   FOR STUDY ONLY
5.2.2.3 Utilities Systems List

The utilities in the following list are included. Of these, only the steam, cooling water, and electric power generation are cost-estimated separately. The consumption of fuel gas is tabulated for its operating cost, while the capital cost is included with the minor utilities in the factor for the offsites and infrastructure. The remaining utilities are included in the minor utilities.

- High Pressure Steam Generation
- Medium Pressure Steam
- Boiler Feed Water
- Condensate Collection
- Cooling Water
- Electric Power
- Natural Gas
- Raw Water
- Treated Water
- Potable Water
- Fire Water
- Nitrogen
- Plant Air
- Instrument Air

5.2.2.4 Offsite and Infrastructure List

The offsites and infrastructure systems that are included in the cost estimate are listed below. The costs for these systems are lumped together and estimated as a percentage of the cost of the major facilities. This cost also includes some of the minor utility systems although they are listed under utilities above.

- Buildings
- Communication System
- Electric Power Distribution (but not Generation)
- Lighting
- Miscellaneous Interconnecting Piping
- Fire Water System
- Oily Water and Storm Water Drains
- Waste Water Treatment
- Roads
- Walks
- Vehicles

The tankage is part of the offsites and includes the following refinery tanks for this case. Utility tanks such as raw water, treated water, and fire water are not listed. The Diesel tank in this case is Diesel for internal consumption in the startup generator, not a product tank.

- Crude Oil Tanks (Fuel Oil for Power Plant)
- Fuel Oil Day Tank
• Diesel Tank

The items covered are those that would be expected. Some items in the categories of extraordinary security and outside-the-fence items are not included. These are listed in the cost estimating section under exclusions.

5.2.3 Production Capacity Summary

This section covers the overall material balance, the emissions, and the product properties. The following table presents the overall material balance and also presents the electric power for export.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td>Electric Power Export, MW</td>
<td></td>
<td></td>
<td>203.6</td>
</tr>
</tbody>
</table>
The table below presents the fuel oil properties. The fuel oil is the crude oil and is consumed in the power plant. There are no petroleum products in this case.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>API Gravity at 60 °F, °API</td>
<td>23.6</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.9123</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>319.1</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>3.05</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>588</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Note 1)</td>
<td>0.95</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
<td>0.26</td>
</tr>
<tr>
<td>Flash Point, °F (Note 1)</td>
<td>60</td>
</tr>
<tr>
<td>Micro Carbon, Wt%</td>
<td>8.4</td>
</tr>
<tr>
<td>Pour Point, °F</td>
<td>35</td>
</tr>
<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>17,960</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>At 60 °F</td>
<td>146.0</td>
</tr>
<tr>
<td>At 100 °F</td>
<td>34.4</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>1.5</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td></td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>2.4</td>
</tr>
<tr>
<td>Salt, Lb/1000 B (Note 2)</td>
<td>?</td>
</tr>
</tbody>
</table>

Notes
1. It is suspected that light ends were lost from the assay sample and that the RVP will be higher. However, it will be suitable for tankage. The flash point may be lower.
2. The value is not available, but the crude will be desalted.
The following table shows the estimated emissions from the refinery part of the plant. In this case, the refinery is only desalting the crude.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>None</td>
</tr>
<tr>
<td>Solids</td>
<td>None</td>
</tr>
<tr>
<td><strong>Liquid Emissions (Water )</strong></td>
<td></td>
</tr>
<tr>
<td>Waste Water, gpm</td>
<td>9</td>
</tr>
</tbody>
</table>
The following table covers the power plant emissions for Case 1.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air</strong></td>
<td></td>
</tr>
<tr>
<td>SO₂ as SO₂, t/d</td>
<td>8.5</td>
</tr>
<tr>
<td><strong>Solids</strong></td>
<td></td>
</tr>
<tr>
<td>Ash, t/d (Contains)</td>
<td>unknown</td>
</tr>
<tr>
<td>Iron, t/d</td>
<td>0.002</td>
</tr>
<tr>
<td>Nickel, t/d</td>
<td>0.003</td>
</tr>
<tr>
<td>Vanadium, t/d</td>
<td>0.010</td>
</tr>
<tr>
<td>Calcium Sulfate, t/d (Gypsum, CaSO₄·2H₂O)</td>
<td>206.6</td>
</tr>
<tr>
<td><strong>Liquid Emissions (Water)</strong></td>
<td></td>
</tr>
<tr>
<td>Waste Water, gpm</td>
<td>381</td>
</tr>
<tr>
<td>Boiler Feed Water Blowdown, gpm</td>
<td>165</td>
</tr>
<tr>
<td>Rain Water</td>
<td></td>
</tr>
<tr>
<td>Utility Water</td>
<td></td>
</tr>
</tbody>
</table>

The NOₓ emissions are not known at this stage. If the flue gas scrubber were not installed, the SO₂ emissions would be 85.4 t/d. The ash content of the crude is not known. The gypsum that is produced can be used as a building material and may be considered a byproduct rather than an emission. The rain water runoff from the process area and the utility water runoff have not been estimated at this time.
5.2.4 Operating Cost Summary

The table below gives the operating costs for Case 1. The table is structured to show the costs when a refinery is present, so a number of the entries are zero.

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Annual Cost</th>
<th>MM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-up Water</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Natural Gas - Fuel:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Heater</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Hydrogen Plant Feed</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Catalyst</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Local Taxes</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>9.27</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous supplies</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Plant staff and operators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Power Plant (29 persons)</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>10.88</strong></td>
<td></td>
</tr>
<tr>
<td>Contingency</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11.43</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Basis for Operating Costs:**
- Cooling water cost: 0.2 $/mgal
- Natural gas: 5.53 $/mmBtu
- Natural gas: 21,500 Btu/lb
- Insurance: 1% of TIC
- Local Taxes: 0% of TIC
- Maintenance: 5% of TIC
- Misc Supplies: 0.15% of TIC
- Payroll Burden: 5,000 $/year/person
- Contingency: 5% of Op Costs
- Uptime: 330 Days/year
Notes:
1. Additional items such as corporate overhead, research and development and sales expense are not included.
2. For Case 1, the operating cost for the limestone utilized for treating the flue gas from the power plant boilers is estimated at approximately $4750/stream day. This cost is not included in the table above.

5.2.5 Total Installed Cost Summary

The table below gives the estimate of total installed cost for Case 1.

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Normal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>POWER PLANT UNITS</strong></td>
<td><strong>Capacity</strong></td>
<td><strong>TIC, MM$</strong></td>
</tr>
<tr>
<td>Desalting Unit, BPSD</td>
<td>10,000</td>
<td>1.6</td>
</tr>
<tr>
<td>Power Plant, MW</td>
<td>226</td>
<td>153.7</td>
</tr>
<tr>
<td><strong>Total Power Plant (ISBL)</strong></td>
<td></td>
<td>155.3</td>
</tr>
<tr>
<td><strong>COOLING WATER SYSTEM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Plant</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Total Cooling Water</strong></td>
<td></td>
<td>0.9</td>
</tr>
<tr>
<td><strong>TANK FARM / STORAGE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.8</td>
<td>7.8</td>
</tr>
<tr>
<td><strong>Total Tank Farm / Storage</strong></td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td><strong>OFFSITE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Plant</td>
<td>31.1</td>
<td>31.1</td>
</tr>
<tr>
<td><strong>Total Offsite</strong></td>
<td></td>
<td>31.1</td>
</tr>
<tr>
<td><strong>CASE 1 GRAND TOTAL</strong></td>
<td></td>
<td>$195.0</td>
</tr>
<tr>
<td><strong>$MTIC/MW</strong></td>
<td></td>
<td>863</td>
</tr>
</tbody>
</table>

Environmental Considerations to meet World Bank Environmental Assessment Guidelines (WBEAG):

A. For the Power plant, add $42MM for Flue Gas Treatment to reduce "SOx" and add $5MM for additional Waste Water Treatment requirements. It is uncertain whether additional facilities are required for "NOx" and particulate matter (PM) removal. Refer to report section 3.1.1 for further discussion on this topic.
5.3 Case 2 - Atmospheric Crude and Vacuum Distillation

5.3.1 Case Description

The crude oil feed rate for Case 2A is 10,000 B/SD and that for Case 2B is 5,000 B/SD. The cases have minimal refining units plus an electric power plant. The processing units are an atmospheric crude tower, a vacuum tower, and a sour water stripper. The vacuum tower feed rate for case 2A is 5,780 B/SD and that for Case 2B is 2,890 B/SD. The distillation units produce a wide-cut diesel that is suitable for low-speed, stationary Diesels. It is not an automotive Diesel. The atmospheric tower also produces a naphtha stream, but the octane number of the naphtha is too low to be suitable for gasoline. The naphtha goes into the power plant fuel. There is also an option to produce asphalt from the bottom of the vacuum tower. This would be done primarily during the summer, so this operation is termed the summer case. The operation when asphalt is not produced is termed the winter case. When the asphalt is not produced as a product, it becomes part of the fuel oil for the power plant. The fuel oil to the power plant is a blend of the naphtha and the vacuum gas oils in the summer case; and a blend of the naphtha, vacuum gas oils, and the vacuum bottoms in the winter case. The power plant uses natural gas as a supplemental fuel in the summer case to keep the production of electricity at the required level. There are three trains in the power plant. Each train has a 500,000 Lb/Hr steam boiler and a nominal 45 MW turbine-generator set.

The summer and winter cases have been presented as all-or-nothing on the production of asphalt. However, it would be possible run intermediate cases where some asphalt is produced but not the maximum amount.

The assay indicates that there are very small amounts of the light components present in the crude. Therefore, it is not worth installing a gas plant to recover them. It is suspected that the sample had weathered, and that a large part of the light ends were lost. This will have to be checked when a fresh assay is available.

The function of the atmospheric crude distillation unit is to separate the light ends, naphtha, jet fuel and Diesel fuel from the crude oil. The crude unit contains a desalter that removes salt from the crude oil as its name implies. The salt would increase the corrosion in the processing units if it were left in the crude. It would also increase the corrosion and fouling of the tubes in the steam boiler in the power plant.

The vacuum distillation unit operates at vacuum to remove additional cuts from the crude without requiring a temperature that would crack the crude excessively. Additional Diesel fuel is recovered in this unit. Two vacuum gas oil streams will probably be drawn to enhance heat recovery. For the summer case, the vacuum tower bottoms become asphalt. The asphalt is actually cut deeper than is needed and blended with heavy vacuum gas oil to provide close control on the properties to meet the asphalt specifications. The assay does not provide asphalt properties, so the predicted yield is an estimate based on an Arabian Heavy crude oil assay.
The flue gas from the power plant contains too much sulfur dioxide to meet the World Bank Environmental Assessment Guidelines, so a flue gas scrubbing process is applied to remove it. There are also guidelines on nitrogen oxides and particulates which the process may have to remove also. This will not be known until a more detailed design stage is reached. Nitrogen oxides are derived from atmospheric nitrogen, and the amount is not such a direct function of the fuel oil properties as the amount of sulfur oxides. The amount generated is a function of the burner design. It is possible that a Selective Catalytic Reduction unit will be required, but that is not in the estimate now.

The power plant uses conventional steam-turbine driven generators. Three trains keep the plant from losing such a large block of power during a shutdown. Natural gas will be used for startup, and then the fuel will be switched to the fuel oil. A small Diesel-driven generator is part of the facilities to provide a cold-start capability without relying on electrical power from the grid.

The tank farm will maintain a 5-day supply of crude oil for the refinery, but this can be used as fuel oil in the power plant if there is a problem in the refinery. This inventory should be sufficient because the plant is located so close to the production fields. The storage at the production facility will act as inventory for the power plant.

The utilities area will produce the utilities such as boiler feed water and instrument air that are required by the power plant. The steam boilers are so intimately connected with the generation of power that they will be thought of more as part of the power plant than as a utility. The maintenance and administration areas complete the facility.

The description above gives a broad picture of the case. The details are presented in the subsequent sections. Although the block flow diagram and plot plan are part of the details, they also help provide an overview of the case.

5.3.2 Process Configuration

This section gives the block flow diagram, the plot plan, the utilities system list, and the offsite and infrastructure list.

5.3.2.1 Block Flow Diagram

This section contains the following block flow diagram:

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>400901-C2AB-B001</td>
<td>Case 2A and 2B Atmospheric Crude and Vacuum Distillation Block Flow Diagram</td>
</tr>
</tbody>
</table>
5.3.2.2 Plot Plan Requirements

This section contains the following plot plans:

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>400901-C2A-A001</td>
<td>Case 2A Atmospheric Crude and Vacuum Distillation Plot Plan</td>
</tr>
<tr>
<td>400901-C2B-A001</td>
<td>Case 2B Atmospheric Crude and Vacuum Distillation Plot Plan</td>
</tr>
</tbody>
</table>
5.3.2.3 Utilities Systems List

The utilities in the following list are included. Of these, only the steam, cooling water, and electric power generation are cost-estimated separately. The consumption of fuel gas is tabulated for its operating cost, while the capital cost is included with the minor utilities in the factor for the offsites and infrastructure. The remaining utilities are included in the minor utilities.

- High Pressure Steam Generation
- Medium Pressure Steam
- Boiler Feed Water
- Condensate Collection
- Cooling Water
- Electric Power
- Natural Gas
- Refinery Fuel Gas
- Raw Water
- Treated Water
- Potable Water
- Fire Water
- Nitrogen
- Plant Air
- Instrument Air

In this case, there is only one low-pressure steam user. Medium pressure steam will be let down and de-superheated at that user.

5.3.2.4 Offsite and Infrastructure List

The offsites and infrastructure systems that are included in the cost estimate are listed below. The costs for these systems are lumped together and estimated as a percentage of the cost of the major facilities. This cost also includes some of the minor utility systems although they are listed under utilities above.

- Buildings
- Communication System
- Electric Power Distribution (but not Generation)
- Lighting
- Miscellaneous Interconnecting Piping
- Fire Water System
- Oily Water and Storm Water Drains
- Waste Water Treatment
- Flares
- Roads
- Walks
- Vehicles
- Product Blending Systems
- Product Loading Systems
The tankage is part of the offsites and includes the following refinery tanks for this case. Utility tanks such as raw water, treated water, and fire water are not listed. One Diesel tank in this case is Diesel for internal consumption in the startup generator, not a product tank.

- Crude Oil Tanks
- Fuel Oil Day Tank
- Diesel Product Tanks
- Asphalt Tanks
- Dry Slops Tank
- Wet Slops Tank
- Diesel Tank

The items covered are those that would be expected. Some items in the categories of extraordinary security and outside-the-fence are not included. These are listed in the cost estimating section under exclusions.
5.3.3 Production Capacity Summary

The table below presents the overall material balance for the summer operation for Cases 2A and 2B. In the summer operation, the vacuum tower produces an asphalt product whereas in the winter operation it does not and this material becomes part of the fuel oil sent to the power plant. Thus, the power plant sees less fuel oil in the summer operation. To prevent a reduction in the electric power output, the power plant fires natural gas as a supplemental fuel. For this reason, the electric power output in both operations is shown as the same.

After the overall material balances, other tables show the product properties for this operation.

<table>
<thead>
<tr>
<th>Overall Material Balance - Case 2A (Summer)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stream</strong></td>
</tr>
<tr>
<td><strong>Feeds</strong></td>
</tr>
<tr>
<td>Crude</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td><strong>Products</strong></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
</tr>
<tr>
<td>Wide-Cut Diesel</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
</tr>
<tr>
<td>Asphalt</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Electric Power Export, MW</td>
</tr>
</tbody>
</table>
The overall material balance for Case 2B, the 5,000 B/SD Case, for the summer operation follows:

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>66,480</td>
<td>23.6</td>
<td>5,000</td>
</tr>
<tr>
<td>Total</td>
<td>66,480</td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>7</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Wide-Cut Diesel</td>
<td>21,866</td>
<td>37.3</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>23,866</td>
<td>0.0</td>
<td>1,820</td>
</tr>
<tr>
<td>Asphalt</td>
<td>20,742</td>
<td>6.9</td>
<td>1,390</td>
</tr>
<tr>
<td>Total</td>
<td>66,480</td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Electric Power Export, MW</strong></td>
<td></td>
<td></td>
<td><strong>65.4</strong></td>
</tr>
</tbody>
</table>
The table below presents the properties for the wide-cut Diesel Fuel. The properties do not change between the summer and winter operation.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>37.3</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.8384</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>1.08</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
<td>67</td>
</tr>
<tr>
<td>Flash Point, °F (Note 1)</td>
<td></td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes
1. Pensky-Martens Closed Cup at 20°C
The table below gives the fuel oil properties for the Case 2 summer operation. The fuel oil is consumed in the power plant and is not an external product.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>26.0</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.8998</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>314.7</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>2.78</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>25</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Notes 1, 2)</td>
<td>0.95</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
<td></td>
</tr>
<tr>
<td>Flash Point, °F (Notes 1, 2)</td>
<td>60</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>0.1</td>
</tr>
<tr>
<td>Pour Point, °F</td>
<td>38</td>
</tr>
<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>18,050</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>At 100 °F</td>
<td>16.5</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Salt, Lb/1000 B</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Notes
1. It is suspected that light ends were lost from the assay sample and that the RVP will be higher. However, it will be suitable for tankage. The flash point may be lower.
2. Assumed the same as the whole crude
The table below gives the overall material balance for the Case 2A winter operation.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>13</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Wide-Cut Diesel</td>
<td>43,733</td>
<td>37.3</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>89,215</td>
<td>17.1</td>
<td>6,420</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Electric Power Export, MW</strong></td>
<td></td>
<td></td>
<td>130.9</td>
</tr>
</tbody>
</table>
The table below gives the overall material balance for the Case 2B winter operation.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>66,480</td>
<td>23.6</td>
<td>5,000</td>
</tr>
<tr>
<td>Total</td>
<td>66,480</td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>7</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Wide-Cut Diesel</td>
<td>21,866</td>
<td>37.3</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>44,608</td>
<td>17.1</td>
<td>3,210</td>
</tr>
<tr>
<td>Total</td>
<td>66,480</td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Electric Power Export, MW</strong></td>
<td></td>
<td></td>
<td>65.4</td>
</tr>
</tbody>
</table>

The properties for the wide-cut Diesel fuel are given above with the properties of the products for the summer operation. The properties do not change between the summer and the winter operation, so they are not repeated here. The table below presents the properties for the fuel oil for the Case 2 winter operation. The properties apply to the cases 2A and 2B. The fuel oil is consumed in the power plant and is not an external product.
### Fuel Oil - Cases 2A and 2B (Winter)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>17.1</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.9535</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>333.5</td>
</tr>
<tr>
<td>Sulfur, Wt% (Note 4)</td>
<td>3.93</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>863</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Notes 1, 3)</td>
<td>0.95</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
<td></td>
</tr>
<tr>
<td>Flash Point, °F (Notes 1, 3)</td>
<td>60</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>12.5</td>
</tr>
<tr>
<td>Pour Point, °F</td>
<td>78</td>
</tr>
<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>17,640</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>At 100 °F</td>
<td>200</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>2.2</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td>3.6</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>10.6</td>
</tr>
<tr>
<td>Salt, Lb/1000 B (Note 2)</td>
<td>?</td>
</tr>
</tbody>
</table>

**Notes**

1. It is suspected that light ends were lost from the assay sample and that the RVP will be higher. However, it will be suitable for tankage. The flash point may be lower.
2. The value is not available, but the crude will be desalted.
3. Assumed to be the same as that of the whole crude.
4. Without the overdesign factor, this would meet the specification for fuel oil.

The following table shows the estimated emissions from the plant. The refinery part of the plant is presented first. The winter operation is the controlling case and is the one presented. The summer operation is not presented.
The fired heaters in the refinery use natural gas. The composition is not presently known and a composition of 100% methane is assumed. There may be some small content of sulfur compounds. Also, there will be some cracking in the furnaces that will generate a small amount of hydrogen sulfide. This will be burned and cause some emission of SO\textsubscript{x}. The cracking is not estimated at this level of detail, but will be small.

The following table covers the power plant emissions for the winter operation of Case 2.
### Power Plant Emissions - Case 2 (Winter)

<table>
<thead>
<tr>
<th>Description</th>
<th>Case 2A Value</th>
<th>Case 2B Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO(_x) as SO(_2), t/d</td>
<td>7.4</td>
<td>3.7</td>
</tr>
<tr>
<td><strong>Solids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, t/d (Contains)</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Iron, t/d</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>Nickel, t/d</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td>Vanadium, t/d</td>
<td>0.010</td>
<td>0.005</td>
</tr>
<tr>
<td>Calcium Sulfate, t/d (Gypsum, CaSO(_4).2H(_2)O)</td>
<td>178.8</td>
<td>89.5</td>
</tr>
<tr>
<td><strong>Liquid Emissions (Water)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste Water, gpm</td>
<td>255</td>
<td>127</td>
</tr>
<tr>
<td>Boiler Feed Water Blowdown, gpm</td>
<td>108</td>
<td>54</td>
</tr>
</tbody>
</table>

The NO\(_x\) emissions are not known at this stage. If the flue gas scrubber were not installed, the SO\(_x\) emissions would be 73.9 t/d in Case 2A and 37.0 t/d in Case 2B. The ash content of the fuel oil is not known. The gypsum that is produced can be used as a building material and may be considered a byproduct rather than an emission. The rain water runoff from the process area and the utility water runoff have not been estimated at this time.
5.3.4 Operating Cost Summary

The following tables give the operating cost summaries for Case 2A and 2B. There is no hydrogen plant in Case 2, so that entry is intentionally blank.

<table>
<thead>
<tr>
<th></th>
<th>Case 2A - Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power Plant</td>
</tr>
<tr>
<td></td>
<td>Annual Cost</td>
</tr>
<tr>
<td></td>
<td>MM$</td>
</tr>
<tr>
<td>Make-up Water</td>
<td>0.12</td>
</tr>
<tr>
<td>Power</td>
<td>-</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>-</td>
</tr>
<tr>
<td>Natural Gas - Fuel:</td>
<td></td>
</tr>
<tr>
<td>Process Heater</td>
<td>0.00</td>
</tr>
<tr>
<td>Hydrogen Plant Feed</td>
<td>-</td>
</tr>
<tr>
<td>Catalyst</td>
<td>0.00</td>
</tr>
<tr>
<td>Insurance</td>
<td>0.67</td>
</tr>
<tr>
<td>Local Taxes</td>
<td>0.00</td>
</tr>
<tr>
<td>Maintenance</td>
<td>6.46</td>
</tr>
<tr>
<td>Miscellaneous supplies</td>
<td>0.20</td>
</tr>
<tr>
<td>Plant staff and operators</td>
<td></td>
</tr>
<tr>
<td>Refinery (57 persons)</td>
<td>0.00</td>
</tr>
<tr>
<td>Power Plant (17 persons)</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td><strong>Subtotal</strong></td>
</tr>
<tr>
<td>Contingency</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

Basis for Operating Costs:
- Cooling water cost: 0.2 $/mgal
- Natural gas: 5.53 $/mmBtu
- Natural gas: 21,500 Btu/lb
- Insurance: 1% of TIC
- Local Taxes: 0% of TIC
- Maintenance: 5% of TIC
- Misc Supplies: 0.15% of TIC
- Payroll Burden: 5,000 $/year/person
- Contingency: 5% of Op Costs
- Uptime: 330 Days/year
Notes:
1. Natural gas is utilized for all refinery fuel requirements (i.e. fired heaters).
2. The power plant supplies the refinery power requirements, which is deducted from electrical power for sale.
3. The power plant fuel requirements are either directly from crude oil or residual oil produced in the refinery (see note 4).
4. For case 2A (summer), 33.13 Mlb/hr of natural gas is required to maintain constant electrical power export from the power plant during the period that asphalt is produced. Other operating costs are approximately the same year round.
5. Additional items such as corporate overhead, research and development and sales expense are not included.
6. For Case 2A, the operating cost for the limestone utilized for treating the flue gas from the power plant boilers is estimated at approximately $4,100/stream day. This cost is not included in the table above.

### Case 2B - Winter

<table>
<thead>
<tr>
<th></th>
<th>Power Plant Annual Cost</th>
<th>Refinery Annual Cost</th>
<th>Total Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-up Water</td>
<td>0.06 MM$</td>
<td>0.01 MM$</td>
<td>0.07 MM$</td>
</tr>
<tr>
<td>Power</td>
<td>- MM$</td>
<td>- MM$</td>
<td>- MM$</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>- MM$</td>
<td>- MM$</td>
<td>- MM$</td>
</tr>
<tr>
<td>Natural Gas - Fuel:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Heater</td>
<td>0.00 MM$</td>
<td>0.61 MM$</td>
<td>0.61 MM$</td>
</tr>
<tr>
<td>Hydrogen Plant Feed</td>
<td>- MM$</td>
<td>- MM$</td>
<td>- MM$</td>
</tr>
<tr>
<td>Catalyst</td>
<td>0.00 MM$</td>
<td>0.02 MM$</td>
<td>0.02 MM$</td>
</tr>
<tr>
<td>Insurance</td>
<td>0.39 MM$</td>
<td>0.31 MM$</td>
<td>0.70 MM$</td>
</tr>
<tr>
<td>Local Taxes</td>
<td>0.00 MM$</td>
<td>0.00 MM$</td>
<td>0.00 MM$</td>
</tr>
<tr>
<td>Maintenance</td>
<td>3.62 MM$</td>
<td>2.90 MM$</td>
<td>6.52 MM$</td>
</tr>
<tr>
<td>Miscellaneous supplies</td>
<td>0.12 MM$</td>
<td>0.09 MM$</td>
<td>0.21 MM$</td>
</tr>
<tr>
<td>Plant staff and operators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery (57 persons)</td>
<td>0.00 MM$</td>
<td>0.29 MM$</td>
<td>0.29 MM$</td>
</tr>
<tr>
<td>Power Plant (17 persons)</td>
<td>0.09 MM$</td>
<td>0.00 MM$</td>
<td>0.09 MM$</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>4.26 MM$</strong></td>
<td><strong>4.24 MM$</strong></td>
<td><strong>8.50 MM$</strong></td>
</tr>
<tr>
<td>Contingency</td>
<td>0.21 MM$</td>
<td>0.21 MM$</td>
<td>0.42 MM$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4.48 MM$</strong></td>
<td><strong>4.45 MM$</strong></td>
<td><strong>8.92 MM$</strong></td>
</tr>
</tbody>
</table>
## Basis for Operating Costs:

- **Cooling water cost**: 0.2 $/mgal
- **Natural gas**: 5.53 $/mmBtu
- **Natural gas**: 21,500 Btu/lb
- **Insurance**: 1% of TIC
- **Local Taxes**: 0% of TIC
- **Maintenance**: 5% of TIC
- **Misc Supplies**: 0.15% of TIC
- **Payroll Burden**: 5,000 $/year/person
- **Contingency**: 5% of Op Costs
- **Uptime**: 330 Days/year

## Notes:

1. Natural gas is utilized for all refinery fuel requirements (i.e. fired heaters).
2. The power plant supplies the refinery power requirements, which is deducted from electrical power for sale.
3. The power plant fuel requirements are either directly from crude oil or resid oil produced in the refinery (see note 4).
4. For case 2B (summer), 16.56 Mlb/hr of natural gas is required to maintain constant electrical power export from the power plant during the period that asphalt is produced. Other operating costs are approximately the same year round.
5. Additional items such as corporate overhead, research and development and sales expense are not included.
6. For Case 2B, the operating cost for the limestone utilized for treating the flue gas from the power plant boilers is estimated at approximately $2,050/stream day. This cost is not included in the table above.
5.3.5 Total Installed Cost Summary

5.3.5.1 TIC Summary Table

The following tables give the Total Installed Cost summaries for Case 2A and 2B.

**Case 2A**

<table>
<thead>
<tr>
<th>PROCESS UNITS</th>
<th>Normal Capacity</th>
<th>Total TIC, MM$ (Atm Unit Only)</th>
<th>Total TIC, MM$ (Atm + Vac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Crude Unit, BPSD</td>
<td>10,000</td>
<td>21.0</td>
<td>21.0</td>
</tr>
<tr>
<td>Desalting Unit, BPSD</td>
<td>10,000</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Vacuum Distillation Unit, BPSD</td>
<td>5,780</td>
<td></td>
<td>18.6</td>
</tr>
<tr>
<td>Sour Water Stripper, gpm</td>
<td>12</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Total Refinery (ISBL) =</td>
<td>22.7</td>
<td>41.9</td>
<td></td>
</tr>
</tbody>
</table>

| POWER PLANT, MW | 141 | 113.2 | 113.2 |
| Total Power Plant (ISBL) = | 113.2 | 113.2 |

<table>
<thead>
<tr>
<th>COOLING WATER SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery</td>
</tr>
<tr>
<td>Power Plant</td>
</tr>
<tr>
<td>Total Cooling Water =</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TANK FARM / STORAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Tank Farm / Storage =</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OFFSITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery</td>
</tr>
<tr>
<td>Power Plant</td>
</tr>
<tr>
<td>Total Offsite =</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GRAND TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery and related offsites</td>
</tr>
<tr>
<td>Power Plant and related offsites</td>
</tr>
<tr>
<td>CASE 2A GRAND TOTAL=</td>
</tr>
</tbody>
</table>

$MTIC/MW = 950
Environmental Considerations to meet World Bank Environmental Assessment Guidelines (WBEAG):

A. For the Power plant, add $34MM for Flue Gas Treatment to reduce "SOx" and add $4MM for additional Waste Water Treatment requirements. It is uncertain whether additional facilities are required for "NOx" and particulate matter (PM) removal. Refer to report section 3.1.1 for further discussion on this topic.

B. For the Refinery, add $3MM for Waste Water Treatment.

Notes:
1. TIC values are on a U.S. Gulf Coast basis.
2. No contingency has been included for the overall TIC.
3. For a listing of cost estimate exclusions refer to Report section 4.3.0.
4. TIC values include design margins where appropriate for crude with a higher API and sulfur content. Refer to Basis of Design for more information.
5. A conventional Power plant is used including steam boilers and steam turbines. Air cooling is used for surface condensers.
6. Refinery Steam is supplied from the Power Plant boilers.
7. If the Power plant is removed from the scope, the Power plant offsites can be removed and the Refinery Offsites will remain the same.
8. For production values with no Vacuum Crude Unit, refer to Case 2 Production Summaries - Winter Case.
### Case 2B

<table>
<thead>
<tr>
<th>PROCESS UNITS</th>
<th>Normal Capacity</th>
<th>Total TIC, MM$ (Atm Unit Only)</th>
<th>Total TIC, MM$ (Atm + Vac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Crude Unit, BPSD</td>
<td>5,000</td>
<td>16.4</td>
<td>16.4</td>
</tr>
<tr>
<td>Desalting Unit, BPSD</td>
<td>5,000</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Vacuum Distillation Unit, BPSD</td>
<td>2,890</td>
<td></td>
<td>16.4</td>
</tr>
<tr>
<td>Sour Water Stripper, gpm</td>
<td>6</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Total Refinery (ISBL)</strong></td>
<td></td>
<td><strong>17.6</strong></td>
<td><strong>34.4</strong></td>
</tr>
<tr>
<td>POWER PLANT, MW</td>
<td>71</td>
<td>62.7</td>
<td>62.7</td>
</tr>
<tr>
<td><strong>Total Power Plant (ISBL)</strong></td>
<td></td>
<td><strong>62.7</strong></td>
<td><strong>62.7</strong></td>
</tr>
<tr>
<td>COOLING WATER SYSTEM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery</td>
<td>0.1</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Power Plant</td>
<td>0.4</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td><strong>Total Cooling Water</strong></td>
<td></td>
<td><strong>0.4</strong></td>
<td><strong>0.6</strong></td>
</tr>
<tr>
<td>TANK FARM / STORAGE</td>
<td></td>
<td><strong>10.7</strong></td>
<td><strong>13.6</strong></td>
</tr>
<tr>
<td><strong>Total Tank Farm / Storage</strong></td>
<td></td>
<td><strong>10.7</strong></td>
<td><strong>13.6</strong></td>
</tr>
<tr>
<td>OFFSITE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery</td>
<td>8.5</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>Power Plant</td>
<td>14.1</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td><strong>Total Offsite</strong></td>
<td></td>
<td><strong>22.6</strong></td>
<td><strong>28.6</strong></td>
</tr>
<tr>
<td>GRAND TOTAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery and related offsites</td>
<td></td>
<td><strong>36.9</strong></td>
<td><strong>62.8</strong></td>
</tr>
<tr>
<td>Power Plant and related offsites</td>
<td></td>
<td><strong>77.2</strong></td>
<td><strong>77.2</strong></td>
</tr>
<tr>
<td><strong>CASE 2B GRAND TOTAL =</strong></td>
<td></td>
<td><strong>$114.1</strong></td>
<td><strong>$139.9</strong></td>
</tr>
</tbody>
</table>

$\text{SMTIC/MW} = 1095$
Environmental Considerations to meet World Bank Environmental Assessment Guidelines (WBEAG):

A. For the Power plant, add $15MM for Flue Gas Treatment to reduce "SOx" and add $2.6MM for additional Waste Water Treatment requirements. It is uncertain whether additional facilities are required for "NOx" and particulate matter (PM) removal. Refer to report section 3.1.1 for further discussion on this topic.
B. For the Refinery, add $2MM for Waste Water Treatment.

Notes:
1. TIC values are on a U.S. Gulf Coast basis.
2. No contingency has been included for the overall TIC.
3. For a listing of cost estimate exclusions refer to Report section 4.3.0.
4. TIC values include design margins where appropriate for crude with a higher API and sulfur content. Refer to Basis of Design, Report section 5.0.0 for more information.
5. A conventional Power plant is used including steam boilers and steam turbines. Air cooling is used for surface condensers.
6. Refinery Steam is supplied from the Power Plant boilers.
7. If the Power plant is removed from the scope, the Power plant offsites can be removed and the Refinery Offsites will remain the same.
8. For production values with no Vacuum Crude Unit, refer to Case 2 Production Summaries - Winter Case, Report section 5.3.3.

5.3.5.2 Sensitivity Analysis for Location Change

The cases presented have assumed a location near the crude oil production fields. The Consultant performed a sensitivity analysis for Case 2A for a location change to a site near a city. An economic overview of the alternate is that the site near the city increases the cost of transporting the crude oil to the refinery but decreases the cost of transporting the Diesel product and the electric power to their markets.

For the base case near the production fields, it has been assumed that the crude oil would be delivered by pipeline. The short pipeline would be almost an extension of the gathering system. It has also been assumed that the Diesel product would be delivered by truck.

In the alternate case near the city, the crude oil would be transported by truck. The Diesel would continue to be transported by truck, but the trucks would be local delivery rather than long-distance trucks. The local delivery trucks are
assumed needed in either case, so they do not enter into the analysis. The economic factors for the change to the alternate location would thus be:

- Add truck loading arms at the production site.
- Add truck unloading arms at the refinery.
- Reduce the electric transmission line and possibly a substation.
- Add loading, unloading, and driver manpower.
- Add trucks.
- Add truck operating expense.

The net increase in capital costs associated with the location change away from the production fields is estimated at $10.4 MM.

This number is determined by assuming that nine loading and unloading stations are used at the well head and at the crude tanks such that nine trucks per hour can be utilized for 10 hours per day. The truck loading stations at the well head are estimated at $10.8 MM TIC. The truck unloading stations at the crude storage tanks are also estimated at $10.8 MM TIC. The TIC for each loading station is $1.2 MM. The cost to install transmission lines in mountainous terrain is $0.15 MM/Mile TIC. This value does not include hostile environment, right of way, or use of helicopters for installation of towers. Assuming that the refinery is moved 75 miles to be near the city, the TIC for the transmission line is $11.3 MM. The net is $10.8 MM times 2 minus $11.3 MM = $10.4 MM.

In addition to the economic factors, there are several qualitative factors that may be considered. The positive factors for locating near the city are:

- There is less electric transmission line to maintain and secure.
- Better aesthetics with the shorter transmission line.
- Better manpower pool for construction and operation.
- Better stores, services, transportation, communications etc.

The negative factors are:

- The refinery is less secure in a high-traffic area.
- There is more truck traffic and road maintenance.
- Production storage does not act as refinery storage.

Another consideration might be whether to utilize a pipeline to transport the crude from the wells to the refinery. This option is fairly costly and provides a less reliable source of supply, especially in Afghanistan, since a pipeline is more easily interfered with than numerous trucks.
5.4 Case 3 - Integrated Refinery

5.4.1 Case Descriptions (3A and 3B)

5.4.1.1 Overview

The crude oil feed rates in these cases are 10,000 B/SD for Case 3A and 15,000 B/SD for Case 3B. Except for the feed rates, the cases are identical. These cases have refining units to produce transportation fuels plus an electric power plant. The major processing units are given below with their feed rates. The feed rate for Case 3A is given first, and that for Case 3B second.

- Atmospheric Crude Tower
- Vacuum Tower (5,780 B/SD; 8,670 B/SD)
- Visbreaker (5,780 B/SD; 8,670 B/SD)
- Gas Plant
- Merifiner (222 B/SD; 334 B/SD)
- Naphtha Hydrotreater (1,199 B/SD; 1,799 B/SD)
- Reformer (1,233 B/SD; 1,849 B/SD)
- Hydrogen Plant (974 Lb/Hr; 1,461 Lb/Hr)
- Jet / Diesel Hydrotreater (2 B/SD; 4 B/SD)

The supporting process units are:

- Sour Water Stripper
- Amine Regenerator (46 GPM; 69 GPM)
- Sulfur Plant (10.9 LT/SD; 16.4 LT/SD)
- Tail Gas Treater (0.6 LT/SD; 0.8 LT/SD)

The power plant units are:

- Steam Boiler (2 @ 480,000 Lb/Hr, 3 @ 480,000 Lb/Hr)
- Turbine-Generator (2 @ 45 MW; 3 @ 45 MW)

5.4.1.2 Processing Scheme

The Gas Plant receives a light ends stream and a combined naphtha stream from the atmospheric tower. From these streams, it produces several product streams. One is a light ends stream that goes to the refinery fuel gas system. This fuel gas is consumed internally and is not a final product. The gas plant also produces a liquefied petroleum gas (LPG) product that is a final product for external sale, and a stream of butanes that is blended into the gasoline. The gas plant produces a light naphtha stream that contains the C5’s and C6’s, including the benzene, and a heavy naphtha stream. A Merifiner removes the mercaptans from the light naphtha. A hydrotreater removes the sulfur from the heavy naphtha and a reformer increases its octane number. The two naphtha streams are blended with butanes from the gas plant to produce an unleaded, 87-octane gasoline.
In addition to the streams that go to the gas plant, the atmospheric tower produces a stream that contains the combined jet fuel and Diesel fuel cuts. The vacuum tower and the visbreaker produce some additional Diesel cut. The Jet/Diesel Hydrotreater removes the sulfur from these streams and saturates some of the aromatics. It then splits the jet fuel and the Diesel fuel as final products. The Diesel fuel is automotive grade Diesel.

The bottom stream can go to either the vacuum tower or the visbreaker. The vacuum tower produces vacuum gas oils and asphalt. Asphalt would be produced primarily during the summer, so this is when the vacuum tower operates and is termed the summer case. The operation when asphalt is not produced is termed the winter case. The fuel oil to the power plant is a blend of the vacuum gas oils in the summer case. Since the winter case produces more fuel oil for the power plant, the power plant uses natural gas as a supplemental fuel in the summer case to keep the production of electricity at the required level.

In the winter case, the atmospheric tower bottoms becomes feed to the visbreaker. The visbreaker thermally cracks the feed to produce light ends, light naphtha, heavy naphtha, and combined jet and diesel fuel cuts. The cracking also reduces the viscosity of the residual product. The residual product, containing all material heavier than Diesel, goes to the power plant as fuel.

The summer and winter cases have been presented as all-or-nothing on the production of asphalt. In the summer case, the visbreaker does not operate and all feed goes to the vacuum tower. In the winter case, the vacuum tower is shut down or its only function is to recover more Diesel range material. It would, in fact, be possible to run intermediate cases where some asphalt is produced but not the maximum amount. The structure of the cases also provides enough information to allow other cases to be approximated. Removing the cost of the visbreaker and looking at the summer case would approximate a case without a visbreaker. Similarly, removing the cost of the vacuum tower and looking at the winter case would approximate a case without a vacuum tower and without the capability to produce asphalt. An additional sub case of the summer case could be considered by feeding the vacuum gas oils to the visbreaker and running it as a thermal cracker. This would produce more light products at the expense of fuel oil to the power plant.

5.4.1.3 Processing Unit Details

The assay indicates that there are very small amounts of the light components present in the crude. It is suspected that the sample had weathered, and that a large part of the light ends were lost. This will have to be checked when a fresh assay is available, and may increase the yield of LPG and butanes. This would also affect the size of the gas plant.

The gas plant comprises several towers and treaters. The first tower is a deethanizer that is a reboiled absorber-stripper. Debutanized naphtha enters the top of the absorber and absorbs propane and heavier material. The overhead vapor flows to a sponge absorber where jet range material is used as a sponge oil to absorb naphtha that vaporized in the absorber-stripper. The rich sponge oil recycles to the crude unit. The overhead vapor flows to an amine scrubber
where the amine absorbs hydrogen sulfide. The sweet gas then enters the refinery fuel system. At the bottom of the stripper section of the absorber-stripper, the reboiler drives off the ethane and lighter components. The bottom stream contains the propanes, butanes, and naphthas.

This naphtha stream flows to the deutronizer where the propanes and butanes are removed overhead. Part of this stream goes to the propane-butane splitter where the butanes are taken from the bottom. This butane stream provides the butane required to adjust the vapor pressure of the gasoline pool, and the rate of this stream is set to provide the required amount. Any excess butane and the part of the feed that bypasses propane-butane splitter joins the overhead to be treated in a Merifiner to remove mercaptans. It then becomes LPG product. The bottom stream from the deutronizer is split. Part of it is pumped back to the deethanizer absorber-stripper as the lean oil for the absorption that was described earlier. The other part flows to the naphtha splitter where the light naphtha; which includes the pentanes and hexanes, and benzene; is fractionated overhead. The heavy naphtha is the bottom product from the tower. The further processing of the naphtha streams will be described later.

The function of the atmospheric crude distillation unit is to separate the light ends, naphthas, jet fuel and Diesel fuel from the crude oil. The light ends and the naphthas are feeds to the gas plant. Their processing there has been described above. The processing of the combined jet and Diesel stream will be described later. The crude unit contains a desalter that removes salt from the crude oil as its name implies. The salt would increase the corrosion in the processing units if it were left in the crude. It would also increase the corrosion and fouling of the tubes in the steam boiler in the power plant.

The vacuum distillation unit operates at vacuum to remove additional cuts from the crude without requiring a temperature that would crack the crude excessively. Additional Diesel fuel is recovered in this unit. Two vacuum gas oil streams will probably be drawn to enhance heat recovery. For the summer case, the vacuum tower bottoms become asphalt. The asphalt is actually cut deeper than is needed and blended with heavy vacuum gas oil to provide close control on the properties to meet the asphalt specifications. The assay does not provide asphalt properties, so the predicted yield is an estimate based on an Arabian Heavy crude oil assay. The vacuum gas oils become fuel oil for the power plant.

The bottom stream from the atmospheric tower can go to the visbreaker instead of the vacuum tower. The visbreaker furnace heats the feed to such a temperature that the feed cracks thermally form lighter products. The furnace effluent goes to a tower similar to the atmospheric crude unit. As in that unit, the light ends and the naphthas go to the gas plant. There is also a combined jet and Diesel cut whose processing will be described next. The bottom stream from the tower becomes fuel oil for the power plant. The processing options of using the vacuum tower and the visbreaker have been described above in the Processing Scheme section.

The combined jet and Diesel cuts from the atmospheric tower and the visbreaker join and go to the jet/Diesel hydrotreater. The feed joins a hydrogen stream and flows through a heater into a catalytic reactor. Sulfur-containing compounds in
the feed react with the hydrogen to form hydrogen sulfide. The conditions are such as to also saturate some of the aromatics in the feed to meet the specifications for the fuel products. The recycle gas stream passes through an amine absorber where the amine absorbs the hydrogen sulfide. The liquid product goes first to a stripper where the light ends and naphtha range material are removed and sent to the gas plant. Then the product is fractionated into jet fuel and Diesel fuel streams. The split between the two products can be varied within limits.

The light naphtha from the gas plant is pumped through a Merifiner where the mercaptans are removed by caustic treating. The Merifiner produces a waste caustic stream which will be a liquid emission for disposal. Normally, this stream is collected by Merichem, but that may not work in Afghanistan. The sweetened light naphtha joins the gasoline pool.

The heavy naphtha from the gas plant flows to the naphtha hydrotreater where the sulfur and nitrogen are converted to hydrogen sulfide and ammonia, respectively. The unit is similar to the jet/Diesel hydrotreater that has already been described, but the reaction conditions are less severe. After the reaction section, there is only a stripper to remove light ends. The desulfurized naphtha goes to the reformer where paraffins and naphthenes are converted to aromatics. The reactors contain a noble-metal catalyst and there is a hydrogen recycle stream as in a hydrotreater. In this case, however, hydrogen is produced rather than consumed. The catalyst must be regenerated frequently. A swing reactor system was chosen to allow this to be done. This design has a lower capital cost and requires a less sophisticated operation than a continuous catalyst regeneration system. The reformer does not make enough hydrogen to supply the entire requirement of the refinery, so a hydrogen plant is required.

The hydrogen plant reacts natural gas and steam to make hydrogen and carbon monoxide in its first reactor, the reforming reactor. Note that the word reforming is used in a different sense here than in the naphtha reformer. The reaction is endothermic, so natural gas is also burned as a fuel to provide the heat. The second reactor, the shift conversion reactor, reacts the carbon monoxide with steam to produce more hydrogen and carbon dioxide. The carbon dioxide absorber, the third step, removes most of the carbon dioxide. The fourth step, the methanator, reacts any remaining carbon monoxide or carbon dioxide with hydrogen in a catalytic reactor to produce methane and steam. The last step is actually the reverse of what the plant is trying to do, but it is only a small clean-up step.

The sour water stripper is a stripping column to remove hydrogen sulfide from sour water so that it may be sent to the waste water treating plant. The amine regenerator is also a stripping column. It removes hydrogen sulfide and ammonia from the rich amine stream and returns lean amine to the various using units. The hydrogen sulfide from both strippers goes to the sulfur plant, a Claus process, where it is converted to elemental sulfur and steam. The tail gas treater, a SCOT unit, converts most of the remaining sulfur compounds to hydrogen sulfide, scrubs them with amine, and sends the amine to the amine regenerator. Elemental sulfur is a product of the sulfur plant.
The flue gas from the power plant contains too much sulfur dioxide to meet the World Bank Environmental Assessment Guidelines, so a flue gas scrubbing process is applied to remove it. There are also guidelines on nitrogen oxides and particulates, which the process may have to remove also. This will not be known until a more detailed design stage is reached. Nitrogen oxides are derived from atmospheric nitrogen, and the amount is not a direct function of the fuel oil properties as is the amount of sulfur oxides. The amount generated is a function of the burner design. It is possible that a Selective Catalytic Reduction unit will be required, but that is not in the estimate now.

The power plant uses conventional steam-turbine driven generators. Multiple trains keep the plant from losing such a large block of power during a shutdown. Natural gas will be used for startup, and then the fuel will be switched to the fuel oil. A small Diesel-driven generator is part of the facilities to provide a cold-start capability without relying on electrical power from the grid.

The tank farm will maintain a 5-day supply crude oil for the refinery, but this can be used as fuel oil in the power plant if a problem occurs in the refinery. This inventory should be sufficient because the plant is located so close to the production fields. The storage at the production facility will act as inventory for the power plant.

The utilities area will produce the utilities such as boiler feed water and instrument air that are required by the power plant. The steam boilers are so intimately connected with the generation of power that they will be thought of more as part of the power plant than as a utility. The maintenance and administration areas complete the facility.

The description above gives a broad picture of the case. The details are presented in the subsequent sections. Although the block flow diagram and plot plan are part of the details, they also help provide an overview of the case.

5.4.2 Process Configurations (Case 3A and 3B)

This section gives the block flow diagram, the plot plans, the utilities system list, and the offsite and infrastructure list.

5.4.2.1 Block Flow Diagram

This section contains the following block flow diagram:

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>400901-C3AB-B001</td>
<td>Case 3A and 3B</td>
</tr>
<tr>
<td></td>
<td>Integrated Refinery</td>
</tr>
<tr>
<td></td>
<td>Block Flow Diagram</td>
</tr>
</tbody>
</table>
### 5.4.2.2 Plot Plan Requirements (Case 3A and 3B)

This section contains the following plot plans:

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>400901-C3A-A001</td>
<td>Case 3A Integrated Refinery Plot Plan</td>
</tr>
<tr>
<td>400901-C3B-A001</td>
<td>Case 3B Integrated Refinery Plot Plan</td>
</tr>
</tbody>
</table>
5.4.2.3 Utilities Systems List

The utilities in the following list are included. Of these, only the steam, cooling water, and electric power generation are cost-estimated separately. The consumption of fuel gas is tabulated for its operating cost, while the capital cost is included with the minor utilities in the factor for the offsites and infrastructure. The remaining utilities are included in the minor utilities.

- High Pressure Steam Generation
- Medium Pressure Steam
- Low Pressure Steam
- Boiler Feed Water
- Condensate Collection
- Cooling Water
- Electric Power
- Natural Gas
- Refinery Fuel Gas
- Raw Water
- Treated Water
- Potable Water
- Fire Water
- Nitrogen
- Plant Air
- Instrument Air

5.4.2.4 Offsite and Infrastructure List

The offsites and infrastructure systems that are included in the cost estimate are listed below. The costs for these systems are lumped together and estimated as a percentage of the cost of the major facilities. This cost also includes some of the minor utility systems although they are listed under utilities above.

- Buildings
- Communication System
- Electric Power Distribution (but not Generation)
- Lighting
- Miscellaneous Interconnecting Piping
- Fire Water System
- Oily Water and Storm Water Drains
- Waste Water Treatment
- Flares
- Roads
- Walks
- Vehicles
- Product Blending Systems
- Product Loading Systems

The tankage is part of the offsites and includes the following refinery tanks for this case. Utility tanks such as raw water, treated water, and fire water are not
listed. One Diesel tank in this case is Diesel for internal consumption in the startup generator, not a product tank.

- Crude Oil Tanks
- Fuel Oil Day Tank
- LPG Bullets
- Butane Spheres
- Gasoline Tanks
- Jet Fuel tanks
- Diesel Product Tanks
- Asphalt Tanks
- De-icer Tank
- Corrosion Inhibitor Tank
- Detergent Tank
- Dry Slops Tank
- Wet Slops Tank
- Diesel Tank

The items covered are those that would be expected. Some items in the categories of extraordinary security and outside-the-fence are not included. These are listed in the cost estimating section under exclusions.
5.4.3 Production Capacity Summaries (Case 3A and 3B)

The table below presents the overall material balance for the summer operation for Cases 3A and 3B. In the summer operation, the vacuum tower produces an asphalt product whereas in the winter operation it does not and this material becomes part of the fuel oil sent to the power plant. Thus, the power plant sees less fuel oil in the summer operation. To prevent a reduction in the electric power output, the power plant fires natural gas as a supplemental fuel. For this reason, the electric power output in both operations is shown as the same.

After the overall material balances, other tables show the product properties for this operation. The first material balance is for Case 3A.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
<td>556</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>133,517</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>1,222</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>LPG</td>
<td>2,587</td>
<td>131.1</td>
<td>329</td>
</tr>
<tr>
<td>Gasoline</td>
<td>9,163</td>
<td>59.1</td>
<td>847</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>5,418</td>
<td>47.9</td>
<td>471</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>40,719</td>
<td>35.5</td>
<td>3,297</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>32,176</td>
<td>19.1</td>
<td>2,350</td>
</tr>
<tr>
<td>Asphalt</td>
<td>41,483</td>
<td>6.9</td>
<td>2,780</td>
</tr>
<tr>
<td>Sulfur</td>
<td>627</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Total</td>
<td>133,396</td>
<td></td>
<td>10,074</td>
</tr>
<tr>
<td>Electric Power Export, MW</td>
<td></td>
<td></td>
<td>77.6</td>
</tr>
</tbody>
</table>

**Notes**

1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the hydrogen plant and is not accounted for in the balance.
In general, the internal balances of the cases are not presented. However, the hydrogen balances are shown to illustrate the need for the hydrogen plant. The table below shows the summer operation for Case 3A.

<table>
<thead>
<tr>
<th>Hydrogen Balance - Case 3A (Summer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Requirement SCF/D</td>
</tr>
<tr>
<td>Naphtha Hydrotreater</td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
</tr>
<tr>
<td>Reformer</td>
</tr>
<tr>
<td>Hydrogen Plant</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
The table below presents the overall material balance for the summer operation for Case 3B.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
<td>834</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Crude</td>
<td>199,441</td>
<td>23.6</td>
<td>15,000</td>
</tr>
<tr>
<td>Total</td>
<td>200,275</td>
<td></td>
<td>15,000</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>1,833</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>LPG</td>
<td>3,881</td>
<td>131.1</td>
<td>494</td>
</tr>
<tr>
<td>Gasoline</td>
<td>13,744</td>
<td>59.1</td>
<td>1,270</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>8,127</td>
<td>47.9</td>
<td>707</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>61,079</td>
<td>35.5</td>
<td>4,945</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>48,265</td>
<td>19.1</td>
<td>3,525</td>
</tr>
<tr>
<td>Asphalt</td>
<td>62,225</td>
<td>6.9</td>
<td>4,170</td>
</tr>
<tr>
<td>Sulfur</td>
<td>940</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Total</td>
<td>200,093</td>
<td></td>
<td>15,112</td>
</tr>
<tr>
<td><strong>Electric Power Export, MW</strong></td>
<td></td>
<td></td>
<td><strong>115.9</strong></td>
</tr>
</tbody>
</table>

Notes
1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the hydrogen plant and is not accounted for, hence the small imbalance.
The table below presents the hydrogen balance for the summer operation for Case 3B.

<table>
<thead>
<tr>
<th>Hydrogen Balance - Case 3B (Summer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Requirement SCF/D</td>
</tr>
<tr>
<td>Naphtha Hydrotreater</td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
</tr>
<tr>
<td>Reformer</td>
</tr>
<tr>
<td>Hydrogen Plant</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

The table below shows the properties for the gasoline for the summer operation for Case 3. There is no difference in the properties between Case 3A and 3B.

<table>
<thead>
<tr>
<th>Gasoline - Case 3A or 3B (Summer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
</tr>
<tr>
<td>Gravity at 60 °F, °API</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
</tr>
<tr>
<td>Density, Lb/B</td>
</tr>
<tr>
<td>Sulfur, wppm</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Note 1)</td>
</tr>
<tr>
<td>Research Octane Number</td>
</tr>
<tr>
<td>Motor Octane Number</td>
</tr>
<tr>
<td>Road Octane Number (Note 2)</td>
</tr>
<tr>
<td>ASTM D-86 Distillation</td>
</tr>
<tr>
<td>10 LV%</td>
</tr>
<tr>
<td>50 LV%</td>
</tr>
<tr>
<td>90 LV%</td>
</tr>
<tr>
<td>100 LV%</td>
</tr>
</tbody>
</table>

Notes

1. RVP is controlled by blending butane.
2. The octane number can be controlled by adjusting the reformer severity.
The important properties of the jet fuel and the Diesel fuel can be controlled by the severity of the hydrotreating in the Jet/Diesel Hydrotreater. Consequently, the properties may be adjusted to meet the specifications and are not shown. The properties of the fuel oil are presented in the following table. There is no difference in the properties between Case 3A and 3B.

### Fuel Oil - Case 3A or 3B (Summer)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>19.1</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.9395</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>328.6</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>3.32</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>306</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g (Note 1)</td>
<td></td>
</tr>
<tr>
<td>Flash Point, °F</td>
<td>367</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>0.2</td>
</tr>
<tr>
<td>Pour Point, °F (Note 2)</td>
<td>85</td>
</tr>
<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>17,740</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>At 100 °F</td>
<td>93</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Salt, Lb/1000 B</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

**Notes**

1. An assay breakdown is not available.
2. An assay breakdown is not available. The estimate is based on Arabian Heavy and could be off.
The material balances and the product properties for the winter operation are shown next. The table below presents the overall material balance for Case 3A.

### Overall Material Balance - Case 3A (Winter)

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
<td>974</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>133,935</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>2,451</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>LPG</td>
<td>4,389</td>
<td>129.1</td>
<td>555</td>
</tr>
<tr>
<td>Gasoline</td>
<td>12,747</td>
<td>59.4</td>
<td>1,180</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>6,515</td>
<td>47.9</td>
<td>567</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>48,967</td>
<td>35.5</td>
<td>3,964</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>57,506</td>
<td>10.2</td>
<td>3,951</td>
</tr>
<tr>
<td>Asphalt</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1,002</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>133,577</td>
<td></td>
<td>10,217</td>
</tr>
<tr>
<td>Electric Power Export, MW</td>
<td></td>
<td></td>
<td>77.6</td>
</tr>
</tbody>
</table>

### Notes

1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the hydrogen plant and is not accounted for.
The table below shows the hydrogen balance for the winter operation for Case 3A.

<table>
<thead>
<tr>
<th>Hydrogen Balance - Case 3A (Winter)</th>
<th>Hydrogen Requirement SCF/D</th>
<th>Hydrogen Production SCF/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha Hydrotreater</td>
<td>184,098</td>
<td></td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
<td>1,984,786</td>
<td></td>
</tr>
<tr>
<td>Reformer</td>
<td>36,979</td>
<td>505,374</td>
</tr>
<tr>
<td>Hydrogen Plant</td>
<td></td>
<td>1,700,489</td>
</tr>
<tr>
<td>Total</td>
<td>2,205,863</td>
<td>2,205,863</td>
</tr>
</tbody>
</table>
## Overall Material Balance - Case 3B (Winter)

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
<td>1,461</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Crude</td>
<td>199,441</td>
<td>23.6</td>
<td>15,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>200,903</td>
<td></td>
<td>15,000</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>3,677</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>LPG</td>
<td>6,583</td>
<td>129.1</td>
<td>832</td>
</tr>
<tr>
<td>Gasoline</td>
<td>19,121</td>
<td>59.4</td>
<td>1,770</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>9,773</td>
<td>47.9</td>
<td>850</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>73,450</td>
<td>35.5</td>
<td>5,947</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>86,259</td>
<td>10.2</td>
<td>5,927</td>
</tr>
<tr>
<td>Asphalt</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1,503</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>200,366</td>
<td></td>
<td>15,325</td>
</tr>
</tbody>
</table>

### Electric Power Export, MW

**115.9**

### Notes

1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the hydrogen plant and is not accounted for.
The next table shows the hydrogen balance for the winter operation for Case 3B.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha Hydrotreater</td>
<td>276,147</td>
<td></td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
<td>2,977,179</td>
<td>758,060</td>
</tr>
<tr>
<td>Reformer</td>
<td>55,468</td>
<td>2,550,734</td>
</tr>
<tr>
<td>Hydrogen Plant</td>
<td>338,794</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3,308,794</td>
<td>3,308,794</td>
</tr>
</tbody>
</table>

The following table presents the gasoline properties for the winter operation for Case 3. The properties are the same for Case 3A and 3B.
<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>57.3</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.7497</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>262.2</td>
</tr>
<tr>
<td>Sulfur, wppm</td>
<td>9.3</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Note 1)</td>
<td>11</td>
</tr>
<tr>
<td>Research Octane Number</td>
<td>91.6</td>
</tr>
<tr>
<td>Motor Octane Number</td>
<td>82.4</td>
</tr>
<tr>
<td>Road Octane Number (Note 2)</td>
<td>87.0</td>
</tr>
<tr>
<td>ASTM D-86 Distillation</td>
<td></td>
</tr>
<tr>
<td>10 LV%</td>
<td>31</td>
</tr>
<tr>
<td>50 LV%</td>
<td>240</td>
</tr>
<tr>
<td>90 LV%</td>
<td>315</td>
</tr>
<tr>
<td>100 LV%</td>
<td>355</td>
</tr>
</tbody>
</table>

**Notes**

1. RVP is controlled by blending butane.
2. The octane number can be controlled by adjusting the reformer severity.

The important properties of the jet fuel and the Diesel fuel can be controlled by the severity of the hydrotreating in the Jet/Diesel Hydrotreater. Consequently, the properties may be adjusted to meet the specifications and are not shown. The properties of the fuel oil are presented in the following table. The properties are the same for Case 3A and 3B.
### Fuel Oil - Case 3A & 3B (Winter)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>10.2</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.9988</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>349.4</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>4.9</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>2,410</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
<td></td>
</tr>
<tr>
<td>Flash Point, °F</td>
<td>374</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>19.4</td>
</tr>
<tr>
<td>Pour Point, °F</td>
<td>100</td>
</tr>
<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>17,320</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>At 100 °F</td>
<td>1,460</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>3.5</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td>5.5</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>16.4</td>
</tr>
<tr>
<td>Salt, Lb/1000 B (Note 1)</td>
<td>?</td>
</tr>
</tbody>
</table>

**Notes**
1. The value is not available, but the crude will be desalted
The following table shows the estimated emissions from the plant. The refinery part of the plant is presented first. The winter operation is the controlling case and is the one presented. The summer operation is not presented.

<table>
<thead>
<tr>
<th>Description</th>
<th>Case 3A Value</th>
<th>Case 3B Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not known but small.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liquid Emissions (Water)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spent Caustic (Merifiner)</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Waste Water, gpm</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Boiler Feed Water Blowdown, gpm</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The fired heaters in the refinery use natural gas. The composition is not presently known and a composition of 100% methane is assumed. There may be some small content of sulfur compounds. Also, there will be some cracking in the furnaces that will generate a small amount of hydrogen sulfide. This will be burned and cause some emission of SO\(_x\). The cracking is not estimated at this level of detail, but will be small.

There will be a small stream of spent caustic from the Merifiner, but the amount has not been estimated.

The following table covers the power plant emissions for the winter operation of Case 3.
### Power Plant Emissions - Case 3 (Winter)

<table>
<thead>
<tr>
<th>Description</th>
<th>Case 3A Value</th>
<th>Case 3B Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{SO}_x$ as $\text{SO}_2$, t/d</td>
<td>5.9</td>
<td>8.8</td>
</tr>
<tr>
<td><strong>Solids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, t/d (Contains)</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Iron, t/d</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Nickel, t/d</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>Vanadium, t/d</td>
<td>0.010</td>
<td>0.015</td>
</tr>
<tr>
<td>Calcium Sulfate, t/d</td>
<td>142.2</td>
<td>213.3</td>
</tr>
<tr>
<td>(Gypsum, $\text{CaSO}_4\cdot2\text{H}_2\text{O}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liquid Emissions (Water)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste Water, gpm</td>
<td>159</td>
<td>239</td>
</tr>
<tr>
<td>Boiler Feed Water Blowdown, gpm</td>
<td>69</td>
<td>103</td>
</tr>
<tr>
<td>Rain Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility Water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The $\text{NO}_x$ emissions are not known at this stage. If the flue gas scrubber were not installed, the $\text{SO}_x$ emissions would be 58.8 t/d in Case 3A and 88.2 t/d in Case 3B. The ash content of the fuel oil is not known. The gypsum that is produced can be used as a building material and may be considered a byproduct rather than an emission. The rain water runoff from the process area and the utility water runoff have not been estimated at this time.
### 5.4.4 Operating Cost Summaries (Case 3A and 3B)

<table>
<thead>
<tr>
<th></th>
<th>Power Plant Annual Cost</th>
<th>Refinery Annual Cost</th>
<th>Total Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-up Water</td>
<td>0.07 MM$</td>
<td>0.04 MM$</td>
<td>0.12 MM$</td>
</tr>
<tr>
<td>Power</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Natural Gas - Fuel:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Heater</td>
<td>0.00 MM$</td>
<td>4.22 MM$</td>
<td>4.22 MM$</td>
</tr>
<tr>
<td>Hydrogen Plant Feed</td>
<td>0.00 MM$</td>
<td>0.92 MM$</td>
<td>0.92 MM$</td>
</tr>
<tr>
<td>Catalyst</td>
<td>0.00 MM$</td>
<td>0.19 MM$</td>
<td>0.19 MM$</td>
</tr>
<tr>
<td>Insurance</td>
<td>0.45 MM$</td>
<td>0.97 MM$</td>
<td>1.42 MM$</td>
</tr>
<tr>
<td>Local Taxes</td>
<td>0.00 MM$</td>
<td>0.00 MM$</td>
<td>0.00 MM$</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4.51 MM$</td>
<td>9.43 MM$</td>
<td>13.94 MM$</td>
</tr>
<tr>
<td>Miscellaneous supplies</td>
<td>0.14 MM$</td>
<td>0.29 MM$</td>
<td>0.43 MM$</td>
</tr>
<tr>
<td><strong>Plant staff and operators</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery (107 persons)</td>
<td>0.00 MM$</td>
<td>0.54 MM$</td>
<td>0.54 MM$</td>
</tr>
<tr>
<td>Power Plant (17 persons)</td>
<td>0.09 MM$</td>
<td>0.00 MM$</td>
<td>0.09 MM$</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>5.25 MM$</td>
<td>16.60 MM$</td>
<td>21.85 MM$</td>
</tr>
<tr>
<td>Contingency</td>
<td>0.26 MM$</td>
<td>0.83 MM$</td>
<td>1.09 MM$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.51 MM$</td>
<td>17.43 MM$</td>
<td>22.94 MM$</td>
</tr>
</tbody>
</table>

**Basis for Operating Costs:**
- Cooling water cost: 0.2 $/mgal
- Natural gas: 5.53 $/mmBtu
- Natural gas: 21,500 Btu/lb
- Insurance: 1% of TIC
- Local Taxes: 0% of TIC
- Maintenance: 5% of TIC
- Misc Supplies: 0.15% of TIC
- Payroll Burden: 5,000 $/year/person
- Contingency: 5% of Op Costs
- Uptime: 330 Days/year
Notes:
1. Natural gas is utilized for all refinery fuel requirements (i.e. fired heaters).
2. The power plant supplies the refinery power requirements, which is deducted from electrical power for sale.
3. The power plant fuel requirements are either directly from crude oil or resid oil produced in the refinery (see note 4).
4. For case 3A (summer), 19.78 Mlb/hr of natural gas is required to maintain constant electrical power export from the power plant during the period that asphalt is produced. Other operating costs are approximately the same year round.
5. Additional items such as corporate overhead, research and development and sales expense are not included.
6. For Case 3A, the operating cost for the limestone utilized for treating the flue gas from the power plant boilers is estimated at approximately $3,270/stream day. This cost is not included in the table above.

<table>
<thead>
<tr>
<th>Case 3B - Winter</th>
<th>Power Plant Annual Cost</th>
<th>Refinery Annual Cost</th>
<th>Total Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MM$</td>
<td>MM$</td>
<td>MM$</td>
</tr>
<tr>
<td>Make-up Water</td>
<td>0.11</td>
<td>0.07</td>
<td>0.18</td>
</tr>
<tr>
<td>Power</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Natural Gas - Fuel:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Heater</td>
<td>0.00</td>
<td>6.25</td>
<td>6.25</td>
</tr>
<tr>
<td>Hydrogen Plant Feed</td>
<td>0.00</td>
<td>1.38</td>
<td>1.38</td>
</tr>
<tr>
<td>Catalyst</td>
<td>0.00</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Insurance</td>
<td>0.66</td>
<td>1.22</td>
<td>1.88</td>
</tr>
<tr>
<td>Local Taxes</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Maintenance</td>
<td>6.55</td>
<td>12.01</td>
<td>18.56</td>
</tr>
<tr>
<td>Miscellaneous supplies</td>
<td>0.20</td>
<td>0.37</td>
<td>0.56</td>
</tr>
<tr>
<td>Plant staff and operators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery (107 persons)</td>
<td>0.00</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>Power Plant (17 persons)</td>
<td>0.09</td>
<td>0.00</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>7.60</strong></td>
<td><strong>22.12</strong></td>
<td><strong>29.72</strong></td>
</tr>
<tr>
<td>Contingency</td>
<td>0.38</td>
<td>1.11</td>
<td>1.49</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7.98</strong></td>
<td><strong>23.23</strong></td>
<td><strong>31.21</strong></td>
</tr>
</tbody>
</table>
## Basis for Operating Costs:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling water cost</td>
<td>0.2</td>
<td>$/mgal</td>
</tr>
<tr>
<td>Natural gas</td>
<td>5.53</td>
<td>$/mmBtu</td>
</tr>
<tr>
<td>Natural gas</td>
<td>21,500</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>Insurance</td>
<td>1%</td>
<td>of TIC</td>
</tr>
<tr>
<td>Local Taxes</td>
<td>0%</td>
<td>of TIC</td>
</tr>
<tr>
<td>Maintenance</td>
<td>5%</td>
<td>of TIC</td>
</tr>
<tr>
<td>Misc Supplies</td>
<td>0.15%</td>
<td>of TIC</td>
</tr>
<tr>
<td>Payroll Burden</td>
<td>5,000</td>
<td>$/year/person</td>
</tr>
<tr>
<td>Contingency</td>
<td>5%</td>
<td>of Op Costs</td>
</tr>
<tr>
<td>Uptime</td>
<td>330</td>
<td>Days/year</td>
</tr>
</tbody>
</table>

**Notes:**

1. Natural gas is utilized for all refinery fuel requirements (i.e. fired heaters).
2. The power plant supplies the refinery power requirements, which is deducted from electrical power for sale.
3. The power plant fuel requirements are either directly from crude oil or resid oil produced in the refinery (see note 4).
4. For case 3B (summer), 29.66 Mlb/hr of natural gas is required to maintain constant electrical power export from the power plant during the period that asphalt is produced. Other operating costs are approximately the same year round.
5. Additional items such as corporate overhead, research and development and sales expense are not included.
6. For Case 3B, the operating cost for the limestone utilized for treating the flue gas from the power plant boilers is estimated at approximately $4,900/stream day. This cost is not included in the table above.
5.4.5  Total Installed Cost Summaries (Case 3A and 3B)

5.4.5.1 TIC Summary Tables

The following is the TIC Summary Table for Case 3A. The table for Case 3B immediately follows this table.

<table>
<thead>
<tr>
<th>PROCESS UNITS</th>
<th>Normal Capacity</th>
<th>Total TIC, MM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Crude Unit, BPSD</td>
<td>10,000</td>
<td>21.0</td>
</tr>
<tr>
<td>Desalting Unit, BPSD</td>
<td>10,000</td>
<td>1.3</td>
</tr>
<tr>
<td>Vacuum Distillation Unit, BPSD</td>
<td>5,780</td>
<td>18.6</td>
</tr>
<tr>
<td>Visbreaker, BPSD</td>
<td>5,780</td>
<td>15.1</td>
</tr>
<tr>
<td>Saturates Gas Plant, MMSCFD</td>
<td>2.19</td>
<td>6.0</td>
</tr>
<tr>
<td>Merifining, BPSD</td>
<td>222</td>
<td>0.3</td>
</tr>
<tr>
<td>Naphtha Hydrotreater, BPSD</td>
<td>1,199</td>
<td>4.7</td>
</tr>
<tr>
<td>Refomer, BPSD</td>
<td>1,233</td>
<td>8.9</td>
</tr>
<tr>
<td>Jet/Diesel Hydrotreater, BPSD</td>
<td>4,621</td>
<td>18.2</td>
</tr>
<tr>
<td>Sour Water Stripper, gpm</td>
<td>12</td>
<td>1.0</td>
</tr>
<tr>
<td>Amine Regenerator, gpm</td>
<td>46</td>
<td>1.2</td>
</tr>
<tr>
<td>Sulfur Recovery, Lton/SD</td>
<td>10.91</td>
<td>6.4</td>
</tr>
<tr>
<td>Hydrogen Unit, MMSCF/SD</td>
<td>1.04</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Total Refinery (ISBL) = 107.0

| POWER PLANT, MW                        | 93              | 73.4          |

Total Power Plant (ISBL) = 73.4

<table>
<thead>
<tr>
<th>COOLING WATER SYSTEM</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Power Plant</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

Total Cooling Water = 2.0

<table>
<thead>
<tr>
<th>TANK FARM / STORAGE</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>41.9</td>
<td></td>
</tr>
</tbody>
</table>

Total Tank Farm / Storage = 41.9

<table>
<thead>
<tr>
<th>OFFSITE</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery</td>
<td>43.1</td>
<td></td>
</tr>
<tr>
<td>Power Plant</td>
<td>16.2</td>
<td></td>
</tr>
</tbody>
</table>

Total Offsite = 59.3
GRAND TOTAL

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery and related offsites</td>
<td>193.4</td>
</tr>
<tr>
<td>Power Plant and related offsites</td>
<td>90.1</td>
</tr>
<tr>
<td><strong>CASE 3A GRAND TOTAL</strong></td>
<td><strong>$283.6</strong></td>
</tr>
</tbody>
</table>

$MTIC/MW = 969

Environmental Considerations to meet World Bank Environmental Assessment Guidelines (WBEAG):

A. For the Power plant, add $22MM for Flue Gas Treatment to reduce "SOx" and add $3MM for additional Waste Water Treatment requirements. It is uncertain whether additional facilities are required for "NOx" and particulate matter (PM) removal. Refer to report section 3.1.1 for further discussion on this topic.

B. For Case 3A for the Refinery, add $2MM for Waste Water Treatment and $6MM for Tail Gas Treating.

Notes:

1. TIC values are on a U.S. Gulf Coast basis.
2. No contingency has been included for the overall TIC.
3. For a listing of cost estimate exclusions refer to Report section 4.3.0.
4. TIC values include design margins where appropriate for crude with a higher API and sulfur content. Refer to Basis of Design, Report section 5.0.0 for more information.
5. A conventional Power plant is used including steam boilers and steam turbines. Air cooling is used for surface condensers.
6. Refinery Steam is supplied from the Power Plant boilers.
7. If the Power plant is removed from the scope, the Power plant offsites can be removed and the Refinery offsites will remain the same.
The TIC Summary Table for Case 3B follows:

<table>
<thead>
<tr>
<th>PROCESS UNITS</th>
<th>Normal Capacity</th>
<th>TIC, MM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Crude Unit, BPSD</td>
<td>15,000</td>
<td>25.0</td>
</tr>
<tr>
<td>Desalting Unit, BPSD</td>
<td>15,000</td>
<td>1.6</td>
</tr>
<tr>
<td>Vacuum Distillation Unit, BPSD</td>
<td>8,670</td>
<td>20.0</td>
</tr>
<tr>
<td>Visbreaker, BPSD</td>
<td>8,670</td>
<td>23.0</td>
</tr>
<tr>
<td>Saturates Gas Plant, MMSCFD</td>
<td>3.29</td>
<td>7.6</td>
</tr>
<tr>
<td>Merging, BPSD</td>
<td>333</td>
<td>0.5</td>
</tr>
<tr>
<td>Naphtha Hydrotreater, BPSD</td>
<td>1,799</td>
<td>5.8</td>
</tr>
<tr>
<td>Reformer, BPSD</td>
<td>1,850</td>
<td>11.0</td>
</tr>
<tr>
<td>Jet/Diesel Hydrotreater, BPSD</td>
<td>6,932</td>
<td>22.5</td>
</tr>
<tr>
<td>Sour Water Stripper, gpm</td>
<td>18</td>
<td>1.3</td>
</tr>
<tr>
<td>Amine Regenerator, gpm</td>
<td>69</td>
<td>1.6</td>
</tr>
<tr>
<td>Sulfur Recovery, Lton/SD</td>
<td>16.37</td>
<td>7.5</td>
</tr>
<tr>
<td>Hydrogen Unit, MMSCF/SD</td>
<td>1.57</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Total Refinery (ISBL) = 132.9

POWER PLANT, MW: 140 110.5

Total Power Plant (ISBL) = 110.5

COOLING WATER SYSTEM

<table>
<thead>
<tr>
<th></th>
<th>Normal Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery</td>
<td>2.2</td>
</tr>
<tr>
<td>Power Plant</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Total Cooling Water = 2.9

TANK FARM / STORAGE

Total Tank Farm / Storage = 54.8

OFFSITE

<table>
<thead>
<tr>
<th></th>
<th>Normal Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery</td>
<td>55.0</td>
</tr>
<tr>
<td>Power Plant</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Total Offsite = 74.9

GRAND TOTAL

<table>
<thead>
<tr>
<th></th>
<th>Normal Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery and related offsites</td>
<td>244.9</td>
</tr>
<tr>
<td>Power Plant and related offsites</td>
<td>131.1</td>
</tr>
</tbody>
</table>

CASE 3B GRAND TOTAL = $376.0

$MTIC/MW = 936
Environmental Considerations to meet World Bank Environmental Assessment Guidelines (WBEAG):

A. For the Power plant, add $32MM for Flue Gas Treatment to reduce "SOx" and add $4MM for additional Waste Water Treatment requirements. It is uncertain whether additional facilities are required for "NOx" and particulate matter (PM) removal. Refer to report section 3.1.1 for further discussion on this topic.

B. For Case 3B for the Refinery, add $2MM for Waste Water Treatment and $7MM for Tail Gas Treating.

Notes:
1. TIC values are on a U.S. Gulf Coast basis.
2. No contingency has been included for the overall TIC.
3. For a listing of cost estimate exclusions refer to Report section 4.3.0.
4. TIC values include design margins where appropriate for crude with a higher API and sulfur content. Refer to Basis of Design, Report section 5.0.0 for more information.
5. A conventional Power plant is used including steam boilers and steam turbines. Air cooling is used for surface condensers.
6. Refinery Steam is supplied from the Power Plant boilers.
7. If the Power plant is removed from the scope, the Power plant offsites can be removed and the Refinery offsites will remain the same.

5.4.5.2 Cost for an Alternate with Fuel Oil Truck Loading Racks

The cost for an alternate to Case 3B was examined with a Fuel Oil truck loading facility in the refinery. This facility would be needed if the power plant were deleted. The facility would require two fuel oil product tanks and five truck loading bays. Note that the fuel oil does not meet the specifications for Number 6 Fuel Oil when asphalt is not produced. The sulfur and viscosity are too high; consequently, customers that are capable of handling this specific fuel oil will be required.

The total indicated cost for the facility is 9.6 million dollars on a present day, USGC basis. This assumes that the items are incremental additions and that all of the infrastructure has been paid for in the base cost for the plant.

The cost includes two 90,000 barrel fuel oil tanks @ $1.8 MM and five truck loading bays capable of a loading rate of 150 gpm @$1.2 MM. This gives a total of $9.6 MM. It is assumed that the cost of the items, such as the transfer pumps, that were in the base estimate to transfer the fuel oil to the power plant will be adequate to transfer it from the tanks to the truck loading bays. It is assumed that the pipe racks, fire water, and other utilities and offsites have been paid for in
the base case and do not require a supplemental charge for the addition of these items. As a result, the cost for these tanks is much less than their cost would have been as a part of the base case.
6.0 Cost Estimation

6.1 Overview

The Total Installed Costs (TIC) estimates in this report were determined as all-inclusive of a grass-roots facility, U.S. Gulf Coast. The estimating accuracy is approximately +/- 30 percent. Exclusions to the estimates are identified and included in next section of the report. The units are based upon using "stick built" standard construction techniques.

This report includes the estimated Total Installed Costs (TIC) for four primary cases listed below.

- Case 1: Maximum Power Generation (10,000 BPSD)
- Case 2A: Atmospheric Crude and Vacuum Distillation Refinery (10,000 BPSD)
- Case 2B: Atmospheric Crude and Vacuum Distillation Refinery (5,000 BPSD)
- Case 3A: Integrated Refinery (10,000 BPSD)
- Case 3B: Integrated Refinery (15,000 BPSD)

The TIC estimates include the costs for the total facilities associated with each case, although some items are excluded as indicated in section 6.3 below. While case 1 is a stand-alone power plant facility, cases 2 and 3A/B include power plant facilities to produce maximum power for residual fuel oil and products that cannot otherwise be sold because they do not meet specifications.

The TIC estimates for each case are included in the corresponding report section for each case.

For Case 2A, a sensitivity analysis for location change is included in the report. The analysis is based upon locating the refinery closer to Sheberghan rather than by the well head. The analysis includes an estimated cost difference associated with additional truck loading and unloading to transport the crude and reduced electrical transmission line requirements. Refer to report section 3.2.5.4 to review the detailed analysis and the corresponding cost numbers.

For case 3B, a cost estimate is provided for a fuel export option in the case that a power plant is not approved. This option is essentially a tank and truck loading rack. Refer to report section 5.4.5.2 to review a more detailed description and to locate the corresponding cost estimate information.

This report evaluated and determined the TIC for the four cases listed above. However, much additional information can be extracted from the report to allow analyzing various alternatives. For example, the TIC Summary Table for case 2 includes sufficient information to determine the economics with or without a Vacuum Unit. Likewise, the TIC Summary tables have been put together to easily remove the Power plant from any of the refinery cases. In this scenario, the fuel oil export estimate for case 3B should be used to determine the cost to export this material. For case 3, the TIC with and without the visbreaker and/or Vacuum unit is fairly straightforward to determine.

Also, capital cost exponent factors have been included for each processing unit and the power plant in report section 4 below. These exponents allow the flexibility to estimate capital costs at increased or decreased plant capacity.
Finally, a site conversion factor has been provided in report section 4, Cost Estimation, to convert the U.S. gulf coast estimate to an Afghanistan basis.

6.2 Methodology

The refinery and power plant TIC estimates were developed using a simplified approach based upon published cost data, in-house data, curve estimates, vendor input and use of factors for utilities, storage and offsites estimation.

Initially, the cases to be evaluated and the corresponding processing schemes were agreed upon.

A crude assay was thought to be available at the outset of the study. However, it was discovered that available distillation information and crude parameters were outdated and contradictory, and not sufficient in order to carry out the refinery study. In late April, a sufficiently large crude sample from Angot field was finally obtained, and after much difficulty, exported to India for a full crude assay. As the results of this assay will not be available until after the submission of this report, and because the oil supply forecasts are heavily dependent on Kashkari field supply, from which a sample is not possible to obtain at this point in time, the Consultant performed a GC distillation on a small sample of Angot crude. API gravity and sulfur as well as additional limited crude properties were also provided from the Angot field and adjusted for the differences between Angot and Kashkari to the extent these were documented. As Kashkari crude (which is in itself a combination of different types of lighter and heavy crude, ranging from 27.6 to 33.8 API Gravity, and varying Sulfur quantities) is a lighter crude than Angot, the economics of all scenarios should be more favorable. A Heavy Arabian crude assay was used as a further guide for the distribution of sulfur, metals and the product property determination.

Estimated product properties were compared to product specifications prescribed for the study to determine what products could be produced and sold for each case. Products that were not salable were then used as power plant fuel. The results for each case are presented in the Production Capacity Summaries for each case located in their respective report sections.

Using this approach, the capacity for each processing unit and power plant for each case was determined.

Cases 2A, 2B, 3A, and 3B, include a refinery. Once the material balances were determined, for these cases, the capacity for each processing unit was set. Because of limited crude analysis at this time, in some units design margins were applied to capacities to take into consideration that the final crude processed might have a higher °API or higher sulfur content. Refer to the report Section 5, Basis of Design, for a summary of the units that are affected.

With refinery processing unit capacities defined, published cost data, in-house data and curve estimates were utilized to determine TIC values for each unit. The TIC values were then fully escalated to reflect mid-2004 year pricing.

Known factors were then applied to estimate the cost of the cooling water systems, tank farm and storage facilities and the remaining utilities and offsites.

All cases include a power plant facility. A conventional power plant options was selected as the basis given the heavy crude and residual material that is utilized as fuel to the power plant. The
conventional approach includes steam boilers, steam turbines and air coolers for the surface condensers.

Late in the study some vendors responded that gas turbines may be able to fire the heavy residual materials. This approach could be a good alternative for the Afghanistan location. These turbines have been utilized in remote third world country applications such as South America. Multiple turbines can be utilized increasing redundancy and reliability. The turbines can be robust and potentially more easily maintained with the proper maintenance staff. The TIC for the conventional steam power plant is approximately $900 to 1000/kilowatt for the cases in this study (U.S. Gulf Coast). The TIC may be able to be reduced to approximately $700/kilowatt using gas turbines (U.S. Gulf Coast). This option should be evaluated further in future phases of study as applicable.

Steam turbine costs were obtained from a single vendor for 45 MW and 75 MW machines. A combination of vendor and in-house data were utilized for the remaining costs of the power plant including the TIC for boilers, air coolers, flue gas treatment, tank farm and storage and utilities and offsites.

The costs were determined as all-inclusive of a grass-roots facility, U.S. Gulf Coast. The estimating accuracy is approximately +/- 30 percent. Exclusions to the estimates are identified and included in next section of the report.

6.3 Exclusions Listing

The cost estimates presented in this report exclude certain items or certain categories of items. The exclusion of these items does not mean that they are not applicable or not important. The lack of information is one of the common reasons for excluding an item. Another is that a specific decision by the owner is required. The lists are provided so that they may be reviewed, decisions made, and the costs added if they are warranted.

The cost estimates in this report are generally based upon costs inside the fence line of the power plant and refinery facilities. Electrical power is brought to the fence line.

There are several general items that are excluded. These are:

- Land
- Site Preparation
- Taxes, Permits and Import Duties
- Construction Camp
- Security During Transportation
- Security During Construction
- Owner's or Lender's Project Teams
- Pre-Commissioning, Commissioning, and Plant Start-Up
- Working Inventories

The cost of land is not known and will be a function of the location of the plant. The taxes, permits and import duties are not known, nor is the possibility of an exemption for such a significant project.

The cost estimates provided in this report do not include any contingency.
Owner manpower not directly associated with running the plant is excluded. Examples would be:

- Corporate Executives
- Sales
- Distribution
- Accounting
- Purchasing
- Advertising
- Public Relations
- Legal
- Human Resources

Items that are not part of the plant proper are not included in the cost estimate. These outside-the-fence items should be reviewed if a project develops and the appropriate corrections made if some of them are necessary. The items are:

- Airstrip
- Bridges
- Food Service
- Hotel
- Housing
- Pipelines
- Power Lines
- Recreation
- Roads
- Railroads
- Stores
- Telephone Lines
- Satellite Communication

Roads and bridges need to be considered for transporting the equipment into the plant during construction as well as any need for them as part of a community.

Another category is that of extraordinary security items. Some of these may be desirable in Afghanistan at the present time, but they are not included. They should be reviewed if a project develops.

- Blast-Resistant Buildings
- Buffer Land
- Buried Lines
- Crash Resistant and Opaque Fence
- Earth-Covered Tanks
- Fire Water Ponds
- Guard Towers
- Increased Unit Spacing
- Increased Flare Load Cases
- Redundancy
- Separation or Isolation of Areas
Some increased unit spacing has been included, and the truck loading racks have been isolated on the periphery of the plant. These items are relatively inexpensive.

### 6.4 Capacity Cost Factors by Unit

The following table provides exponents and cost factors to utilize for determining capital costs for different capacities for the various units that have been studied in this report.

<table>
<thead>
<tr>
<th>PROCESS UNITS</th>
<th>Exponents for Process Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Crude Unit</td>
<td>0.36</td>
</tr>
<tr>
<td>Desalting Unit</td>
<td>0.45</td>
</tr>
<tr>
<td>Vacuum Distillation Unit</td>
<td>0.18</td>
</tr>
<tr>
<td>Visbreaker</td>
<td>0.65</td>
</tr>
<tr>
<td>Saturates Gas Plant</td>
<td>0.61</td>
</tr>
<tr>
<td>Merifining</td>
<td>0.65</td>
</tr>
<tr>
<td>Naphtha Hydrotreater</td>
<td>0.47</td>
</tr>
<tr>
<td>Reformer</td>
<td>0.51</td>
</tr>
<tr>
<td>Jet/Diesel Hydrotreater</td>
<td>0.59</td>
</tr>
<tr>
<td>Sour Water Stripper</td>
<td>0.55</td>
</tr>
<tr>
<td>Amine Regenerator</td>
<td>0.67</td>
</tr>
<tr>
<td>Sulfur Recovery</td>
<td>0.40</td>
</tr>
<tr>
<td>Hydrogen Unit</td>
<td>0.53</td>
</tr>
<tr>
<td>Power Plant</td>
<td>937.2</td>
</tr>
</tbody>
</table>

**Notes:**

1. These exponents should be applied using the equation:

   \[
   \text{Cost Plant 2} = \left( \frac{\text{Capacity Plant 2}}{\text{Capacity Plant 1}} \right)^{\text{Exponent}} \times \text{Cost Plant 1}
   \]

2. The exponents should only be utilized within a reasonable range of capacity (approximately 5,000 to 20,000 BPSD).

3. The factor for the power plant should be used as a multiplier, not an exponent.

   \[
   \text{Cost Plant 2} = \text{Capacity Plant 2 (Megawatts)} \times \left( \frac{\text{Total Installed Cost/MW}}{\text{Factor}} \right)
   \]

   The value is based upon a conventional power plant using steam boilers, steam turbines and air cooling for surface condensers. The value is based upon generating between 90 and 225 Megawatts utilizing 2 and 3 train configurations with either 45 or 75 MW steam turbines.
6.5 Conversion Factor from USGC to Afghanistan

Trade-offs exist between equipment and material pricing, transportation and freight to land locked northern Afghanistan, and lower labor costs along with lower productivities. All considered, we believe the cost to construct a unit in Afghanistan is approximately the same as the US Gulf Coast, perhaps slightly higher, but within the accuracy of the estimates of +/-30%.

Contracting and procurement methodology will play a significant role in establishing the costs for the facilities. A turnkey US or European contractor will likely increase the cost estimate by 30 to 50%. Asian or Middle Eastern contractors, particularly Chinese, Thai, Korean, Turkish, Gulf or Indian contractors should be able to deliver the project at or about US Gulf Coast prices. It is expected that significant project management involvement will be needed to ensure that cost, schedule and quality considerations are met in this case. The cost of project management and supervision should be budgeted at 4-5% of total facility cost.

A paper is included in the Appendix of this report titled, "Sources of International Cost Data", September 11, 1997, with partial updates through November 2003, by Dr. Kenneth K. Humphreys. Mr. Humphreys is Secretary-Treasurer of the International Cost Engineering Council. While the paper does not specifically include Afghanistan labor, productivity, or cost conversion factors, it can be a useful guide to understanding how these factors vary in different regions of the world.
7.0 Basis of Design

The basis of design comprises the crude assay, some instructions to allow for variations from the assay in gravity and sulfur content, the design rates, the product specifications, and some miscellaneous items. These elements of the basis of design are presented in the following sections.

7.1 Feed Basis

The feed basis consists of the crude oil composition and the feed rates for the various cases. These are presented in the following sections.

7.1.1 Crude Oil Composition

The crude oil properties for this study are from the assay of Angot crude by Core Laboratories. A summary of the properties is presented below. The complete assay is given in Appendix D.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity, °API</td>
<td>23.6</td>
</tr>
<tr>
<td>Carbon Residue – Micro, Wt%</td>
<td>8.4</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>2.65</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>588</td>
</tr>
<tr>
<td>Nickel + Vanadium, wppm</td>
<td>9.5</td>
</tr>
</tbody>
</table>

The crude assay is from a single sample from Angot, the heaviest. In the design, allowances have been made for a lighter crude, i.e., one with a higher °API, and for a crude with a 15% higher sulfur content. The design changes made to handle these changes from the presented assay are described below.

The capacities of the following units were increased by 15% to provide the flexibility to handle a lighter crude:

- Atmospheric Crude Unit
- Desalter
- Saturates Gas Plant
- Light Naphtha Merifiner
- Naphtha Hydrotreater
- Reformer
- Jet/Diesel Hydrotreater
- Hydrogen Plant
- Sour Water Stripper
7.1.2 Feedrate Bases for Cases

The feedrate bases for the various cases in the study are given in the table below.

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Feed Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Whole Crude to Power Plant</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>Atmospheric &amp; Vacuum Distillation</td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>Only</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>Atmospheric &amp; Vacuum Distillation</td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>Only</td>
<td>5,000</td>
</tr>
<tr>
<td></td>
<td>Atmospheric &amp; Vacuum Distillation</td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>Integrated Refinery</td>
<td>10,000</td>
</tr>
<tr>
<td>3B</td>
<td>Integrated Refinery</td>
<td>15,000</td>
</tr>
</tbody>
</table>

7.2 Product Specifications

7.2.1 Case 1 - Maximum Power Generation

There are no petroleum products in this case; consequently, there are no product specifications.

7.2.2 Cases 2A and 2B - Atmospheric and Vacuum Distillation

The only petroleum product in Case 2 is a wide-cut Diesel fuel. This Diesel fuel will meet the Pakistan State Oil Company, Ltd., (PSOCL) specifications for their Light Diesel Oil. Note that this name is misleading and that this is like a marine or railroad Diesel, not an automotive Diesel. The complete specifications are given in Appendix C.
7.2.3 Case 3A and 3B - Integrated Refinery

The petroleum product specifications are outlined below.

Liquefied Petroleum Gas. The LPG will meet the specifications of GPA Standard 2140 for Butane-Propane mixtures. Because this standard is so brief, it is given in its entirety here.
GPA Liquefied Petroleum Gas Specifications  
GPA Standard 2140

<table>
<thead>
<tr>
<th>Product Characteristics</th>
<th>Commercial B-P Mixtures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>Predominantly mixture of butanes and/or butylenes with propane and/or propylene.</td>
</tr>
<tr>
<td>Vapor Pressure at 100 °F, psig, max</td>
<td>208</td>
</tr>
<tr>
<td>Volatile residue:</td>
<td></td>
</tr>
<tr>
<td>Temperature at 95% evaporation, ° F, max. or Pentane and heavier, liquid volume percent, max</td>
<td>36.0</td>
</tr>
<tr>
<td>Corrosion, copper strip, max</td>
<td>No. 1</td>
</tr>
<tr>
<td>Volatile sulfur, grains per 100 cu ft, max.</td>
<td>15</td>
</tr>
</tbody>
</table>

**Gasoline.** The gasoline will be an 87-octane, unleaded gasoline. It can meet the following specifications:

   ASTM D 4814-03a Automotive Spark-Ignition Engine Fuel
   Pakistan State Oil Co., Ltd., Premium Plus (SGP)

The ASTM specification is presented in full in Appendix A, and the PSOCL specification is presented in Appendix C.

**Jet Fuel.** The jet will meet the following specifications:

   ASTM D1655-03a Aviation Turbine Fuels for Jet A-1
   NATO F-34 & F-35

The ASTM specification is presented in full in Appendix A, and the NATO specification is presented in Appendix B.

**Diesel Fuel.** The Diesel fuel will meet the following specifications:

   ASTM D975-04 Diesel Fuel Oils for Grade No. 2-D
   NATO F-54
   Pakistan State Oil Co., Ltd., High Speed Diesel

The Pakistani specification calls for a Cetane Index of 45. The sulfur will be less than the specification of 0.5 Wt% because all of the Diesel pool will be
hydrotreated for aromatics reduction, but it will not be low enough to be a low sulfur Diesel.

The ASTM specification is presented in full in Appendix A, the NATO specification is presented in Appendix B, and the PSOCL specification is presented in Appendix C.
8.0 Design Considerations

8.1 Overview

This section covers items in two general categories. The first has to do with some choices that were made during the study and aspects of the study. These items, in one sense, add to those in the methodology section of the discussion on cost estimating. Since the prime focus of the study is the cost estimate, there is not much distinction between design methodology and cost estimating methodology. Qualitative considerations about the execution of the project make up the second category. These particularly concern building a major project in Afghanistan. The considerations are presented in the next section as a series of independent items in no particular order.

8.2 Specific Considerations

The catalytic refinery processes are typically done as licensed processes, at least for large units. To be conservative, a licensing fee has been included in the cost estimate for the units in this study. Units this small would normally be done as open art unless there were other considerations. There is less value in the licensor's better data for yields and catalyst life in small units. The fee for the basic design would be the same as for a large unit, and a minimum licensing fee might be encountered. If open art without a process guarantee would be acceptable to the lending institutions, it should be considered.

The boilers in the power plant provide the steam requirement for the refinery. Consequently, these boilers are oversized so that any boiler can provide the full requirement of the refinery in the event that it is the only boiler running.

The split between water cooling and air cooling is arbitrarily fixed in cost-curve type estimating and tilts toward water cooling. The split between steam turbines and electric motors similarly tilts toward electric motors. These would be revised during an actual design and should not be thought of as indicating what would actually be done. If water supply is a problem, air cooling would be maximized.

Plant design should emphasize reliability and simplicity. The operating staff is unlikely to be highly skilled, at least initially. In the study, these considerations influenced the choice of a reformer design with swing reactor regeneration over continuous catalyst regeneration. Dust is a specific problem and required some robust design choices.

The training of construction personnel needs to be considered in the construction budget and schedule. Sufficient numbers of skilled construction workers are unlikely to be available. The employment of local labor may be an objective of the project and may prevent the use of large numbers of skilled expatriate workers.

The training of the operating staff also needs to be planned. Again, sufficient numbers of skilled workers are unlikely to be available. There are companies that specialize in training that could provide the necessary training. It should be possible to place key operating personnel in operating refineries for training. The operating engineers could be placed in residence in the design offices to become familiar with their units as they are being designed. The Initial
Operations staff can do some training during the startup. There are many possibilities, but the cost of any of them has not been included in the estimate and must be considered separately.

The transportation of equipment to the job site is an issue. Afghanistan is landlocked and does not have any ports. A port, such as Karachi in Pakistan would have to be used. There are no also no operating railroads. The roads are in poor repair and many are unpaved. The transportation considerations may limit the size of the equipment items that could be transported and would need to be known prior to detailed design. This may put a limitation on some alternate schemes such as purchasing a used refinery or doing modular construction. Local trucking companies may not have the necessary truck and some trucks would have to be specially leased. Security during transportation will also be a problem. In addition to terrorists and bandits, passing through territory not under the firm control of the central government could subject the shipments to the imposition of passage fees by the local warlords. One way, albeit an expensive one, to avoid some of these problems would be to ship as much as possible by air to Mazar-E-Sharif. Large cargo planes are available that can carry some fairly large pieces. This would add significantly to the construction cost.

Security during construction to protect both the equipment and the personnel is an issue. In addition to the project’s security, vendors may plan to bring their own security services and include the cost in their bid. The pay incentives to get their personnel to go to Afghanistan may increase the price.

The location of the project affects the costs. An analysis of the change in location from near the production fields to near a city is presented in Section 5.

The lack of infrastructure may be a problem, and may require a project to build infrastructure ahead of the main project. The power plant includes a Diesel generator to provide a cold-start capability without drawing electrical power from the grid. It may be necessary to install this generator early to provide electric power for construction.

Petroleum products are presently being supplied from outside the country, so a distribution network of some kind must exist. The products could be supplied from the project refinery without any further investment in the distribution network. The same is not true of the electric power. In addition to the transmission line to tie into the existing grid, further investment in the grid may be required to get the power to the consumers.
9.0 Pre-Owned Equipment Alternative

9.1 Overview

This section summarizes the results of the effort made in support of the pre-owned equipment alternative. Search was made for pre-owned refining facilities, either idled or immediately available, that would be suitable for the required service. Of the pre-owned refineries considered, two were identified as possible candidates for immediate relocation and operation in Afghanistan. These have nominal capacity of 6,000 BPSD, and 17,000 BPSD respectively. The first one was determined to be suitable and economical, and is discussed below. The second one would be more expensive to refurbish and relocate because the larger equipment is more difficult to modularize and transport to the site. Therefore the larger unit was not considered further, and is not described here.

Evaluation was made for processing the design basis crude in the selected unit. Information on the facility was used to estimate the achievable throughput.

The work that would be necessary to make the 6,000 BPSD pre-owned refinery fully functional at the Afghanistan site was addressed. Only the power required for operating the refinery was considered. No additional power generation capability has been included. The use of locally available labor, material, and engineering/management services and operating personnel is assumed for the purpose of estimating capital cost and annual operating cost. The existing tanks, connecting piping, and control systems, although available for sale, were not included in the basis for the evaluation.

Preliminary results are very encouraging and indicate the 6000 BPSD unit to be a more economical and viable option for the Case 2 product configuration as compared with the grass-roots option. Further investigation will need to be undertaken to define the overall cost estimate and schedule for implementing this option. It is recommended to pursue this option by taking the following steps as soon as possible, while the equipment is still available:

- Make a site visit to better assess the equipment. It may be possible that more equipment than has been assumed can be refurbished and utilized (i.e. storage tanks, etc.), which can reduce costs even further.
- Perform a definitive process evaluation utilizing equipment data and drawings provided by the seller.

9.2 Refurbished 6,000 BPSD Refinery

9.2.1 Description of the Pre-Owned Equipment

This topping unit, located in U.S., was placed in service in June 1990 and was shut down in April 1999. Some of the equipment (e.g. the vacuum heater) was already present at the site prior to this time. The unit is currently intact with all the equipment in a stand-by mode. When in operation this unit had a design capacity of 6,000 BPSD of crude oil with API gravities ranging from 30 to 35, but
has been reportedly operated at higher throughputs, as discussed in section 9.2.2 below.

The crude unit is capable of producing full-range naphtha, kerosene, diesel, atmospheric gas oil, and residual fuel oil. The unit can also produce military jet fuel in lieu of kerosene. The vacuum tower was used to produce asphalt for the roofing industry.

The refinery consists of two process skids plus a fired heater which is block mounted (Refer to the attached Plot Plan). The crude received from the storage is routed through the preheat train to the Desalters (Refer to the attached PFD's). Crude preheat is accomplished with inlet shell and tube heat exchangers where heat is exchanged with kerosene, diesel, diesel pumparound, gas oil and topped crude. The desalted crude is preheated further and then sent to the crude heater. Fractionation process includes the main atmospheric crude tower plus side strippers for naphtha, kerosene and diesel. Air cooling is provided for condensing atmospheric tower overhead and for cooling diesel and topped crude products. The atmospheric tower bottoms is further heated in the vacuum heater, and sent to the vacuum tower. Vacuum resid or asphalt is produced from the vacuum tower bottoms. The overhead is cooled and condensed via the jets that maintain vacuum in the tower.

### 9.2.2 Unit Capacity and Products

The original design capacity of the unit was 6,000 BPSD of crude oil with API gravities ranging from 30 to 35. The unit was operated at 8,000 to 9,000 BPSD of 32 API crude with indication that some of the pumps and other equipment (e.g. the vacuum section) was the limit to higher capacities. The feed had 1-1.5 wt% sulfur. The jet fuel product (for the U.S military) and diesel were still meeting the specification. Prior to shutdown, the owner had reportedly undertaken studies to expand the refinery capacity even further.

After preliminary evaluation, it is estimated that the refinery will process the 24 API Afghan crude at 6,000 BPSD with the Case 2 product configuration. Further work is necessary to verify this as discussed later in this report.

The table below presents the estimated overall material balance for the summer operation for 6,000 BPSD throughput. It assumes operation with asphalt production (i.e. summer). Wide cut diesel properties are also included in a separate Table.

These results need to be defined and verified by further evaluation and study. The facility must be visited and systematically inspected. Physical and mechanical condition of the various components must be ascertained, and parts and equipment to be replaced identified. This will assure a viable life cycle of the unit.

Also, the processing capacity and limitation of the various systems, and of individual pieces of equipment need to be confirmed to establish the overall unit
capacity and potential bottlenecks. Inadequate equipment must be identified and any modifications defined. A design heat and material balance at the stipulated crude throughput needs to be prepared to define the rate and duty for each equipment and system. Existing equipment data sheets for each piece of equipment need to be obtained and reviewed for the calculated duty. Detailed P&ID’s are needed to allow verification of system hydraulics and capacity, etc.

<table>
<thead>
<tr>
<th>Overall Material Balance - 6000 BPSD (Summer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream</td>
</tr>
<tr>
<td>Feeds</td>
</tr>
<tr>
<td>Crude</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Products</td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
</tr>
<tr>
<td>Wide-Cut Diesel</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
</tr>
<tr>
<td>Asphalt</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
The following table presents the estimated properties for the wide-cut Diesel Fuel. The properties do not change between the summer and winter operation.

<table>
<thead>
<tr>
<th>Wide-Cut Diesel - 6,000 BPSD Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Property</strong></td>
</tr>
<tr>
<td>Gravity at 60 °F, °API</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
</tr>
<tr>
<td>Flash Point, °F (Note 1)</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
</tr>
</tbody>
</table>

Notes
1. Pensky-Martens Closed Cup at 20°C

### 9.2.2 Refurbishing of the Pre-Owned Equipment

The pre-owned equipment will be inspected at its present location, cleaned, dismantled in proper manner and shipped to Houston for refurbishing. Following refurbishing, the selected items to be included in the proposed refinery will be modularized for shipping to Afghanistan.

The pre-owned unit was shutdown and decommissioned in an organized and systematic way. The equipment was drained, flushed and purged. The exchanger bundles were pulled as considered necessary. It is not known if there is an inert blanket, but the equipment condition is reported to be good.

It is highly recommended that an early visit to the facility be made to inspect and determine the physical condition of the equipment and the extent that it can be re-utilized.

### 9.2.3 Additional Equipment for Fully Functional Refinery

To make the refinery fully functional, those pieces of equipment, or systems, including off-sites that are not taken to the site, will need to be replaced. As noted above, after evaluation of each piece of equipment for the required new duty, certain items may need to be modified or replaced. Other equipment such as tankage and offsite facilities will probably be best discarded and replaced with new ones at the site.
Following is a list of items and considerations for adding at the new site.

- Storage tanks at the job site in Afghanistan.
- Any ISBL equipment modifications identified upon further engineering evaluation.
- Instrumentation and control systems will be procured in the U.S. and shipped to Houston for programming.
- It is estimated that generators with total capacity of 750 kW will be required for the operation of the proposed refinery. The generators will be purchased most likely abroad in Europe or Asia and shipped directly to the site in Afghanistan.
- Miscellaneous items to make the refinery fully functional.

9.3 Advantages of Pre-Owned Equipment

9.3.1 Costs and Economics

Preliminary cost data are summarized in the following table where comparison is made with Case 2B i.e. 5,000 BPSD grass-roots unit. As can be seen the pre-owned unit option results in savings of about 40%.

<table>
<thead>
<tr>
<th>Item</th>
<th>5,000 BPSD Case 2B</th>
<th>6,000 BPSD Pre-Owned Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISBL</td>
<td>34.4</td>
<td>12.5</td>
</tr>
<tr>
<td>Tank Farm</td>
<td>13.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Offsites (Incl Util.)</td>
<td>14.7</td>
<td>13.0</td>
</tr>
<tr>
<td>Total</td>
<td>62.8</td>
<td>38.5</td>
</tr>
</tbody>
</table>

9.3.2 Schedule

It is estimated that the schedule for the refurbished unit from start to mechanical completion will be a total of 12 - 15 months. This reduces the typical schedule for a grass-roots unit by about half. The time savings result primarily in the time required to design, procure and fabricate a new grass-roots unit vs. simply checking and refurbishing the pre-owned unit.

An article titled "Effective Relocation of Existing Refining Units", by G. Grame and D. Posey is included in the Appendix E of this report, which concludes
similar reductions in capital cost and project schedule as has been estimated in this report.

9.3.3 Transportation

Transportation costs will be similar whether the equipment is new or refurbished assuming similar design is used.

9.3.4 Modular Design and Ease of Installation

Using a skid mounted refinery whether previously owned or brand new will have advantages in terms of ease of installation and reduced time in the field. The cost savings are primarily in installation labor and schedule.

9.4 Conclusions and Recommendations:

1. Information obtained thus far, and very preliminary calculations, indicate that the pre-owned topping facility can process 6,000 BPSD of the 24 API Afghan crude, with the Case 2 product configuration. Wide-cut diesel and asphalt will be produced.

2. A site visit needs to be made as the next step, to inspect and determine the present condition of the equipment, piping and other components of the existing facility.

3. Drawings including but not limited to the plot plan, PFD's, P&ID's, and equipment data sheets, instrument specifications, and other documentation need to be obtained to allow evaluation.

4. Heat and material balances need to be prepared for the stipulated throughput and product configuration, to define the capacity and duty spec for each equipment and system so an evaluation can be made. This evaluation will take approximately 10-12 weeks.
### 10.0 Financial and Economic Analysis

#### 10.1 Pricing and Model Inputs

##### 10.1.1 Crude Oil Disposition Options

This report considers twenty (20) different crude oil disposition options, which fall into the following three categories:

- Exporting the crude oil
- Consuming the crude oil directly as fuel for a new thermal power plant
- Refining the crude oil in Afghanistan to make transportation fuels, asphalt and fuel oil under 5,000, 10,000 and 15,000 BPD scenarios, and with or without asphalt production.

##### 10.1.2 Export Market for Afghan Crude Oil

Although there are a number of refineries in the region that could purchase Afghan crude, the optimum crude oil market for Northern Afghanistan is considered by the Consultant to be the Seidy Refinery in Turkmenistan. This is the closest refinery to Sar-I-Pul/Sheberghan (430 km), and is connected by rail to Kerki near the border between the two countries. The Seidy refinery has a nameplate capacity of 120,000 BPD and has the capabilities to process the types of crude found in Afghanistan; In addition, the Seidy refinery has been

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**Ilyas Charyev**, chairman of STC Turkmenneftegas, speaking on reconstruction and modernization of the Turkmenbashi and Seidy Oil Refineries, and principal routes, structure, and procedures to export hydrocarbons from Turkmenistan.

“We have two refineries: Turkmenbashi and Seidy. Production capacity at each of these sites in terms of primary oil refining is 6 million tonnes per year. This represents 5% of the oil capacity of the CIS, or 0.36% of world oil refining capacity. The Turkmenbashi refinery was opened in 1943, the Seidy refinery in 1991. The Seidy refinery is a new facility with a developed infrastructure. However, because it does not have a continuous source of hydrocarbon raw material in sufficient quantity (at least 4 million tonnes per year) the refinery is operated according to a cyclical scheme: accumulation of raw material refining accumulation. Most of the hydrocarbon raw material which is refined here, about 80%, is Kokdumalak crude with 2% Sulphur content, and Kokdumalak gas condensate with 0.85% sulphur content. The range of output includes straight run petrol, diesel fuel and fuel oil. The imbalance between design capacity and actual refined volume, as well as the higher sulphur content, means it is not possible to generate high quality oil products, nor to ensure uninterrupted work in the refinery, which would require substantial change to the existing refinery pattern. The main element in the reconstruction programme at Seidy will be to add bitumen production to the existing complex, a diesel fuel hyrofining unit, and a unit to generate extraction solvent. . . once we have secured guaranteed supplies of hydrocarbons to be processed for a fee, more than 2 million tonnes per year.”

Source: Oil & Gas of Turkmenistan / July 2002

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underutilized in the past years and is looking for suppliers of crude oil to increase its utilization. There are a number of options that can be considered when looking at sale and export of crude oil, among them: the crude could be sold to the refinery, or alternatively, a refining processing agreement could be signed whereby Afghanistan would get refined products in return. Only the former option is considered in this report.

10.1.3 Crude Oil and Product Prices

We have used a base case average crude oil price projection corresponding to the “World Bank Average” (hereinafter “WBA”) crude basket (priced equivalent to approximately WTI minus $1 per bbl) averaged over the last five years, equal to 25.80 $/bbl. The underlying assumption is that OPEC will continue to be successful in maintaining the OPEC basket of crude oil prices within a band of $22 to $28 per bbl. Given current industry projections for crude oil price based on increasing worldwide demand, we have assumed that this market condition is sustainable and thus have assumed 25.80 $/bbl as our base average world crude price for the analysis.

10.1.3.1 Afghanistan Crude Oil Prices

We have conservatively assumed the price of Afghanistan crude oil as a single export blend of crude of 23.6 API and 2.55% wt Sulfur content, based on the reserves of the Angot field. An average differential of $3.70 /bbl between the World Average crude oil price and Arabian Heavy (27 API) plus a $1.50 /bbl estimated as the differential between Arabian Heavy and Angot crude (23.6 API) yields $20.60 /bbl as the price a refiner should be willing to pay for Angot. The price of the Afghan crude oil for this base case is equivalent to $17.57 /bbl at the refinery gate, assuming that it will have to be moved by truck 230 Kilometers to Kerki inside the Turkmenistan border, and subsequently 200 Kilometers by rail to the Seidy (Turkmenabad) refinery where it will achieve the $20.60 /bbl price.

Table 10-A: Crude Price Projection Assumptions

<table>
<thead>
<tr>
<th>Crude</th>
<th>Base Price</th>
<th>High Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank Average Oil Price</td>
<td>25.80</td>
<td>34.80</td>
</tr>
<tr>
<td>Differential (WB-Arabian Heavy)</td>
<td>-3.70</td>
<td>-3.70</td>
</tr>
<tr>
<td>Arabian Heavy 27°</td>
<td>22.10</td>
<td>31.10</td>
</tr>
<tr>
<td>Differential (to 23° Angot)</td>
<td>-1.50</td>
<td>-1.50</td>
</tr>
<tr>
<td>Afghan Crude at Seidy refinery</td>
<td>20.60</td>
<td>29.60</td>
</tr>
<tr>
<td>Differential (Transportation)</td>
<td>-3.03</td>
<td>-3.03</td>
</tr>
<tr>
<td>Afghan Crude at Sheberghan</td>
<td>17.57</td>
<td>26.57</td>
</tr>
</tbody>
</table>

The Consultant has used Angot crude results for both refinery yield calculations as well as for crude oil pricing. Only an Angot crude sample was available for analysis. It should be noted that this results in a very conservative analysis of the refinery economics, as available data indicates that the remaining four fields’ reserves are lighter crudes at an approximate weighted average of 27 API, comparable to Arabian Heavy. Furthermore, the refinery product mix from lighter crude will be more favorable toward the lighter ends, hence increasing the net back of the refinery option.
In addition to the base crude case described above, a protracted high crude oil price scenario is presented using recent (May 2004) crude oil prices, which correspond to a steady WBA price of $34.80 /bbl. This scenario assumes that world crude prices will maintain an average price over the next 15 years equal to today’s prices. The price of the exported Afghan crude oil for this case is equivalent to $26.57 /bbl at the refinery gate.

Figure 10-1 below shows the various crude oil price projections for both the base case and high price scenarios.

10.1.3.2 Afghanistan Product Prices

The World Bank’s historical correlation between products and crude oil was used as the conversion factor to determine forecast petroleum product prices, applied to the WBA crude price. Transportation costs to Sheberghan were then factored in to obtain what would represent projected prices at the new refinery gate in Sheberghan.

In order to confirm the validity of this projection, the projected product price differentials were then applied to the High Price Scenario, the appropriate transportation costs applied, and the resulting projected prices were compared to current Afghanistan market prices for petroleum products. The results were within +/- 10% of product prices obtained from the Consultant’s product price.

7 Transportation costs within Afghanistan were determined from an in-country survey of transportation companies and individual transporters. The routes in the survey included Sheberghan-Mazar, Mazar-Kabul, Kabul-Pakistan Border, Sheberghan-Heart, Heart-Pakistan Border, Sheberghan-Turkmenistan Border, and Heart-Iran Border. Although the prices varied among suppliers, they generally were in the range of USD 0.07 per kilometer-ton.
surveys in Kabul, Mazar-E-Sharif and Sheberghan\(^8\). The only substantial exception to this rule is jet fuel, which is currently selling in Kabul for almost $500 per ton, significantly higher than gasoline at an average of $430 per ton, and not in line with the historical correlations (or conventional market pricing).

The historical coefficients used are depicted graphically in Figure 10-2, and are listed in Table 10-B at the end of this section.

**Figure 10-2: World Bank Petroleum Price Differentials 1986-2003 (as % of crude)**

For export of fuel oil from Sheberghan to Pakistan, we have assumed international fuel oil prices in Islamabad less transportation costs to Sheberghan, based on the assumption that Turkmenistan, Uzbekistan and Iran would not provide a market for HSFO.

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\(^8\) A product price survey was performed to determine both wholesale and retail prices of petroleum products in Kabul, Sheberghan and Mazar-E-Sharif. It was interesting to note that products varied not only by type, but also by origin; that is, diesel fuels of different origins had slightly different prices, even though the provenance was not easily established, nor the quality of the fuel easily determined.
### Table 10-B: Petroleum Product Correlation Coefficients

<table>
<thead>
<tr>
<th>Product</th>
<th>Relative Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>124.65% of Crude Oil price</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>123.88% of Crude Oil price</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>120% of Crude Oil price</td>
</tr>
<tr>
<td>Kerosene</td>
<td>116.53% of Crude Oil price</td>
</tr>
<tr>
<td>High Sulfur Fuel Oil (HSFO)</td>
<td>75.8% of Crude Oil price</td>
</tr>
<tr>
<td>LPG</td>
<td>63% of Gasoline Price^9</td>
</tr>
<tr>
<td>Asphalt</td>
<td>120% of Fuel Oil Price^10</td>
</tr>
</tbody>
</table>

10.1.3.3 **Electricity prices**

As several of the refinery case analyses included power generation options, we have used 7.0 US cents/kWh as the bulk power sales price for electricity, which is the price at which all higher cost power generation from diesel and naphtha will be non-competitive. Although number is significantly higher than current electricity import prices (at 2.3 cents/kWh) and the commercial tariffs in effect in Afghanistan, the consultant believes it is a realistic number given the current status of the Afghan power sector. Furthermore, this figure compares with AIC costs ranging from 7.8 cents/kWh to 12.5 cents/kWh in Norconsult’s power master plan for a new 50 MW Combined Cycle Gas Fired Plant and the Kabul North West Power Plant (run on Diesel), respectively.

10.2 **Methodology for the Economic Analysis**

The following are the other key assumptions behind the methodology used to compare the eighteen refinery and integrated refinery/power plant cases, and to select two “best cases” on which to perform more detailed economic analysis:

8. The export price for crude oil at Sheberghaan was calculated to be $17.57 /bbl for the base case and $26.57 /bbl for the high crude price scenario.

9. A discount rate of 11.5% was used for all cases.

10. All projections and DCF calculations were performed assuming a 15-year life.

11. The net back price for crude oil at the refinery gate was calculated in order to cover all operating costs and the cost of capital.

12. The net back price of crude oil was compared with the value of the crude exported to determine if it is higher or lower than this export value. The difference is the value created or destroyed by the refinery or power plant as compared to exporting the crude oil.

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^9 The World Bank did not provide conversion factors for LPG and Asphalt. These were derived from other historical pricing databases.

^10 ibid
13 Sensitivity analyses were done in order to determine what changes to the investment or the price of electricity were necessary for the refinery or power plant to match the crude export prices.

14 Capital investment costs were assumed to be equal to US Gulf Coast (with contingency of about 30%). Although location factors could have been considered, there is no reliable data source for determining such location factors for Afghanistan, and just applying a higher location factor would only serve to make the investments less feasible.

10.2.1 Summary of Results

The results from the financial model developed for this project are shown on the following page in Table 10-C. The table shows, for each case, the refinery or refinery/power plant characteristics, including size, capital investment and operating expenditures, and then proceeds to analyze each pricing case (base and current pricing) against the do-nothing scenario of exporting the crude oil.

Netback values at the refinery and project Internal Rates of Return (IRR) are given for each case. Additionally, values required to obtain the necessary netback at the refinery and meet the project’s hurdle rate are given for Investment and the Price of Electricity.
## Table 10-C: Summary of Financial Analyses - All Cases

<table>
<thead>
<tr>
<th>Case Description</th>
<th>1</th>
<th>2A</th>
<th>2B</th>
<th>3A</th>
<th>3B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity, BPSD</strong></td>
<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
<td>5,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Power Plant Capacity, MW</td>
<td>226</td>
<td>0</td>
<td>141</td>
<td>0</td>
<td>71</td>
</tr>
<tr>
<td>Export Power, MW</td>
<td>204</td>
<td>0</td>
<td>131</td>
<td>0</td>
<td>65</td>
</tr>
<tr>
<td>Investment, $MM</td>
<td>242</td>
<td>104</td>
<td>265</td>
<td>76</td>
<td>160</td>
</tr>
<tr>
<td>Annual Operating Costs, $MM</td>
<td>11</td>
<td>7</td>
<td>15</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Annual Cost of Natural Gas, $MM</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td><strong>1) Base Case Pricing Scenario</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude Oil price, $/BBL</td>
<td>25.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Afghan Mix, $/BBL (Seidi)</td>
<td>20.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Afghan Mix, $/BBL (Refinery Gate)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheberghan</td>
<td>17.57</td>
<td>17.57</td>
<td>17.57</td>
<td>17.57</td>
<td>17.57</td>
</tr>
<tr>
<td>Netback at refinery, $/BBL</td>
<td>20.39</td>
<td>14.34</td>
<td>17.46</td>
<td>11.58</td>
<td>14.07</td>
</tr>
<tr>
<td>Project IRR (15-year period)</td>
<td>19.2%</td>
<td>-2.6%</td>
<td>14.1%</td>
<td>-11.1%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Values required to obtain netback equal to Afghan Mix at Refinery Gate</td>
<td>304</td>
<td>34</td>
<td>263</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Investment, $MM</td>
<td>6.43</td>
<td>N/A</td>
<td>7.04</td>
<td>8.10</td>
<td>N/A</td>
</tr>
<tr>
<td>Price of electricity, $/cent/Kwh</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2) Current Pricing Scenario</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude Oil price, $/BBL</td>
<td>34.80</td>
<td></td>
<td></td>
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<tr>
<td>Afghan Mix, $/BBL (Seidi)</td>
<td>29.60</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Afghan Mix, $/BBL (Refinery Gate)</td>
<td>26.57</td>
<td>26.57</td>
<td>26.57</td>
<td>19.90</td>
<td>20.46</td>
</tr>
<tr>
<td>Netback at refinery, $/BBL</td>
<td>20.39</td>
<td>22.66</td>
<td>22.35</td>
<td>19.90</td>
<td>20.46</td>
</tr>
<tr>
<td>Project IRR (15-year period)</td>
<td>1.2%</td>
<td>-8.5%</td>
<td>6.7%</td>
<td>-20.5%</td>
<td>-0.9%</td>
</tr>
<tr>
<td>Values required to obtain netback equal to Afghan Mix at Refinery Gate</td>
<td>107</td>
<td>19</td>
<td>173</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>Investment, $MM</td>
<td>8.25</td>
<td>N/A</td>
<td>8.32</td>
<td>9.39</td>
<td>N/A</td>
</tr>
<tr>
<td>Price of electricity, $/cent/Kwh</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The model’s results indicate that, besides the Power Plant only option, which has the highest IRR at 19.2%, Case 2A is the most likely economic and financially viable option. This is the case for the construction of a 10,000 BOPD simple refinery (topping plant) with or without asphalt capability:

- For Case 2A without the vacuum distillation unit, the refinery cost including all offsites is $57.5 M, the 141 MW (131 MW Net Export) power plant cost is $133.9 MM, for a combined cost of $191.4 MM, which would increase to $232.4 MM with the addition of WBEAG environmental mitigation costs.

- For Case 2A with the vacuum distillation unit, the refinery cost including all offsites is $90.4 M, the 141 MW (131 MW Net Export) power plant cost is $133.9 MM, for a combined cost of $224.3 MM, which would increase to $265.3 MM with the addition of WBEAG environmental mitigation costs.

Highlights of the results of the financial and economic analysis to support this recommendation are as follows:

**For the base price scenario, 17.57 $/B export price:**

- The best net back option is $19.29 /bbl corresponding to a simple 10,000 BPD refinery integrated with a power plant that consumes the produced fuel oil (case 2A, integrated refinery and power plant) without asphalt production capabilities. The next best net back option is the same case 2A with the vacuum distillation tower for asphalt production, at $17.46 /bbl.

- None of the standalone refineries can pay the export crude value. The best case is 2A (Simple 10,000 BPD refinery) which can pay $14.34 /bbl for the crude oil.

**For the high price scenario, 26.57 $/B export price:**

- None of the cases can pay the export crude oil value under the high price scenario.

- Based on the above analysis, it seems that among the various refining options considered, Case 2A, consisting of a 10,000 BOPD refinery with power plant combination seems the most viable option because the power plant provides the option for the disposition of fuel oil that would be produced as part of the refinery slate. However, such a refinery is small and does not benefit from economy of scale; and at an estimated cost of $224 million ($90.4 million for the refinery and $134 million for a 140 MW power plant), such a refinery can only be economically feasible assuming a low cost of crude ($17/barrel), a high cost of power generation (at about $0.07/kwh) and significant government subsidy in form of low cost of capital. Furthermore, even at a high electricity price of $0.07/kwh at the power plant gate, the economics of this project are at best marginal. As such, this can only be a long term project, and economically viable only (if and when all other cheap sources of power including coal, are exhausted). In addition, further work needs to be done to firm up the reserve of crude. In this regard a refinery investment is not considered a priority in the short-term. Its viability could however be re-evaluated in the future when there are confirmed increases in oil reserves/production to justify a more economic size. While the country
continues to import products, the consultant recommends that the government establish a regulating and monitoring agency to ensure the quality and standard of products being imported.

10.2.2 Sensitivity Analysis

In performing further sensitivity analyses, we chose Case 2A as the best configuration for utilizing the crude reserves in Afghanistan, as the only option that yields more value than exporting the crude oil or using the crude oil as fuel.

The following four pages depict tornado analyses performed for Cases 2A under both base and current pricing scenarios, for both asphalt-producing and non-asphalt producing variants. The charts depict the sensitivity of the project IRR to the following changes:

- A change of +/- 10% in the price of Wide-Cut Diesel (or Spec Diesel)
- A change of +/-2 cents per kWh in the sale price of electricity
- A change of +/- 30% in capital investment costs

The analyses confirm the high sensitivity of project IRRs to the price of electricity under both pricing scenarios. However, it should be realized that the assumed sale price of 7 cents/kwh is significantly higher than current electricity import prices (at 2.3 cents/kwh) and the estimated price of electricity to be generated from the 150 MW gas fired power plant planned in Sherberghan, which would be about 3 cents/kwh.

Case 2A without asphalt capability, however, shows strong resilience to prices changes for all of the variables.

It should also be noted that the price of crude has a significant impact on the economics of the project, as can be seen from comparing the two sets of analyses for the base case and the high oil price case.

The 20 individual case listings are presented at the end of this section, in a total of twenty pages.
Case 2a Sensitivity Analysis - Base Case Prices

- Hurdle Rate
  - Base Case: 11.5%
  - 10% +/- in Wide cut diesel price: 12.1%
  - 2 cents +/- in electricity price: 1.9%
  - 30% +/- in Capital Investment: 24.0%
  - 30% +/- in Capital Investment: 22.2%

Project IRR vs. Scenarios

0% 5% 10% 15% 20% 25% 30%

1.9% 9.3% 11.5% 14.1% 16.0% 24.0% 22.2%
Case 2a No Asphalt Sensitivity Analysis - Base Case Prices

SCENARIOS

- Base Case: 17.5%
- 10% +/- in Wide cut diesel price: 15.3% and 19.6%
- 2 cents +/- in electricity price: 12.1%
- 30% +/- in Capital Investment: 4.5% and 28.4%
- Hurdle Rate: 11.5%
Case 2a Sensitivity Analysis - Current Prices

- Base Case: 6.7%
- Hurdle Rate: 11.5%
- 10% +/- in Wide cut diesel price: 3.5% - 9.7%
- 2 cents +/- in electricity price: 17.8%
- 30% +/- in Capital Investment: 2.9% - 12.9%
Case 2a No Asphalt Sensitivity Analysis - Current Prices

**SCENARIOS**
- 30% +/- in Capital Investment
- 2 cents +/- in electricity price
- 10% +/- in Wide cut diesel price

**Hurdle Rate**
- 11.5%

**Base Case**
- 7.1%

**Project IRR**

- -16.4%
- 3.2%
- 3.5%
- 10.4%
- 19.5%

-20% -15% -10% -5% 0% 5% 10% 15% 20% 25% 30%
### Inputs and Assumptions

<table>
<thead>
<tr>
<th>Input/Assumption</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>17.57</td>
<td>Equity</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>242.1</td>
<td>Cost of debt</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>11.4</td>
<td>Tax Income</td>
</tr>
</tbody>
</table>

### Prices ($/B)

<table>
<thead>
<tr>
<th>Product</th>
<th>Price ($/B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>23</td>
</tr>
<tr>
<td>Gasoline</td>
<td>34</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>34</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>34</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>33</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>23</td>
</tr>
<tr>
<td>Asphalt</td>
<td>29</td>
</tr>
</tbody>
</table>

### Production (BPSD)

<table>
<thead>
<tr>
<th>Season</th>
<th>LPG</th>
<th>Gasoline</th>
<th>Jet Fuel</th>
<th>Diesel (automotive)</th>
<th>Wide-cut diesel</th>
<th>Fuel oil (to power)</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10,000</td>
<td>0</td>
</tr>
<tr>
<td>Winter</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10,000</td>
<td>0</td>
</tr>
</tbody>
</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th>Season</th>
<th>LPG</th>
<th>Gasoline</th>
<th>Jet Fuel</th>
<th>Diesel (automotive)</th>
<th>Wide-cut diesel</th>
<th>Fuel oil (to power)</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Winter</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Annual</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>62,424</td>
<td>62,424</td>
<td>124,848</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>62,424</td>
<td>62,424</td>
<td>124,848</td>
</tr>
</tbody>
</table>

### Costs ($000)

<table>
<thead>
<tr>
<th>Cost</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>63,252</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>11,435</td>
</tr>
<tr>
<td>Debt Service</td>
<td>27,580</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>12,421</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>114,688</strong></td>
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### Net Annual Profit before tax ($000)

<table>
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<th>Profit</th>
<th>Value</th>
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<tr>
<td>10,160</td>
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### Project IRR (15-year Period)

<table>
<thead>
<tr>
<th>Rate</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRR</td>
<td>19.2%</td>
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</tbody>
</table>
Case 1  
Crude to Power 10,000 BPD  
Refinery + Power plant (Only Power Plant in Case 1)  
Current International Prices

### Inputs and Assumptions

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>26.57</td>
<td>Equity</td>
<td>30%</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
<td>70%</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>242.1</td>
<td>Cost of debt</td>
<td>10%</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
<td>15%</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>11.4</td>
<td>Tax Income</td>
<td>0%</td>
</tr>
</tbody>
</table>

### Prices ($/B)

- LPG: 30
- Gasoline: 46
- Jet Fuel: 46
- Diesel (automotive): 45
- Wide-cut diesel: 43
- Fuel oil (to power): 29
- Asphalt: 37

### Production (BPSD)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0</td>
<td>0</td>
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</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>62,424</td>
<td>62,424</td>
<td>124,848</td>
</tr>
<tr>
<td><strong>Total Revenues</strong></td>
<td>62,424</td>
<td>62,424</td>
<td>124,848</td>
</tr>
</tbody>
</table>

### Costs ($000)

- Crude Oil Costs: 95,652
- Natural Gas Costs: 0
- O&M Costs: 11,435
- Debt Service: 27,580
- Capital Return (Equity): 12,421

| Total Costs                  | 147,088 |

### Net Annual Profit before tax ($000)

- (22,240)

### Project IRR (15-year Period)

- 1.2%
**Case 2a**  
**Simple Refinery  10,000 BPD**  
**Refinery stand alone**  
**Base Case Prices**

### Inputs and Assumptions

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<thead>
<tr>
<th></th>
<th>Input Value</th>
<th>Assumptions</th>
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<tr>
<td>Crude Oil Price ($/B)</td>
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<td>Equity 30%</td>
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<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt 70%</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>104.4</td>
<td>Cost of debt 10%</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity 15%</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>6.8</td>
<td>Tax Income 0%</td>
</tr>
</tbody>
</table>

### Prices ($/B)

- LPG: 23
- Gasoline: 34
- Jet Fuel: 34
- Diesel (automotive): 34
- Wide-cut diesel: 33
- Fuel oil (to power): 11
- Asphalt: 29

### Production (BPSD)

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>3,580</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,640</td>
<td>6,420</td>
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<tr>
<td>Asphalt</td>
<td>2,780</td>
<td>0</td>
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### Revenues ($000)

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>21,142</td>
<td>21,142</td>
<td>42,283</td>
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<tr>
<td>Fuel oil (to power)</td>
<td>6,880</td>
<td>12,134</td>
<td>19,014</td>
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<tr>
<td>Asphalt</td>
<td>14,347</td>
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<td>14,347</td>
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<tr>
<td>Refinery Revenues</td>
<td>42,368</td>
<td>33,276</td>
<td>75,644</td>
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<tr>
<td>Electricity Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Revenues</strong></td>
<td><strong>42,368</strong></td>
<td><strong>33,276</strong></td>
<td><strong>75,644</strong></td>
</tr>
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</table>

### Costs ($000)

<table>
<thead>
<tr>
<th></th>
<th>Cost Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>63,252</td>
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<tr>
<td>Natural Gas Costs</td>
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</tr>
<tr>
<td>O&amp;M Costs</td>
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</tr>
<tr>
<td>Debt Service</td>
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<tr>
<td>Capital Return (Equity)</td>
<td>5,356</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>87,274</strong></td>
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</tbody>
</table>

### Net Annual Profit before tax ($000)

- $(11,630)$

### Project IRR (15-year Period)

- 2.6%
## Case 2a
Simple Refinery 10,000 BPD
Refinery stand alone
Current International Prices

### Inputs and Assumptions

<table>
<thead>
<tr>
<th>Input/Assumption</th>
<th>Value</th>
</tr>
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<tr>
<td>Crude Oil Price ($/B)</td>
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</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>104.4</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>6.8</td>
</tr>
<tr>
<td>Equity percentage</td>
<td>30%</td>
</tr>
<tr>
<td>Debt percentage</td>
<td>70%</td>
</tr>
<tr>
<td>Cost of debt percentage</td>
<td>10%</td>
</tr>
<tr>
<td>Cost of equity percentage</td>
<td>15%</td>
</tr>
<tr>
<td>Tax Income percentage</td>
<td>0%</td>
</tr>
</tbody>
</table>

### Prices ($/B)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

### Production (BPSD)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>3,580</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,640</td>
<td>6,420</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2,780</td>
<td>0</td>
</tr>
</tbody>
</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>27,900</td>
<td>27,900</td>
<td>55,800</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>11,349</td>
<td>20,017</td>
<td>31,367</td>
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<tr>
<td>Asphalt</td>
<td>18,443</td>
<td>0</td>
<td>18,443</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>57,693</td>
<td>47,917</td>
<td>105,610</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Revenues</strong></td>
<td><strong>57,693</strong></td>
<td><strong>47,917</strong></td>
<td><strong>105,610</strong></td>
</tr>
</tbody>
</table>

### Costs ($000)

<table>
<thead>
<tr>
<th>Cost Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>95,652</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>6,773</td>
</tr>
<tr>
<td>Debt Service</td>
<td>11,893</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>5,356</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>119,674</strong></td>
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### Net Annual Profit before tax ($000)

<table>
<thead>
<tr>
<th>Profit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(14,064)</td>
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### Project IRR (15-year Period)

<table>
<thead>
<tr>
<th>Project IRR</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-8.5%</td>
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</table>
### Inputs and Assumptions

<table>
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<tr>
<th></th>
<th>Crude Oil Price ($/B)</th>
<th>Cost of Electricity ($/Kwh)</th>
<th>Capital Costs ($MM)</th>
<th>WACC</th>
<th>O&amp;M Annual Costs ($MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>17.57</td>
<td>0.07</td>
<td>232.5</td>
<td>11.5%</td>
<td>14.7</td>
</tr>
<tr>
<td>Equity</td>
<td>30%</td>
<td>70%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debt</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of equity</td>
<td>15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tax Income</td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

### Prices ($/B)

<table>
<thead>
<tr>
<th>Material</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>3,580</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,640</td>
<td>6,420</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Production (BPSD)

<table>
<thead>
<tr>
<th>Material</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>3,580</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,640</td>
<td>6,420</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th>Material</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>21,142</td>
<td>21,142</td>
<td>42,283</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>21,142</td>
<td>21,142</td>
<td>42,283</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>40,134</td>
<td>40,134</td>
<td>80,268</td>
</tr>
<tr>
<td><strong>Total Revenues</strong></td>
<td><strong>61,276</strong></td>
<td><strong>61,276</strong></td>
<td><strong>122,551</strong></td>
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</table>

### Costs ($000)

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>63,252</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>14,690</td>
</tr>
<tr>
<td>Debt Service</td>
<td>26,487</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>11,928</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>116,357</strong></td>
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</tbody>
</table>

### Net Annual Profit before tax ($000)

<table>
<thead>
<tr>
<th>Profit Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project IRR (15-year Period)</td>
<td>6,194</td>
</tr>
<tr>
<td><strong>Project IRR</strong></td>
<td><strong>17.5%</strong></td>
</tr>
</tbody>
</table>
Case 2a
Simple Refinery 10,000 BPD
Refinery + Power plant (Only Power Plant in Case 1)
Base Case Prices

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>17.57</td>
<td>Equity</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>265.3</td>
<td>Cost of debt</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>14.7</td>
<td>Tax Income</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prices ($/B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>23</td>
</tr>
<tr>
<td>Gasoline</td>
<td>34</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>34</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>34</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>33</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>23</td>
</tr>
<tr>
<td>Asphalt</td>
<td>29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>3,580</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,640</td>
<td>6,420</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2,780</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>21,142</td>
<td>21,142</td>
<td>42,283</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>14,347</td>
<td>0</td>
<td>14,347</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>35,489</td>
<td>21,142</td>
<td>56,630</td>
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<tr>
<td>Electricity Revenues</td>
<td>40,134</td>
<td>40,134</td>
<td>80,268</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>75,622</td>
<td>61,276</td>
<td>136,898</td>
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</table>

<table>
<thead>
<tr>
<th>Costs ($000)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>63,252</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>15,525</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>14,690</td>
</tr>
<tr>
<td>Debt Service</td>
<td>30,223</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>13,611</td>
</tr>
<tr>
<td>Total Costs</td>
<td>137,302</td>
</tr>
</tbody>
</table>

| Net Annual Profit before tax ($000)      | (404)   |
| Project IRR (15-year Period)             | 14.1%   |
## Case 2a

**Simple Refinery 10,000 BPD**

Refinery + Power plant (Only Power Plant in Case 1)

### Current International Prices

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>26.57</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>232.5</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>14.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prices ($/B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>30</td>
</tr>
<tr>
<td>Gasoline</td>
<td>46</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>46</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>45</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>43</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>29</td>
</tr>
<tr>
<td>Asphalt</td>
<td>37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>3,580</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,640</td>
<td>6,420</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>27,900</td>
<td>27,900</td>
<td>55,800</td>
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<tr>
<td>Fuel oil (to power)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>27,900</td>
<td>27,900</td>
<td>55,800</td>
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<tr>
<td>Electricity Revenues</td>
<td>40,134</td>
<td>40,134</td>
<td>80,268</td>
</tr>
<tr>
<td><strong>Total Revenues</strong></td>
<td><strong>68,034</strong></td>
<td><strong>68,034</strong></td>
<td><strong>136,068</strong></td>
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<table>
<thead>
<tr>
<th>Costs ($000)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>95,652</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>14,690</td>
</tr>
<tr>
<td>Debt Service</td>
<td>26,487</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>11,928</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>148,757</strong></td>
</tr>
</tbody>
</table>

**Net Annual Profit before tax ($000)**: (12,689)

**Project IRR (15-year Period)**: 7.1%
### Inputs and Assumptions

<table>
<thead>
<tr>
<th></th>
<th>Crude Oil Price ($/B)</th>
<th>Equity</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>265.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>14.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Prices ($/B)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Asphalt</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

### Production (BPSD)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>3,580</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,640</td>
<td>6,420</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2,780</td>
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</tbody>
</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>27,900</td>
<td>27,900</td>
<td>55,800</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Asphalt</td>
<td>18,443</td>
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<td>18,443</td>
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<tr>
<td><strong>Total Revenues</strong></td>
<td><strong>86,477</strong></td>
<td><strong>68,034</strong></td>
<td><strong>154,511</strong></td>
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### Costs ($000)

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
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<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>95,652</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>15,525</td>
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<tr>
<td>O&amp;M Costs</td>
<td>14,690</td>
</tr>
<tr>
<td>Debt Service</td>
<td>30,223</td>
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<tr>
<td>Capital Return (Equity)</td>
<td>13,611</td>
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<tr>
<td><strong>Total Costs</strong></td>
<td><strong>169,702</strong></td>
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### Net Annual Profit before tax ($000)

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
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<tbody>
<tr>
<td><strong>Net Annual Profit before tax</strong></td>
<td>-(15,191)</td>
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### Project IRR (15-year Period)

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
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<tr>
<td><strong>Project IRR</strong></td>
<td>6.7%</td>
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Case 2b
Simple Refinery  5,000 BPD
Refinery stand alone
Base Case Prices

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
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<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>17.57</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>75.8</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>4.5</td>
</tr>
<tr>
<td>Equity</td>
<td>30%</td>
</tr>
<tr>
<td>Debt</td>
<td>70%</td>
</tr>
<tr>
<td>Cost of debt</td>
<td>10%</td>
</tr>
<tr>
<td>Cost of equity</td>
<td>15%</td>
</tr>
<tr>
<td>Tax Income</td>
<td>0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prices ($/B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>23</td>
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<tr>
<td>Gasoline</td>
<td>34</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>34</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>34</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>33</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>11</td>
</tr>
<tr>
<td>Asphalt</td>
<td>29</td>
</tr>
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<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>1,790</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>1,820</td>
<td>3,210</td>
</tr>
<tr>
<td>Asphalt</td>
<td>1,390</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>10,571</td>
<td>10,571</td>
<td>21,142</td>
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<tr>
<td>Fuel oil (to power)</td>
<td>3,440</td>
<td>6,067</td>
<td>9,507</td>
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<tr>
<td>Asphalt</td>
<td>7,173</td>
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<td>7,173</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>21,184</td>
<td>16,638</td>
<td>37,822</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>21,184</td>
<td>16,638</td>
<td>37,822</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs ($000)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>31,626</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>4,463</td>
</tr>
<tr>
<td>Debt Service</td>
<td>8,635</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>3,889</td>
</tr>
<tr>
<td>Total Costs</td>
<td>48,613</td>
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</tbody>
</table>

Net Annual Profit before tax ($000)  (10,791)
Project IRR (15-year Period) -11.1%
## Case 2b
### Simple Refinery  5,000 BPD
#### Refinery stand alone
#### Current International Prices

### Inputs and Assumptions

<table>
<thead>
<tr>
<th></th>
<th>Value 1</th>
<th>Value 2</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>26.57</td>
<td></td>
<td>Equity 30%</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td></td>
<td>Debt 70%</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>75.8</td>
<td></td>
<td>Cost of debt 10%</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td></td>
<td>Cost of equity 15%</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>4.5</td>
<td></td>
<td>Tax Income 0%</td>
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</tbody>
</table>

### Prices ($/B)

<table>
<thead>
<tr>
<th></th>
<th>Value 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>30</td>
</tr>
<tr>
<td>Gasoline</td>
<td>46</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>46</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>45</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>43</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>17</td>
</tr>
<tr>
<td>Asphalt</td>
<td>37</td>
</tr>
</tbody>
</table>

### Production (BPSD)

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>1,790</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>1,820</td>
<td>3,210</td>
</tr>
<tr>
<td>Asphalt</td>
<td>1,390</td>
<td>0</td>
</tr>
</tbody>
</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>13,950</td>
<td>13,950</td>
<td>27,900</td>
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<tr>
<td>Fuel oil (to power)</td>
<td>5,675</td>
<td>10,009</td>
<td>15,683</td>
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<td>Asphalt</td>
<td>9,222</td>
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<td>9,222</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery Revenues</td>
<td>28,846</td>
<td>23,959</td>
<td>52,805</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Revenues</td>
<td>28,846</td>
<td>23,959</td>
<td>52,805</td>
</tr>
</tbody>
</table>

### Costs ($000)

<table>
<thead>
<tr>
<th></th>
<th>Value 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>47,826</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>4,463</td>
</tr>
<tr>
<td>Debt Service</td>
<td>8,635</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>3,889</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Value 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Costs</td>
<td>64,813</td>
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</table>

### Net Annual Profit before tax ($000)
(12,008)

### Project IRR (15-year Period)
-20.5%
**Case 2b**

**Simple Refinery  5,000 BPD**

**Refinery + Power plant (Only Power Plant in Case 1)**

**Base Case Prices**

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>17.57</td>
<td>Equity</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>159.6</td>
<td>Cost of debt</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>9.0</td>
<td>Tax Income</td>
</tr>
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</table>

**Prices ($/B)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>1,790</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>1,820</td>
<td>3,210</td>
</tr>
<tr>
<td>Asphalt</td>
<td>1,390</td>
<td>0</td>
</tr>
</tbody>
</table>

**Production (BPSD)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>1,790</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>1,820</td>
<td>3,210</td>
</tr>
<tr>
<td>Asphalt</td>
<td>1,390</td>
<td>0</td>
</tr>
</tbody>
</table>

**Revenues ($000)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>10,571</td>
<td>10,571</td>
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<tr>
<td>Fuel oil (to power)</td>
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<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>7,173</td>
<td>0</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>17,744</td>
<td>10,571</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>20,052</td>
<td>20,052</td>
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<tr>
<td>Total Revenues</td>
<td>37,796</td>
<td>30,622</td>
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**Costs ($000)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>31,626</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>7,763</td>
</tr>
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<td>O&amp;M Costs</td>
<td>8,957</td>
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<tr>
<td>Debt Service</td>
<td>18,182</td>
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<tr>
<td>Capital Return (Equity)</td>
<td>8,188</td>
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<tr>
<td>Total Costs</td>
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</table>

**Net Annual Profit before tax ($000)**

(6,297)

**Project IRR (15-year Period)**

9.2%
Case 2b
Simple Refinery 5,000 BPD
Refinery + Power plant (Only Power Plant in Case 1)
Current International Prices

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
<th>Value</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>26.57</td>
<td>Equity</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>159.6</td>
<td>Cost of debt</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>9.0</td>
<td>Tax Income</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prices ($/B)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>30</td>
</tr>
<tr>
<td>Gasoline</td>
<td>46</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>46</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>45</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>43</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>29</td>
</tr>
<tr>
<td>Asphalt</td>
<td>37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>1,790</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>1,820</td>
<td>3,210</td>
</tr>
<tr>
<td>Asphalt</td>
<td>1,390</td>
<td>0</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
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<tbody>
<tr>
<td>LPG</td>
<td>0</td>
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</tr>
<tr>
<td>Gasoline</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jet Fuel</td>
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<td>0</td>
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<tr>
<td>Diesel (automotive)</td>
<td>0</td>
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<tr>
<td>Wide-cut diesel</td>
<td>13,950</td>
<td>13,950</td>
<td>27,900</td>
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<tr>
<td>Fuel oil (to power)</td>
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<td>47,826</td>
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<tr>
<td>Natural Gas Costs</td>
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<tr>
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</table>

| Net Annual Profit before tax ($000)     | (13,691) |
| Project IRR (15-year Period)            | 2.3%     |
Case 3a
Complex Refinery 10,000 BPD
Refinery stand alone
Base Case Prices

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
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<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>17.57</td>
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<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
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<tr>
<td>Capital Costs ($MM)</td>
<td>212.6</td>
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<tr>
<td>WACC</td>
<td>11.5%</td>
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<tr>
<td>O&amp;M Annual Costs ($MM)</td>
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<tr>
<td>Equity</td>
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<tr>
<td>Debt</td>
<td>70%</td>
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</tr>
<tr>
<td>Cost of equity</td>
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<tr>
<td>Tax Income</td>
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<table>
<thead>
<tr>
<th>Prices ($/B)</th>
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<tr>
<td>LPG</td>
<td>23</td>
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<td>Gasoline</td>
<td>34</td>
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<tr>
<td>Jet Fuel</td>
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<tr>
<td>Diesel (automotive)</td>
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<tr>
<td>Asphalt</td>
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<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>329</td>
<td>555</td>
</tr>
<tr>
<td>Gasoline</td>
<td>847</td>
<td>1,180</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>471</td>
<td>567</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>3,297</td>
<td>3,964</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>2,350</td>
<td>3,951</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2,780</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>1,364</td>
<td>2,301</td>
<td>3,665</td>
</tr>
<tr>
<td>Gasoline</td>
<td>5,245</td>
<td>7,307</td>
<td>12,552</td>
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<tr>
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<td>2,925</td>
<td>3,521</td>
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<td>20,002</td>
<td>24,048</td>
<td>44,050</td>
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<tr>
<td>Wide-cut diesel</td>
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<td>0</td>
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<tr>
<td>Fuel oil (to power)</td>
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<td>11,909</td>
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<tr>
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<tr>
<td>Refinery Revenues</td>
<td>48,324</td>
<td>44,644</td>
<td>92,968</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>48,324</td>
<td>44,644</td>
<td>92,968</td>
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</table>

<table>
<thead>
<tr>
<th>Costs ($000)</th>
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</tr>
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<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>63,252</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>17,430</td>
</tr>
<tr>
<td>Debt Service</td>
<td>24,220</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>10,907</td>
</tr>
<tr>
<td>Total Costs</td>
<td>115,809</td>
</tr>
</tbody>
</table>

| Net Annual Profit before tax ($000) | (22,841) |
| Project IRR (15-year Period)        | -1.7%    |
### Case 3a
#### Complex Refinery 10,000 BPD
##### Refinery stand alone
##### Current International Prices

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
<th>Value</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>26.57</td>
<td>Equity 30%</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt 70%</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>212.6</td>
<td>Cost of debt 10%</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity 15%</td>
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<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>17.4</td>
<td>Tax Income 0%</td>
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<table>
<thead>
<tr>
<th>Prices ($/B)</th>
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<th></th>
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<tbody>
<tr>
<td>LPG</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>46</td>
<td></td>
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<tr>
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<td></td>
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<tr>
<td>Wide-cut diesel</td>
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<td></td>
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<tr>
<td>Fuel oil (to power)</td>
<td>17</td>
<td></td>
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<tr>
<td>Asphalt</td>
<td>37</td>
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</table>

<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>329</td>
<td>555</td>
</tr>
<tr>
<td>Gasoline</td>
<td>847</td>
<td>1,180</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>471</td>
<td>567</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>3,297</td>
<td>3,964</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
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<td>Fuel oil (to power)</td>
<td>2,350</td>
<td>3,951</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2,780</td>
<td>0</td>
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</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>1,783</td>
<td>3,007</td>
<td>4,790</td>
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<tr>
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<td>16,645</td>
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<tr>
<td>Jet Fuel</td>
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<td>8,528</td>
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<td>0</td>
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<tr>
<td>Fuel oil (to power)</td>
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<td>19,646</td>
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<tr>
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<td>18,443</td>
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<td>61,429</td>
<td>126,218</td>
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<tr>
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<td>0</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>64,789</td>
<td>61,429</td>
<td>126,218</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Costs ($000)</th>
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<th></th>
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</thead>
<tbody>
<tr>
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<td>Natural Gas Costs</td>
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<tr>
<td>O&amp;M Costs</td>
<td>17,430</td>
<td></td>
</tr>
<tr>
<td>Debt Service</td>
<td>24,220</td>
<td></td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
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<tr>
<td>Total Costs</td>
<td>148,209</td>
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</table>

| Net Annual Profit before tax ($000) | (21,991) |
| Project IRR (15-year Period)       | -0.9%    |
Case 3a  
Complex Refinery 10,000 BPD  
Refinery + Power plant (Only Power Plant in Case 1)  
Base Case Prices

**Inputs and Assumptions**

<table>
<thead>
<tr>
<th></th>
<th>Crude Oil Price ($/B)</th>
<th>Cost of Electricity ($/Kwh)</th>
<th>Capital Costs ($MM)</th>
<th>WACC</th>
<th>O&amp;M Annual Costs ($MM)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>17.57</td>
<td>0.07</td>
<td>316.7</td>
<td>11.5%</td>
<td>23.0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equity</td>
<td>30%</td>
<td>Debt</td>
<td>Cost of debt</td>
<td></td>
<td>Tax Income</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10%</td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>Cost of equity</td>
<td>15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td></td>
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<td></td>
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**Prices ($/B)**

<table>
<thead>
<tr>
<th></th>
<th>LPG</th>
<th>Gasoline</th>
<th>Jet Fuel</th>
<th>Diesel (automotive)</th>
<th>Wide-cut diesel</th>
<th>Fuel oil (to power)</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>33</td>
<td>23</td>
<td>29</td>
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**Production (BPSD)**

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>329</td>
<td>555</td>
</tr>
<tr>
<td>Gasoline</td>
<td>847</td>
<td>1,180</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>471</td>
<td>567</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>3,297</td>
<td>3,964</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>2,350</td>
<td>3,951</td>
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<tr>
<td>Asphalt</td>
<td>2,780</td>
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**Revenues ($000)**

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>1,364</td>
<td>2,301</td>
<td>3,665</td>
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<td>44,050</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
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<td>0</td>
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<tr>
<td>Asphalt</td>
<td>14,347</td>
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<td>14,347</td>
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<td>23,792</td>
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<td><strong>Total Revenues</strong></td>
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<td><strong>60,969</strong></td>
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**Costs ($000)**

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<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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<tr>
<td>Crude Oil Costs</td>
<td></td>
<td></td>
<td>63,252</td>
</tr>
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<td>9,269</td>
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<tr>
<td>O&amp;M Costs</td>
<td></td>
<td></td>
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<tr>
<td>Debt Service</td>
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<td><strong>Total Costs</strong></td>
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**Net Annual Profit before tax ($000)**

<p>| | |</p>
<table>
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<th></th>
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<tbody>
<tr>
<td><strong>(19,158)</strong></td>
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</tbody>
</table>

**Project IRR (15-year Period)**

<p>| | |</p>
<table>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>6.3%</strong></td>
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### Case 3a
Complex Refinery 10,000 BPD
Refinery + Power plant (Only Power Plant in Case 1)
Current International Prices

#### Inputs and Assumptions
<table>
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<tr>
<th></th>
<th>Value</th>
<th>Source</th>
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</tr>
<tr>
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<td>23.0</td>
<td>Tax Income 0%</td>
</tr>
</tbody>
</table>

#### Prices ($/B)
<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>30</td>
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<td>567</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
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<tr>
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<tr>
<td>Fuel oil (to power)</td>
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<td>3,951</td>
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<tr>
<td>Asphalt</td>
<td>2,780</td>
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</table>

#### Revenues ($000)
<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>1,783</td>
<td>3,007</td>
<td>4,790</td>
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<tr>
<td>Gasoline</td>
<td>6,955</td>
<td>9,690</td>
<td>16,645</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>3,870</td>
<td>4,659</td>
<td>8,528</td>
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<tr>
<td>Diesel (automotive)</td>
<td>26,411</td>
<td>31,754</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
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<td>18,443</td>
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<tr>
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<td>106,572</td>
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<td>23,792</td>
<td>47,584</td>
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<tr>
<td>Total Revenues</td>
<td>81,254</td>
<td>72,902</td>
<td>154,156</td>
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#### Costs ($000)
<table>
<thead>
<tr>
<th>Product</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>95,652</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>9,269</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>22,953</td>
</tr>
<tr>
<td>Debt Service</td>
<td>36,079</td>
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<tr>
<td>Capital Return (Equity)</td>
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<td>Total Costs</td>
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#### Net Annual Profit before tax ($000)
<table>
<thead>
<tr>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>(26,045)</td>
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</table>

#### Project IRR (15-year Period)
<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9%</td>
</tr>
</tbody>
</table>
Case 3b
Complex Refinery 15,000 BPD
Refinery stand alone
Base Case Prices

| Inputs and Assumptions |  |  |
|------------------------|-------------------------------|
| Crude Oil Price ($/B)  | 17.57                        |
| Cost of Electricity ($/Kwh) | 0.07                      |
| Capital Costs ($MM)    | 265                          |
| WACC                   | 11.5%                        |
| O&M Annual Costs ($MM) | 23.2                         |
|                      |                              |

<table>
<thead>
<tr>
<th>Prices ($/B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>23</td>
</tr>
<tr>
<td>Gasoline</td>
<td>34</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>34</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>34</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>33</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>11</td>
</tr>
<tr>
<td>Asphalt</td>
<td>29</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>494</td>
<td>832</td>
</tr>
<tr>
<td>Gasoline</td>
<td>1,270</td>
<td>1,770</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>707</td>
<td>850</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>4,945</td>
<td>5,947</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,525</td>
<td>5,927</td>
</tr>
<tr>
<td>Asphalt</td>
<td>4,170</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>2,048</td>
<td>3,450</td>
<td>5,498</td>
</tr>
<tr>
<td>Gasoline</td>
<td>7,864</td>
<td>10,960</td>
<td>18,825</td>
</tr>
<tr>
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<td>4,390</td>
<td>5,278</td>
<td>9,668</td>
</tr>
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<td>29,999</td>
<td>36,078</td>
<td>66,078</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>6,662</td>
<td>11,202</td>
<td>17,864</td>
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<tr>
<td>Asphalt</td>
<td>21,520</td>
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<td>21,520</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>72,485</td>
<td>66,968</td>
<td>139,453</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>72,485</td>
<td>66,968</td>
<td>139,453</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs ($000)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>94,878</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>23,237</td>
</tr>
<tr>
<td>Debt Service</td>
<td>30,189</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>13,596</td>
</tr>
<tr>
<td>Total Costs</td>
<td>161,900</td>
</tr>
</tbody>
</table>

| Net Annual Profit before tax ($000) | (22,447) |
| Project IRR (15-year Period)       | 2.5%     |
**Case 3b**

**Complex Refinery 15,000 BPD**

**Refinery stand alone**

**Current International Prices**

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>26.57</td>
<td>Equity</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>265</td>
<td>Cost of debt</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>23.2</td>
<td>Tax Income</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Prices ($/B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>30</td>
</tr>
<tr>
<td>Gasoline</td>
<td>46</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>46</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>45</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>43</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>17</td>
</tr>
<tr>
<td>Asphalt</td>
<td>37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production (BPSD)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>494</td>
<td>832</td>
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<td>1,270</td>
<td>1,770</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>707</td>
<td>850</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>4,945</td>
<td>5,947</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,525</td>
<td>5,927</td>
</tr>
<tr>
<td>Asphalt</td>
<td>4,170</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues ($000)</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>2,677</td>
<td>4,508</td>
<td>7,185</td>
</tr>
<tr>
<td>Gasoline</td>
<td>10,429</td>
<td>14,535</td>
<td>24,963</td>
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<tr>
<td>Jet Fuel</td>
<td>5,809</td>
<td>6,984</td>
<td>12,792</td>
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<tr>
<td>Diesel (automotive)</td>
<td>39,613</td>
<td>47,639</td>
<td>87,252</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Fuel oil (to power)</td>
<td>10,991</td>
<td>18,480</td>
<td>29,471</td>
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<tr>
<td>Asphalt</td>
<td>27,665</td>
<td>0</td>
<td>27,665</td>
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<tr>
<td>Refinery Revenues</td>
<td>97,183</td>
<td>92,146</td>
<td>189,328</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>97,183</td>
<td>92,146</td>
<td>189,328</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs ($000)</th>
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</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>143,478</td>
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<tr>
<td>Natural Gas Costs</td>
<td>0</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>23,237</td>
</tr>
<tr>
<td>Debt Service</td>
<td>30,189</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>13,596</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td>210,500</td>
</tr>
</tbody>
</table>

| Net Annual Profit before tax ($000)    | (21,171)      |
| Project IRR (15-year Period)           | 3.3%          |
### Case 3b
Complex Refinery 15,000 BPD
Refinery + Power plant (Only Power Plant in Case 1)
Base Case Prices

<table>
<thead>
<tr>
<th>Inputs and Assumptions</th>
<th>Value</th>
<th>Assumption</th>
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</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>17.57</td>
<td>Equity</td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>421.1</td>
<td>Cost of debt</td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
</tr>
<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>31.2</td>
<td>Tax Income</td>
</tr>
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</table>

### Prices ($/B)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Asphalt</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

### Production (BPSD)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>494</td>
<td>832</td>
</tr>
<tr>
<td>Gasoline</td>
<td>1,270</td>
<td>1,770</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>707</td>
<td>850</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>4,945</td>
<td>5,947</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>3,525</td>
<td>5,927</td>
</tr>
<tr>
<td>Asphalt</td>
<td>4,170</td>
<td>0</td>
</tr>
</tbody>
</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th>Product</th>
<th>Summer</th>
<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>2,048</td>
<td>3,450</td>
<td>5,498</td>
</tr>
<tr>
<td>Gasoline</td>
<td>7,864</td>
<td>10,960</td>
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<td>4,390</td>
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<td>Diesel (automotive)</td>
<td>29,999</td>
<td>36,078</td>
<td>66,078</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>0</td>
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</tr>
<tr>
<td>Asphalt</td>
<td>21,520</td>
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<td>21,520</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>65,822</td>
<td>55,766</td>
<td>121,588</td>
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<td>35,535</td>
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<td><strong>91,301</strong></td>
<td><strong>192,658</strong></td>
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### Costs ($000)

<table>
<thead>
<tr>
<th>Item</th>
<th>Summer</th>
<th>Winter</th>
<th>Total Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td></td>
<td></td>
<td>94,878</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td></td>
<td></td>
<td>13,904</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td></td>
<td></td>
<td>31,227</td>
</tr>
<tr>
<td>Debt Service</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Capital Return (Equity)</td>
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<tr>
<td><strong>Total Costs</strong></td>
<td><strong>209,586</strong></td>
<td><strong>209,586</strong></td>
<td><strong>209,586</strong></td>
</tr>
</tbody>
</table>

**Net Annual Profit before tax ($000)**  
(16,927)

**Project IRR (15-year Period)**  
9.1%
## Case 3b
Complex Refinery 15,000 BPD  
Refinery + Power plant (Only Power Plant in Case 1)  
Current International Prices

### Inputs and Assumptions

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Price ($/B)</td>
<td>26.57</td>
<td>Equity</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Cost of Electricity ($/Kwh)</td>
<td>0.07</td>
<td>Debt</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>Capital Costs ($MM)</td>
<td>421.1</td>
<td>Cost of debt</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>WACC</td>
<td>11.5%</td>
<td>Cost of equity</td>
<td>15%</td>
<td></td>
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<tr>
<td>O&amp;M Annual Costs ($MM)</td>
<td>31.2</td>
<td>Tax Income</td>
<td>0%</td>
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### Prices ($/B)

<p>| | |</p>
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<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>30</td>
</tr>
<tr>
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</tr>
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</tr>
<tr>
<td>Asphalt</td>
<td>37</td>
</tr>
</tbody>
</table>

### Production (BPSD)

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<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
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<td>850</td>
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<td>5,947</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
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<td>5,927</td>
</tr>
<tr>
<td>Asphalt</td>
<td>4,170</td>
<td>0</td>
</tr>
</tbody>
</table>

### Revenues ($000)

<table>
<thead>
<tr>
<th></th>
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<th>Winter</th>
<th>Annual</th>
</tr>
</thead>
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<tr>
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<td>7,185</td>
</tr>
<tr>
<td>Gasoline</td>
<td>10,429</td>
<td>14,535</td>
<td>24,963</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>5,809</td>
<td>6,984</td>
<td>12,792</td>
</tr>
<tr>
<td>Diesel (automotive)</td>
<td>39,613</td>
<td>47,639</td>
<td>87,252</td>
</tr>
<tr>
<td>Wide-cut diesel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel oil (to power)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>27,665</td>
<td>0</td>
<td>27,665</td>
</tr>
<tr>
<td>Refinery Revenues</td>
<td>86,192</td>
<td>73,666</td>
<td>159,857</td>
</tr>
<tr>
<td>Electricity Revenues</td>
<td>35,535</td>
<td>35,535</td>
<td>71,070</td>
</tr>
<tr>
<td><strong>Total Revenues</strong></td>
<td><strong>121,727</strong></td>
<td><strong>109,200</strong></td>
<td><strong>230,927</strong></td>
</tr>
</tbody>
</table>

### Costs ($000)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil Costs</td>
<td>143,478</td>
</tr>
<tr>
<td>Natural Gas Costs</td>
<td>13,904</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>31,227</td>
</tr>
<tr>
<td>Debt Service</td>
<td>47,972</td>
</tr>
<tr>
<td>Capital Return (Equity)</td>
<td>21,605</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>258,186</strong></td>
</tr>
</tbody>
</table>

### Net Annual Profit before tax ($000)

(27,258)

### Project IRR (15-year Period)

5.6%
11.0 Product Pricing Policy

This section addresses refined oil product pricing. In some sense, this issue has already been resolved in Afghanistan through a reasonably well-functioning market for refined oil products. The current system, a combination of both normal product imports and a "grey market" of small scale subsidized oil imports from Iran and Turkmenistan, yields prices that offer little scope for arbitrage within the country; a workable definition of market efficiency.

Unlike the situations typical of many developing countries, refined products in Afghanistan are already sold on the basis of import market price plus freight basis. Prices for refined products tend to be relatively high, given the significant freight and other fees that must be incurred to move these products around the country.\(^\text{11}\) The key concerns for the government involve questions of taxation of refined products, pricing of locally produced crude oil and fuel quality specifications.

With the ready availability of imports from a variety of sources, several market-distorting features of refined product pricing around the world have become essentially impossible in Afghanistan. These features include the following ones:

- High taxation of gasoline vis-à-vis diesel;
- Differential user taxes for diesel;
- Subsidies for prices of middle distillates, especially kerosene;
- Price stabilization funds to buffer price movements; and
- Import duties on refined products.

In many countries gasoline is taxed at a high level to discourage demand and to promote the adoption of diesel engines. Such a policy is not likely to prove effective in Afghanistan as long as supplies are available from a variety of imported sources, without any significant ability of the central government to restrict such product movements.

Another common tool of oil product pricing policy is the differential user tax. Such differential taxes are seen as a means of providing certain types of users, usually farmers, with lower cost access to diesel fuel than other transportation sector users of that fuel. With little ability to control the allocation of oil products and lack of basic consumer data about end uses, it would be difficult to design a process that can accurately allocate the low tax fuels to the designated beneficiaries.

For the same reasons cited directly above, subsidies for kerosene intended for household use are also unlikely to be implemented effectively. Even where the government controls virtually all of the import and export of refined products, it is difficult to restrict the use to which a subsidized fuel is put. Countries with significant experience in providing subsidies for kerosene, such as Indonesia, had to abandon such efforts eventually as the cost eventually became prohibitive when increasing volumes of subsidized kerosene ended up as industrial or transportation fuel.

\(^{11}\) Arbitrage of refined products from one region of the country to another is not common. Due to high freight costs, there must be a significant price differential to justify moving products over the mountains from one basin of the country to another. At the same time, the informal "taxation" of such products would increase if refined product wholesalers attempted to capitalize on price differentials, thereby removing much of the incentive for such arbitrage.
Without effective control over internal prices, another common tool, the price stabilization fund, is also unlikely to be an effective one. Where such funds work reasonably well, as is South Korea, the oil refiners collaborate closely with the government on stocks, pricing, and taxation of refined oil products. Without any effective control of physical stocks of oil products the Government of Afghanistan will find its “fill” phase undone when grey market fuel falls in price during weak oil product prices while the official market price remains above that level in order to replenish the fund.

A modest tax on refined product imports might be effective if coupled with an effort to police the overall quality of the imported and locally produced refined products. An ad valorem import duty of under 10% for all full-specification products should give the government the wherewithal to fund inspections and testing for product quality and measurement. As with the other taxation proposals, any significant price gaps raise the possibility of grey market growth in order to circumvent the high taxation.

If the government wishes to raise significant funds from the oil sector, this goals is better achieved at the production end. In particular, the government may want to look at its royalty and tax options for gas and crude oil production and at income taxation of the proposed oil refinery. However, the government’s revenue aims with regard to the oil sector need to keep in mind such other goals as promoting domestic oil and gas production and utilization, a policy that could be vitiated by high resource taxes on crude oil.

The consultants recommend that the government not attempt to control or otherwise manipulate the prices paid for refined oil products. There is simply no evidence that such a policy could be implemented effectively, fairly and efficiently. Rather, the team recommends that the government consider a small import duty on refined products, intended to raise about $40-$50 million annually in its first 1-2 years. At least some of the proceeds from such a duty should be used to enforce improvement and subsequent maintenance of improved product specifications in the marketplace. Domestic oil product supplies, if they materialize, can be taxed at both the resource level (royalty) and production level (income tax), to raise more resources for the government.

---

12 Such a duty might raise as much as $40-50 million at current price and volume levels. Within 5 years, an import duty could potentially raise $100 million. However, it appears from the regional price differentials that a price gap of more than 10% might give rise to arbitrage and smuggling possibilities that could actually reduce the government’s take from an import tax.

13 Once again the experience of Indonesia is instructive. The very high production share of the government in that country has made economical exploitation of small oil reserves infeasible, except under conditions of very high oil prices, as at present. So, while the share of the government in profits may be high, the total volume of such profits is lower than would be the case if the government’s share of profits were reduced.
12.0 Financing Options

The consultant believes that there are limited short or medium-term opportunities for private sector participation in most of the oil and gas infrastructure rehabilitation projects discussed so far. The Consultant has assumed the following in recommending whether private sector participation in the sector is realistic:

- Large volumes of public funds are unlikely to be available over the long term for Afghanistan’s energy infrastructure needs;
- Operating subsidies required are beyond the fiscal ability of the central government;
- Limited funds from bilateral and multilateral agencies;
- Similarly, local funding is limited and can play a role primarily in civil works and other labor intensive phases of each investment; and
- Commercial banks, private investors and export credit agencies will not become major players in the energy sector until infrastructure improvement is under way.

In addition to the above, there are these other factors that would hinder private sector participation. These include: (i) none of the infrastructure projects (Fertilizer/Power/Gas processing plants) are considered viable without significant government subsidies; (ii) lack of efficient gas sector transmission and distribution infrastructure, combined with the lack of recent and acceptable data on gas reserves and production potential; (iii) poor or inadequate regulatory and institutional framework, including gas pricing structures; (iv) political risk and insecurity concerns; and (v) uncertainty over Afghanistan’s political and economic sustainability.

These therefore imply that initial infrastructure investments will have to be made with public sector or/and donor funding until the above factors are improved enough to attract private sector investment.

The consequences are that some of these investments would have to be postponed to later years, or be implemented in phases. However, a key piece of information required to get things started is the determination of the Afghanistan real oil and gas reserve potential, production rate and costs. This could be done relatively quickly (within 2-5 years) through technical assistance to the Afghan Gas company with some supervisory and advisory help from international management consultants. This issue has been addressed in more detail in the Task 1A report on Gas Supply.

Such information would then facilitate decision making in prioritizing the infrastructure projects and how they should be implemented.
13.0 Environmental

An overview of environmental considerations taken during the preparation of this report is outlined in this chapter. Each case analysis presented in Section 5.0 includes the following with respect to environmental considerations:

1) Air, water and soil emissions for both refinery and power plant facilities
2) Fuel specifications for refined products
3) Additional mitigation measures have been included and priced to satisfy World Bank Environmental Guidelines, which are included in Appendix E of this report.
4) The economic analyses include the cost of the above environmental mitigation measures.

13.1 Current situation

Afghanistan imports products from most of its neighboring countries with no control over product specifications. Interviews with traders indicate that high sulfur diesel of lower quality than the specification used for our simples refinery case 2A or 2B is used today in transportation diesel engines. This damages the engines which increases emissions from poor combustion.

The small quantities of oil that are currently produced from the Angot field are currently refined using artisanal techniques in ground pits. This method is very conducive to soil and water pollution.

Nafta and diesel are used in thousands of electric generators in Kabul and other cities to heat and provide minimum electricity requirements; this has undesirable environmental impacts on the population.

Hundreds of trucks are currently being used to bring products to Afghanistan from neighboring countries; this in itself requires a large amount of diesel fuel for transportation and has a long term impact on the roads of this country.

A refinery and power plant installation will have an overall positive environmental impact by:

- Reducing the overall transportation requirements of products within Afghanistan. The distance to be traveled is shorter and easier to control and will require less trips to achieve the same level of distribution.
- Providing at least half of the consumed products with a clear specification, setting a national standard for what product qualities should be, and raising the standard of quality for the consumer. This is particularly the case for the more complex refineries in cases 3A and 3B.
- Reducing a large number of the small generators that use nafta or diesel for small electricity demands, by having a thermal power plant that forms part of a national power grid.
13.2 Refinery Product Qualities

The refinery transportation fuel specifications used are consistent with ASTM specifications for Gasoline, Jet Fuel and Automotive diesel when those products are manufactured (Cases 3A and 3B).

The specifications for Wide Cut Diesel produced in cases 2A and 2B are equivalent to those of Light Diesel Oil of neighboring Pakistan (PSOCL). This product is not an automotive diesel, but more like a marine diesel or railroad diesel that can be used for slow speed Diesel engines.

As the only disposition for the fuel oil was assumed to be that of a new thermal power plant with flue gas scrubbing, no attempt was made to meet a sulfur specification for heavy fuel oil; it was a byproduct of streams that could not be recovered as diesel or asphalt for the different cases.

13.3 Refinery and Power Plant Emissions

The refinery capacities are very small considered to most other locations with a relatively small environmental impact. The air, water and solid emission levels for the refinery and power plants have been estimated for each case under Section 5.0. In addition, the following measures, in compliance with World Bank Environmental Guidelines have been incorporated:

- Natural Gas was used as fuel to all refinery furnaces and as back up of power plant fuel when the refinery is shutdown or the flue gas scrubber in the power plant is unavailable.

- All recovered sour water is stripped of Hydrogen Sulfide and Ammonia for disposal of these streams in a sulfur plant facility. The sulfur plant has a tail gas treater or SCOT unit, to recover most of the sulfur compounds that would go to the atmosphere. The stripped sour water is sent to a waste water treating plant. A total of 13 gpm (gallons per minute) of waste water represents the total liquid emission for Case 3A for example.

- The flue gas from the power plant is sent to a flue gas scrubber using a conventional limestone solution, where 90% of the SOx produced is recovered producing Calcium Sulfate by-product that can be used as a building material.

- Flares: the refinery will have the capability of flaring during emergency or start-up/shut-down operations with an adequately sized flare minimizing the emissions of hydrocarbons.
Volume II: Appendices
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A  ASTM Specifications
B  NATO Specifications
C  Pakistan State Oil Company Fuel Specifications
D  Crude Assay
E  Environmental Guidelines
F  Effective Relocation of Existing Refining Units
G  Calculations
A  ASTM Specifications

This appendix contains parts of the appropriate ASTM specifications for the products of interest in this study. Parts of specifications are provided for:

- D 4814-03a  Automotive Spark-Ignition Engine Fuel
- D 3699-03  Kerosine
- D 1655-03a  Aviation Turbine Fuels
- D 975-04  Diesel Fuel Oils
- D 396-02a  Fuel Oils
TABLE 1 Vapor Pressure and Distillation Class Requirements

<table>
<thead>
<tr>
<th>Vapor Pressure/Distillation Class</th>
<th>Vapor Pressure, °C, kPa (mm-Hg)</th>
<th>Distillation Temperature, °C (F), at % Evaporated, max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>max.</td>
<td>10 volume %, max.</td>
</tr>
<tr>
<td>A</td>
<td>54(7.8)</td>
<td>70(169)</td>
</tr>
<tr>
<td>B</td>
<td>49(6.9)</td>
<td>70(169)</td>
</tr>
<tr>
<td>C</td>
<td>61(10.0)</td>
<td>65(149)</td>
</tr>
<tr>
<td>D</td>
<td>70(11.5)</td>
<td>60(140)</td>
</tr>
<tr>
<td>E</td>
<td>110(15.0)</td>
<td>55(121)</td>
</tr>
</tbody>
</table>

1. The rounding method of Practice E 29. The use of a trailing decimal point in a limit indicates that the digit preceding the decimal point is a significant digit.

1.8 The values stated in SI units are the standard, except when other units are specified by federal regulation. Values given in parentheses are provided for information only.

NIST 2—Many of the values shown in Table 1 were originally developed using U.S. customary units and were subsequently reconverted to SI values. As a result, conversion of the SI values will sometimes differ slightly from the U.S. customary values shown because of round-off. In some cases, federal regulations specify non-SI units.

1.9 The following safety hazard caveat pertains only to the test method portion, Annex A1 of this specification. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure
D 244 Test Method for Copper and Tin in Petroleums and Petroleum Products (Copper Strip Tarnish Test)
D 287 Test Method for Aff Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D 381 Test Method for Gun Contact in Fuels by Jet Evaporation
D 449 Test Method for Automotive Gasoline
D 525 Test Method for Oxidation Stability of Gasoline (Induction Period Method)
D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)
D 1298 Test Method for Density, Relative Density, Specific Gravity, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D 2533 Test Method for Vapor-Liquid Ratio of Spark-Ignition Engine Fuels
D 2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D 2699 Test Method for Research Octane Number of Spark-Ignition Engine Fuel
D 2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel
D 2885 Test Method for Research and Motor Octane Numbers Using On-Line Analyzers
D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Gas Chromatography
D 3231 Test Method for Phosphorus in Gasoline
D 3237 Test Method for Lead in Gasoline by Atomic Absorption Spectrometry
D 3341 Test Method for Lead in Gasoline—Iodine Monochloride Method
D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter
D 4815 Test Method for Determination of MTBE, ETBE, TAME, DIPE, tertiary Butyl Alcohol and C1 to C4 Alcohols in Gasoline by Gas Chromatography
D 4953 Test Method for Vapor Pressure of Gasoline and Gasoline Oxygenate Blends (Dry Method)
D 5059 Test Methods for Lead in Gasoline by X-ray Spectroscopy
D 5188 Test Method for Vapor-Liquid Ratio Temperature Determination of Fuels (Evacuated Chamber Method)
D 5190 Test Method for Vapor Pressure of Petroleum Products (Automotive Method)
D 5191 Test Method for Vapor Pressure of Petroleum Products (Mini Method)
D 5453 Test Method for the Determination of Color in Light Hydrocarbons, Motor Fuels, and Oils by Ultraviolet Spectrophotometry
D 5482 Test Method for Vapor Pressure of Petroleum Products (Mini Method—Atmospheric)

1 For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For annual book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website. 
2 Withdrawn.
vapor pressure in the summertime. Tables 8-11 show at several vapor lock protection levels the areas that require federal reformulated spark-ignition engine fuel in the summertime. Table 12 shows the areas with restrictive local vapor pressure limits that have been approved under the EPA state implementation plan (SIP).

5.2.2 The EPA vapor pressure regulations can cause the distillation of the fuel to be less volatile, which for some vehicles, results in a worse warm-up driveability performance.

5.2.3 Driveability Index (DI) is intended to provide control of distillation parameters that influence cold start and warm-up driveability. It is a function of the 10%, 50%, and 90% evaporated distillation temperatures measured by Test Method D 86.

5.2.4 Test Method D 2533 contains procedures for measuring temperature-VL of both gasoline and gasoline-oxygenate blends. For gasoline-oxygenate blends, the procedure requires that mercury be used as the confining fluid in place of glycerin. Either confining fluid may be used for gasoline. Test Method D 5188 is an alternative method for determining vapor-liquid ratio temperatures by an evacuated chamber method for gasoline-oxygenate blends, as well as gasoline. In case of dispute, Test Method D 2533 is the referee method. The method for estimating temperature-VL (see Appendix X2) is only applicable for gasoline.

5.3 Antiknock index (AKI) is very important to engine performance. The matching of engine octane requirement to fuel octave level (AKI) is critical to the durability and performance of engines; this cannot be accomplished with a single specified minimum level of anti-knock index. Appendix XI includes a discussion of antiknock indexes of fuels currently marketed and relates these levels to the octave needs of broad groups of engines and vehicles. Also discussed is the effect of altitude and weather on vehicle antiknock requirements.

5.4 Additional fuel requirements are shown in Table 2.

5.5 The properties of gasoline-oxygenate blends can differ considerably from those of gasoline. Consequently, additional requirements are needed for gasoline-oxygenate blends. These requirements involve evaluation of compatibility with plastic and elastomeric materials in fuel systems, corrosion of metals, and especially in the case of gasoline-alcohol blends, water tolerance. Requirements for metal corrosion (other than copper) and material compatibility are not given because test methods and appropriate limits are still under development. When these have been developed they will be included in this specification. Water tolerance is specified in Table 13.

5.6 Depending on oxygenate type and concentration in the blend, vehicle driveability with gasoline-oxygenate blends can differ significantly from that with gasolines having similar volatility characteristics.

5.7 Water Tolerance:

5.7.1 The term water tolerance is used to indicate the ability of a gasoline-oxygenate blend to dissolve water without phase separation. This may not be a problem with gasoline-oxygenate blends, but it is of primary concern for alcohol-containing blends, as blends of gasoline with low-molecular weight alcohols generally will dissolve about 0.1 to 0.7 mass % of water under normal conditions, depending on the nature and amount of alcohol(s) used, the specific hydrocarbons present, and the temperature of the blend. When blends are exposed to a greater amount of water than they can dissolve, they separate into an alcohol-rich aqueous phase, the volume of which can be significantly greater than that of the additional water, and an alcohol-poor hydrocarbon phase. As the aqueous phase can be highly corrosive to many metals and the engine cannot operate on it, such separation is very undesirable. Blends containing low-molecular weight alcohols are generally hygroscopic and can eventually absorb enough moisture from ambient air to cause separation. The problem of phase separation can usually be avoided if the fuels are sufficiently water-free initially and care is taken during distribution to prevent contact with water. To help ensure this, gasoline-alcohol blends shall be tested at the lowest temperatures to which they can be subjected, dependent on the time and place of intended use, as indicated in Table 13. The values in Table 13 are the 10th percentile 6-h minimum temperatures, with each reading specifically defined as the highest temperature of the six coldest consecutive hourly temperature readings of a 24-h day. For April through September (and occasionally October, and year-round for Hawaii), Table 13 specifies a minimum phase separation temperature of 10°C (50°F), even though the 10th percentile 6-h minimum temperature can be higher. Use of this temperature limit also reduces the risk of separation of the fuel in storage tanks where temperatures may be lower than ambient.

NOTE 5—The values in Table 13 are taken from the U.S. Army Belvoir.
### TABLE 1 Detailed Requirements of Aviation Turbine Fuels

<table>
<thead>
<tr>
<th>Property</th>
<th>Jet A or Jet A-1</th>
<th>ASTM Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COMPOSITION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidity, total mg KOH/g</td>
<td>max 0.10</td>
<td>D 3242</td>
</tr>
<tr>
<td>Aromatic, vol %</td>
<td>max 25</td>
<td>D 1319</td>
</tr>
<tr>
<td>Sulfur, mercaptan, weight %</td>
<td>max 0.003</td>
<td>D 3227</td>
</tr>
<tr>
<td>Sulfur, total weight %</td>
<td>max 0.00</td>
<td>D 3209, D 1655, D 2622, D 4326, or D 6409</td>
</tr>
<tr>
<td>VOLATILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distillation, one of the following requirements shall be met:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Physical Distillation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distillation temperature, °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% recovered, temperature</td>
<td>max 205</td>
<td>D 60</td>
</tr>
<tr>
<td>20% recovered, temperature</td>
<td>max ...</td>
<td></td>
</tr>
<tr>
<td>50% recovered, temperature</td>
<td>max 3000</td>
<td></td>
</tr>
<tr>
<td>Final boiling point, temperature</td>
<td>max 1.6</td>
<td></td>
</tr>
<tr>
<td>Distillation loss, %</td>
<td>max 1.5</td>
<td>D 2667</td>
</tr>
<tr>
<td>2. Simulated Distillation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distillation temperature, °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% recovered, temperature</td>
<td>max 180</td>
<td></td>
</tr>
<tr>
<td>50% recovered, temperature</td>
<td>max 340</td>
<td></td>
</tr>
<tr>
<td>Final boiling point, temperature</td>
<td>min 12</td>
<td>D 56 or D 3228</td>
</tr>
<tr>
<td>Density at 15°C, kg/m³</td>
<td>0.77 to 0.840</td>
<td>D 1298 or D 4052</td>
</tr>
<tr>
<td>FLUIDITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freezing point, °C</td>
<td>max -40 Jet A</td>
<td>D 2360 or D 5972</td>
</tr>
<tr>
<td>Viscosity, °C/°C</td>
<td>max 8.9</td>
<td>D 445</td>
</tr>
<tr>
<td>COMBUSTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net heat of combustion, MJ/kg</td>
<td>min 42.8</td>
<td>D 4529, D 3338, or D 4809</td>
</tr>
<tr>
<td>One of the following requirements shall be met:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Smoke point, mm or</td>
<td>min 25</td>
<td>D 1322</td>
</tr>
<tr>
<td>(2) Smoke point, mm, and</td>
<td>min 10</td>
<td>D 1323</td>
</tr>
<tr>
<td>Naphthenes, vol %</td>
<td>max 3.0</td>
<td>D 1640</td>
</tr>
<tr>
<td>CORROSION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper strip, 2 h at 100°C</td>
<td>max No. 1</td>
<td>D 1290</td>
</tr>
<tr>
<td>THERMAL STABILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JFTOT (2.5 h at control temperature of 260°C)</td>
<td>max 25</td>
<td>D 3241</td>
</tr>
<tr>
<td>Filler pressure drop, mm Hg</td>
<td>max 25</td>
<td></td>
</tr>
<tr>
<td>Tube deposits less than No. Feseck or Abnormal/Color Deposits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTAMINANTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evident gum, mg/100 mL</td>
<td>max 7</td>
<td>D 381</td>
</tr>
<tr>
<td>Water reaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface rating</td>
<td>max 1b</td>
<td>D 1094</td>
</tr>
<tr>
<td>ADDITIVES</td>
<td>See 5.2</td>
<td>D 2624</td>
</tr>
</tbody>
</table>

Notes:
- For compliance of test results against the requirements of Table 1, see 6.3.
- The test methods indicated in this table are referred to in Section 10.
- The mercaptan sulfur determination may be waived if the fuel is considered sweet by the doctor test described in Test Method D 4852.
- Test Method D 2667 can not be used for Jet B.
- A higher minimum flash point specification may be agreed upon between purchaser and supplier.
- Results obtained by Test Methods D 3209 may be up to 2°C lower than those obtained by Test Method D 56, which is the preferred method. In case of dispute, Test Method D 56 will apply.
- Other freezing points may be agreed upon between supplier and purchaser.
- 1°C/°C = 1 CSF.
- 1 psig = 1 × 10^-5 atm / cm².
- Additional test requirements may be agreed upon between supplier and purchaser.
- Preferred SI units are 3.3 kPa, max.
- For all grades use either Eq 1 or Table 1 in Test Method D 4529 or Eq 2 in Test Method D 3338. Test Method D 4809 may be used as an alternative. In case of dispute, Test Method D 4529 shall be used.
- Preferred SI units are 1.3 kPa, max.
- Tube deposit ratings shall always be reported by the Visual Method; a rating by the Tube Deposit Rating (TDR) optical density method is desirable but not mandatory.
- If electrical conductivity additive is used, the conductivity shall not exceed 450 pS/m at the point of use of the fuel. When electrical conductivity additive is specified by the purchaser, the conductivity shall be 50 to 450 pS/m under the conditions at point of delivery.

Copyright by ASTM Intl (all rights reserved)
TABLE 1 Detailed Requirements for Diesel Fuel Oils

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Test Method</th>
<th>Grade Low Sulfur No. 1-D*</th>
<th>Grade Low Sulfur No. 2-D*</th>
<th>Grade No. 1-D2*</th>
<th>Grade No. 2-D2*</th>
<th>Grade No. 4-D2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash Point, °C, min.</td>
<td>0.94</td>
<td>38</td>
<td>62*</td>
<td>38</td>
<td>52*</td>
<td>65</td>
</tr>
<tr>
<td>Water and Sediment, % vol, max</td>
<td>0.2709</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Distillation—One of the following requirements shall be met:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Physical Distillation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distillation Temperature, °C, 90 %, % vol Recovered max</td>
<td>0.1706</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>2. Simulated Distillation</td>
<td>0.2867</td>
<td>288</td>
<td>338</td>
<td>288</td>
<td>338</td>
<td></td>
</tr>
<tr>
<td>Distillation Temperature, °C, 90 %, % vol Recovered max</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic Viscosity, mm²/s at 40°C</td>
<td>0.445</td>
<td>304</td>
<td>356</td>
<td>304</td>
<td>356</td>
<td>356</td>
</tr>
<tr>
<td>Ash % mass, max</td>
<td>0.482</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.10</td>
</tr>
<tr>
<td>Sulfur % mass, max</td>
<td>0.2822</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper strip corrosion rating max 3 h at 50°C</td>
<td>0.75</td>
<td>No. 3</td>
<td>No. 3</td>
<td>No. 3</td>
<td>No. 3</td>
<td></td>
</tr>
<tr>
<td>Cloud point, °C, max</td>
<td>0.2500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or LFTC/PPP, °C, max</td>
<td>0.4538</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramsbottom carbon residue on 10 % distillation residue, % mass, max</td>
<td>0.624</td>
<td>0.15</td>
<td>0.35</td>
<td>0.15</td>
<td>0.35</td>
<td></td>
</tr>
</tbody>
</table>

a) These test methods are indicated by the appropriate test methods. Other acceptable methods are indicated in 3.1.

b) Under United States regulations, if Grades Low Sulfur No. 1-D or Low Sulfur No. 2-D are sold for tax exempt purposes then, at or beyond terminal storage tanks, they are required by 26 CFR Part 80 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.9 lb per thousand barrels of the solid dye Solvent Red 28, or the tax must be collected.

c) When a cloud point less than −12°C is specified, as can occur during cool months, it is permitted and normal blending practice to combine Grades No. 1 and No. 2 to meet the low temperature requirements. In that case, the minimum flash point shall be 38°C, the minimum viscosity at 40°C shall be 1.7 mm²/s, and the minimum 90 % recovered temperature shall be waived.

d) These test methods are specified in 40 CFR Part 80.

4. Workmanship

4.1 The diesel fuel shall be visually free of undissolved water, sediment, and suspended matter.

5. Requirements

5.1 The grades of diesel fuel oils herein specified shall be hydrocarbon oils conforming to the detailed requirements shown in Table 1.

5.2 Grades No. 2-D and Low Sulfur No. 2-D—When a cloud point less than −12°C is specified, as can occur during cool months, it is permitted and normal blending practice to combine Grades No. 1 and No. 2 to meet the low temperature requirements. In that case, the minimum flash point shall be 38°C, the minimum viscosity at 40°C shall be 1.7 mm²/s, and the minimum 90 % recovered temperature shall be waived.

6. Keywords

6.1 diesel, fuel oil, petroleum and petroleum products
TABLE 1  Detailed Requirements for Fuel Oils

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Test Method</th>
<th>No. 1 Low Sulfur</th>
<th>No. 2 Low Sulfur</th>
<th>No. 3</th>
<th>No. 4 Grade</th>
<th>No. 5 (Light)</th>
<th>No. 6 (Heavy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash Point, °C, min</td>
<td>89 – Proc. A</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>99 – Proc. B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water and sediment, % vol, max</td>
<td>D 2799</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>(0.50)</td>
<td>(1.00)</td>
</tr>
<tr>
<td></td>
<td>D 445</td>
<td></td>
<td>0.05</td>
<td></td>
<td></td>
<td>(0.50)</td>
<td>(1.00)</td>
</tr>
<tr>
<td>Distillation temperature °C</td>
<td>D 86</td>
<td>215</td>
<td>215</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 % volume recovered, max</td>
<td>D 86</td>
<td>206</td>
<td>206</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 % volume recovered, min</td>
<td>D 86</td>
<td>293</td>
<td>293</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic viscosity at 40°C, mm²/s</td>
<td>D 445</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>&gt;5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic viscosity at 100°C, mm²/s</td>
<td>D 445</td>
<td>2.1</td>
<td>2.1</td>
<td>2.1</td>
<td>5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual carbon residue on 10 % distillation residue % max</td>
<td>D 86</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.15</td>
</tr>
<tr>
<td>Ash, % mass, max</td>
<td>D 482</td>
<td></td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur, % mass max</td>
<td>D 129</td>
<td></td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper strip corrosion rating, 3h at 50°C</td>
<td>D 130</td>
<td>No. 3</td>
<td>No. 3</td>
<td>No. 3</td>
<td>No. 3</td>
<td>No. 3</td>
<td>No. 3</td>
</tr>
<tr>
<td>Density at 15°C, g/cm³</td>
<td>D 123</td>
<td></td>
<td>675</td>
<td>675</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POUR Point, °C, max a</td>
<td>D 97</td>
<td></td>
<td>875</td>
<td>875</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a It is the intent of these classifications that failure to meet any requirement of a given grade does not automatically place an oil in the next lower grade unless in fact it meets all requirements of the lower grade. However, to meet special operating conditions, modifications of individual limiting requirements may be agreed upon among the purchaser, seller, and manufacturer.

b The test methods indicated are the approved referee methods. Other acceptable methods are indicated in Section 2 and 8.1.

c Under United States regulations, Grades No. 1, No. 2, No. 3, No. 4, and No. 6 are required by 40 CFR Part 80 to contain a sufficient amount of the dye Solvent Red 16 to the presence is visually apparent. At storage, terminal storage tanks, they are required by 40 CFR Part 80 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.0 lb per thousand barrels of the cold dye standard Solvent Red 26.

d The amount of water by distillation by Test Method D 473 plus the amount by extraction by Test Method D 473 shall not exceed 0.50 mass %, and a deduction in quantity shall be made for all water and sediment in excess of 1.1 mass %.

e Where low sulfur fuel oil is required, fuel oil falling in the viscosity range of a lower number grade does to and including No. 4 can be supplied by agreement between the purchaser and supplier. The viscosity range of the initial shipment shall be identified and advance notice shall be required when changing from one viscosity range to another. This notice shall be in sufficient time to permit the user to make the necessary adjustments.

f Other sulfur limits may apply in selected areas in the United States and in other countries.

g This limit ensures a minimum heating value and also prevents misrepresentation and misapplication of this product as Grade No. 2.

h Lower or higher pour points can be specified whenever required by conditions of storage or use. When a lower pour point less than -18°C is specified, the minimum viscosity at 40°C for grade No. 2 shall be 1.7 mm²/s and the minimum 95% recovered temperature shall be waived.

i Where low sulfur fuel oil is required, Grade No. 6 fuel oil will be classified as Low Pour (-15°C max) or High Pour (no max). Low Pour fuel oil should be used unless tanks and lines are heated.

2.2 Other Documents:
26 CFR Part 48 Diesel Fuel Excise Tax; Dye Color and Concentration
40 CFR Part 80 Regulation of Fuel and Fuel Additives

3. General Requirements
3.1 The grades of fuel oil specified herein shall be homogenous hydrocarbon oils, free from inorganic acid, and free from excessive amounts of acid or fibrous foreign matter.
3.2 All grades containing residual components shall remain uniform in normal storage and not separate by gravity into light and heavy oil components outside the viscosity limits for the grade.

4. Detailed Requirements
4.1 The various grades of fuel oil shall conform to the limiting requirements shown in Table 1. A representative sample shall be taken for testing in accordance with Practice D 4057.
### TABLE 2: Detailed Requirements for Additives in Aviation Turbine Fuels

<table>
<thead>
<tr>
<th>Additive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Performance Enhancing Additives</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Antioxidants&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>One of the following:</td>
</tr>
<tr>
<td>2,6-ditertiary-butyl phenol</td>
</tr>
<tr>
<td>2,6-ditertiary-butyl-4-methyl phenol</td>
</tr>
<tr>
<td>2,4-dimethyl-6-tertiary-butylphenol</td>
</tr>
<tr>
<td>75% minimum, 2,6 ditertiary-butyl phenol plus</td>
</tr>
<tr>
<td>25% maximum mixed tertiary and ditertiary phenols</td>
</tr>
<tr>
<td>65% minimum 24-dimethyl-6-tertiary-butyl phenol plus</td>
</tr>
<tr>
<td>15% minimum 2,6 ditertiary-butyl-4-methyl phenol</td>
</tr>
<tr>
<td>remainder as nonphenyl and dimethyl tertiary-butyl phenols</td>
</tr>
<tr>
<td>72% minimum 2,4-dimethyl-6-tertiary-butyl phenol plus</td>
</tr>
<tr>
<td>28% maximum monophenyl and dimethyl tertiary-butyl phenols</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Metal Deactivants&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>N,a-diisobutyl-o-2-propylamine</td>
</tr>
<tr>
<td>On initial blending</td>
</tr>
<tr>
<td>After blending cumulative concentration</td>
</tr>
<tr>
<td>Fuel System icing inhibitor&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diethylene Glycol Nonomethyl Ether (see Specification D 4171)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fuel Handling and Maintenance Additives</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Electrical Conductivity Improver&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Saturic 450&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
<tr>
<td>On initial blending</td>
</tr>
<tr>
<td>After blending cumulative concentration</td>
</tr>
<tr>
<td>If the additive concentration is unknown at time of treatment,</td>
</tr>
<tr>
<td>additional concentration is restricted to 2 mg/L max</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Leak Detection Additive&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tracer A (Dita A)&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> The active ingredient of the additive must meet the composition specified.

<sup>d</sup> Supporting data (a list of proprietary products meeting the composition requirements for oxidation inhibitors) have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: DD1126.

<sup>f</sup> The active ingredient (not including weight of solvent).

<sup>g</sup> The quantity must be declared by the fuel supplier and agreed to by the purchaser.

<sup>e</sup> Electrical conductivity improver is used, the conductivity shall not exceed 450 µS/m at the point of use of the fuel. When electrical conductivity additive is specified by the purchaser, the conductivity shall be 50 to 450 µS/m under the conditions at point of delivery.

<sup>b</sup> Brookfield AV-CAP D 4150.

### Keywords

- 11.1 aviation turbine fuel; aviation jet, Jet A; jet A-1; jet fuel; turbine fuel
TABLE 2: Detailed Requirements for Additives in Aviation Turbine Fuels

<table>
<thead>
<tr>
<th>Additive</th>
<th>Conformance Test Method(s)</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Antioxidant(s)
| 2, 6-di-tert-butyl phenol |
| 2, 6-di-tert-butyl-4-methyl phenol |
| 2, 6-dimethyl-4-tert-butyl phenol |
| T5 % minimum: 2, 6-di-tert-butyl phenol plus |
| 25 % maximum mixed arohy and hindered arohy phenols |
| 50 % minimum: 2, 6-di-tert-butyl-4-methyl phenol |
| 10 % minimum: 2, 6-di-tert-butyl-4-methyl phenol |
| 20 % minimum: isobutylyl and dimethylisobutyl phenols |

| Motor Octane | 0.12 | 0.15 |
| Octane Number | 91 | 91 |

| Electrical Conductivity Impeller |
| 0.02 | 0.02 |
| Octane Number | 0.12 | 0.15 |

| Leak Detection Additive |
| 0.01 | 0.01 |

| Base Oil Additive |
| 0.01 | 0.01 |

---

1) The active ingredient of the additive must meet the composition specified.
2) Supporting data for all proprietary products meeting the composition requirements (including inhibitors) have been filed with ASTM International Headquarters and may be obtained by requesting Technical Report D-2024-02.
3) Active ingredient (not including weight of diluent).
4) If copper contamination is suspected, initial treatment may exceed 3 mg/g but cumulative total requires below 0.5 mg/g.
5) The quantity must be determined by the user's supplier and agreed to by the purchaser.
6) If electrical conductivity is required, the additive shall not exceed 450 pS/m at the point of use of the fuel. When electrical conductivity additive is specified, the purchaser the conductivity shall be 50 to 450 pS/m under the conditions of point of delivery.

10.1.13. Thermal Stability—Test Method D 3241
10.1.15. Smoke Point—Test Method D 3922
10.1.16. Sulfur Property—Test Method D 1166
10.1.17. Electrical Conductivity—Test Method D 2024

Keywords: jet aviation turbine fuel; avtur; jet A; jet A-1; jet fuel; turbine fuel
B　NATO Specifications
Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment

Annex A

Aide Memoire on Fuels in NATO

AVIATION FUELS

NATO CODE

F-18

is an aviation gasoline (low lead) in limited use by certain NATO nations. Also known as AVGAS 100LL.

F-34

is a military kerosene type aviation turbine fuel with Fuel System Icing Inhibitor (FSII) (NOTE 1) used by land based military gas turbine engined aircraft in all NATO countries. (NOTE 2) Also known as JP-8 or AVTUR/FSII.

F-35

is a military kerosene type aviation turbine fuel equivalent to that used by most civil operators of gas turbine engined aircraft. Also known as JET A-1 or AVTUR.

F-40

is a military wide cut type aviation turbine fuel with FSII used by land based military gas turbine engined aircraft (NOTE 2). Also known as JP-4 or AVTAG/FSII. Within NATO it is an emergency substitute for F-34/F-35.

F-44

is a military high flash point kerosene type aviation turbine fuel with FSII used by ship borne military gas turbine engine aircraft in most NATO countries. Also known as JP-5 or AVCAT/FSII.

NOTES:

JET A and JET B (See NOTES 4 and 5)
1. FSII NATO Code S-1745. Additive to aviation turbine fuels as system icing inhibitor.
2. Until 1986, F-40 was used by land based gas turbine engined aircraft in all NATO countries except France and the United Kingdom which had converted to F-34 some 15 years earlier. Following a decision by NATO Defence Ministers all nations except Turkey switched from F-40 to F-34. The conversion (known as Stage 1 of the Single Fuel Concept) was completed in 1988. Turkey completed its conversion from F-40 to F-34 in 1996.

3. The term "additives" used in this Aide Memoire can include FSII corrosion inhibitor/lubricity improver additive and static-dissipater additive (SDA).
4. JET A is a civil grade of kerosene type aviation turbine fuel only supplied for operations in the United States. It has a freezing point of -40°C max which differs from JET A-1 (-47°C).
5. JET B is a civil grade of wide cut type aviation turbine fuel which has a different freezing point (-50°C) from F-40 (-58°C) and does not normally contain FSII.
6. For further details about these fuels, see Annex C to STANAG 1135.

GROUND FUELS

GASOLINES

F-46

is a military fuel used in certain armored and non-armored vehicle spark ignition engines in NATO Europe areas outside Denmark and the United Kingdom. Also known as gasoline automotive: Military (91 RON) or COMBATGAS. Availability of this fuel is now limited and has been replaced by F-57.

F-57

low leaded gasoline introduced to replace F-46. It is interchangeable with commercial gasoline automotive (98 RON).

F-67

unleaded gasoline automotive interchangeable with commercial gasoline (95 RON).

DIESEL FUELS

F-54

is a military fuel used in compression ignition engines in NATO Europe areas outside Denmark, Greece, Italy, Portugal, Spain and the United Kingdom. Also known as Diesel Fuel: MILITARY or DF-2. It has a Pour Point specification of 18°C maximum.

F-65

low temperature diesel/kerosene fuel blend.
F-75

is a military fuel used in compression ignition engines in Denmark and Greece. It is normally referred to as FUEL NAVAL DISTILLATE, low pour point. (See Naval fuels).

NOTE: For further details about these fuels, see Annex C to STANAG 1135.

NAVAL FUELS

F-75

is a naval fuel used in compression ignition engines and in naval gas turbines and ships' boilers for steam raising. Also known as FUEL, NAVAL DISTILLATE, low pour point. (See Ground Fuels).

F-76

is the primary naval fuel used as for F-75 above but it may require special handling and storage due to low temperature characteristics. Also known as FUEL, NAVAL DISTILLATE (NOTE 1).

F-77

is a naval residual fuel used for boiler steam raising for certain ships in France, Greece and Turkey. Also known as FUEL, RESIDUAL, light viscosity boiler or 50/50 FFO (NOTE 2).

NOTES:

2. F-77 may also be used in slow speed diesel engines.
3. F-44 Naval aviation turbine fuels - see Aviation Fuels.
4. For further details about these fuels, see Annex C to STANAG 1135.
C  Pakistan State Oil Company Fuel Specifications

The specifications on the following pages were taken from the Pakistan State Oil Company web site.

The specifications provided are:

- High Octane Blending Component
- Premium Plus (SGP)
- High Speed Diesel
- Light Diesel Oil
### FUEL OILS

### HIGH OCTANE BLENDING COMPONENT

#### HOBC

#### MARKETING SPECIFICATION

<table>
<thead>
<tr>
<th>TEST</th>
<th>TEST METHOD</th>
<th>SPECIFICATION LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Distillation:</td>
<td>ASTM D-86</td>
<td></td>
</tr>
<tr>
<td>10% Vol. Recovery at °C</td>
<td>Max. 100</td>
<td></td>
</tr>
<tr>
<td>50% Vol. Recovery at °C</td>
<td>Max. 150</td>
<td></td>
</tr>
<tr>
<td>90% Vol. Recovery at °C</td>
<td>Max. 180</td>
<td></td>
</tr>
<tr>
<td>End Point at °C</td>
<td>Max. 205</td>
<td></td>
</tr>
<tr>
<td>Residue % Vol</td>
<td>Max. 2</td>
<td></td>
</tr>
<tr>
<td>2. Octane Number (Research)</td>
<td>ASTM D-2699</td>
<td>Min. 97</td>
</tr>
<tr>
<td>3. Lead Content, gm/litre.</td>
<td>ASTM D-3341</td>
<td>Max. 0.84</td>
</tr>
<tr>
<td>4. Existent Gum, mg/100ml</td>
<td>ASTM D-381</td>
<td>Max. 4</td>
</tr>
<tr>
<td>5. Sulphur, % wt.</td>
<td>ASTM D-1266</td>
<td>Max. 0.1</td>
</tr>
<tr>
<td>6. Doctor Test</td>
<td>ASTM D-484</td>
<td>Negative</td>
</tr>
<tr>
<td>7. Colour</td>
<td></td>
<td>Reddish</td>
</tr>
<tr>
<td>8. Copper Strip Corrosion @</td>
<td>ASTM D-130</td>
<td>Max. No. 1</td>
</tr>
<tr>
<td>50 °C</td>
<td></td>
<td>Marketable</td>
</tr>
<tr>
<td>9. Odour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Reid Vapour Pressure at</td>
<td>ASTM D-323</td>
<td>Max. 9</td>
</tr>
<tr>
<td>37.8°F, psi</td>
<td></td>
<td>Max. 10</td>
</tr>
<tr>
<td>a. Summer (Mar-Oct)</td>
<td></td>
<td>Clear &amp; free from</td>
</tr>
<tr>
<td>b. Winter</td>
<td></td>
<td>water &amp; suspended</td>
</tr>
<tr>
<td>12. Appearance</td>
<td></td>
<td>impurities.</td>
</tr>
</tbody>
</table>

PSO product conforms to PSI standards.

Issued: Jan, 2001
## PREMIUM PLUS (SGP)

### MARKETING SPECIFICATION

<table>
<thead>
<tr>
<th>TEST</th>
<th>TEST METHOD</th>
<th>SPECIFICATION LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Distillation:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10% Vol. Recovery at °C</td>
<td>Max. 70</td>
</tr>
<tr>
<td></td>
<td>50% Vol. Recovery at °C</td>
<td>Max. 125</td>
</tr>
<tr>
<td></td>
<td>90% Vol. Recovery at °C</td>
<td>Max. 180</td>
</tr>
<tr>
<td></td>
<td>End Point at °C</td>
<td>Max. 205</td>
</tr>
<tr>
<td></td>
<td>Residue % Vol.</td>
<td>Max. 2</td>
</tr>
<tr>
<td>2.</td>
<td>Specific Gravity at 15.6°C</td>
<td>Max. 0.74</td>
</tr>
<tr>
<td>3.</td>
<td>Octane Number (Research)</td>
<td>Min. 87</td>
</tr>
<tr>
<td>4.</td>
<td>Lead Content, gm/litre.</td>
<td>Max. 0.35</td>
</tr>
<tr>
<td>5.</td>
<td>Existent Gum, mg/100ml</td>
<td>Max. 4</td>
</tr>
<tr>
<td>6.</td>
<td>Sulphur, % wt.</td>
<td>Max. 0.1</td>
</tr>
<tr>
<td>7.</td>
<td>Doctor Test</td>
<td>Negative Pinkish</td>
</tr>
<tr>
<td>8.</td>
<td>Colour</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Copper Strip Corrosion @ 50 °C</td>
<td>Max. No. 1 Marketable</td>
</tr>
<tr>
<td>10.</td>
<td>Odour</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Reid Vapour Pressure at 37.8 °F, psi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. Summer (Mar-Oct)</td>
<td>Max. 9</td>
</tr>
<tr>
<td></td>
<td>b. Winter</td>
<td>Max. 10</td>
</tr>
<tr>
<td></td>
<td>Clear &amp; free from water &amp; suspended impurities</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Appearance</td>
<td></td>
</tr>
</tbody>
</table>

PSO Product conforms to PSO standards.
## FUEL OILS

### HIGH SPEED DIESEL (HSD)

#### MARKETING SPECIFICATION

<table>
<thead>
<tr>
<th>TEST</th>
<th>TEST METHOD</th>
<th>SPECIFICATION LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Specific Gravity 15.6 °C</td>
<td>ASTM D-1298</td>
<td>Min. 0.820, Max. 0.870</td>
</tr>
<tr>
<td>2. Colour</td>
<td>ASTM D-1600</td>
<td>Max. 3.0</td>
</tr>
<tr>
<td>3. Flash Point (PMCC) °C</td>
<td>ASTM D-93</td>
<td>Max. 66</td>
</tr>
<tr>
<td>4. Sulphur Content, % wt.</td>
<td>ASTM D-129</td>
<td>Max. 1.0</td>
</tr>
<tr>
<td>5. Copper Strip Corrosion 3 hrs. @ 100 °C</td>
<td>ASTM D-130</td>
<td></td>
</tr>
<tr>
<td>6. Viscosity Kinematic @ 40 °C cSt.</td>
<td>ASTM D-445</td>
<td>Max. 1.0</td>
</tr>
<tr>
<td>7. Cloud Point, °C</td>
<td>ASTM D-2600</td>
<td>Min. 1.5, Max. 6.5</td>
</tr>
<tr>
<td>8. Pour Point °C</td>
<td>ASTM D-97</td>
<td>Max. 9° (Summer), Max. 6° (Winter), Max. 3° (Summer)</td>
</tr>
<tr>
<td>9. Conradson Carbon Residue on 10% residue, % wt.</td>
<td>ASTM D-169</td>
<td>Max. 0.2</td>
</tr>
<tr>
<td>10. Ash Content, % wt.</td>
<td>ASTM D-462</td>
<td>Max. 0.01</td>
</tr>
<tr>
<td>11. Sediment, % wt.</td>
<td>ASTM D-973</td>
<td>Max. 0.01</td>
</tr>
<tr>
<td>12. Water % wt.</td>
<td>ASTM D-95</td>
<td>Max. 0.05</td>
</tr>
<tr>
<td>13. Cetane Index (Calculated)</td>
<td>ASTM D-978</td>
<td>Min. 45</td>
</tr>
<tr>
<td>14. Strong Acid Number mg KOH/g</td>
<td>ASTM D-974</td>
<td>Nil</td>
</tr>
<tr>
<td>15. Total Acid Number mg KOH/g</td>
<td>ASTM D-974</td>
<td>Max. 0.5</td>
</tr>
</tbody>
</table>

a (Mar - Oct)  
b (Nov - Feb)

PSO Product conforms to PSI standards.

Issued: Jan, 2001
# FUEL OILS

## LIGHT DIESEL DIESEL OIL (LDO)

### MARKETING SPECIFICATION

<table>
<thead>
<tr>
<th>TEST</th>
<th>TEST METHOD</th>
<th>SPECIFICATION LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Specific Gravity 15.6 °C</td>
<td>ASTM D-1298</td>
<td>Max.: 0.920</td>
</tr>
<tr>
<td>4. Flash Point (PMCC).°C</td>
<td>ASTM D-93</td>
<td>Min.: 54.5</td>
</tr>
<tr>
<td>5. Sulphur Content, % wt.</td>
<td>ASTM D-1551</td>
<td>Max.: 1.8</td>
</tr>
<tr>
<td>7. Viscosity Kinematic @ 37.8 °C cSt.</td>
<td>ASTM D-445</td>
<td>Max.: 14</td>
</tr>
<tr>
<td>10. Conradson Carbon Residue on 10% distillation residue, % wt.</td>
<td>ASTM D-189</td>
<td>Max.: 1.5</td>
</tr>
<tr>
<td>11. Ash, % wt.</td>
<td>ASTM D-482</td>
<td>Max.: 0.02</td>
</tr>
<tr>
<td>12. Sediment, % wt.</td>
<td>ASTM D-473</td>
<td>Max.: 0.05</td>
</tr>
<tr>
<td>13. Water Content, % Vol.</td>
<td>ASTM D-95</td>
<td>Max.: 0.25</td>
</tr>
<tr>
<td>15. Strong Acid Number mg KOH/g</td>
<td>ASTM D-974</td>
<td>Nil</td>
</tr>
<tr>
<td>16. Total Acid Number mg KOH/g</td>
<td>ASTM D-974</td>
<td>Max.: 0.5</td>
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</table>

PSO Product conforms to PSI standards.
D  Crude Assay
<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Units</th>
<th>Method</th>
<th>Date</th>
<th>Analyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Number</td>
<td>0.26</td>
<td>mg KOH/g</td>
<td>ASTM D-664</td>
<td>3/31/2004</td>
<td>CB</td>
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<tr>
<td>API Gravity</td>
<td>.236</td>
<td>@ 60 F</td>
<td>ASTM D-5002</td>
<td>3/30/2004</td>
<td>SD</td>
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<tr>
<td>Carbon Residue-Micro</td>
<td>8.4</td>
<td>WT %</td>
<td>ASTM D-4530</td>
<td>4/2/2004</td>
<td>VS</td>
</tr>
<tr>
<td>Iron</td>
<td>1.5</td>
<td>ppm wt</td>
<td>ASTM D-5708</td>
<td>4/2/2004</td>
<td>KC</td>
</tr>
<tr>
<td>Kinematic Viscosity</td>
<td>146.0</td>
<td>cSt @ 60 F</td>
<td>ASTM D-445</td>
<td>3/31/2004</td>
<td>DRG</td>
</tr>
<tr>
<td>Kinematic Viscosity</td>
<td>34.43</td>
<td>cSt @ 100 F</td>
<td>ASTM D-445</td>
<td>4/1/2004</td>
<td>DRG</td>
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**Light Ends Analysis**

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Units</th>
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<th>Date</th>
<th>Analyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>&lt; 0.01</td>
<td>LV %</td>
<td>ASTM D-5134Mod.</td>
<td>4/1/2004</td>
<td>CC</td>
</tr>
<tr>
<td>Ethane</td>
<td>&lt; 0.01</td>
<td>LV %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>0.02</td>
<td>LV %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iso-Butane</td>
<td>0.07</td>
<td>LV %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-Butane</td>
<td>0.14</td>
<td>LV %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neopentane</td>
<td>&lt; 0.01</td>
<td>LV %</td>
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<tr>
<td>Iso-Pentane</td>
<td>0.24</td>
<td>LV %</td>
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<td></td>
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<tr>
<td>N-Pentane</td>
<td>0.26</td>
<td>LV %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hexanes</td>
<td>1.11</td>
<td>LV %</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Heptanes Plus</td>
<td>98.16</td>
<td>LV %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>2.4</td>
<td>ppm wt</td>
<td>ASTM D-5708</td>
<td>4/2/2004</td>
<td>KC</td>
</tr>
<tr>
<td>Nitrogen Total by Chemilum.</td>
<td>588</td>
<td>ppm wt</td>
<td>ASTM D-4629</td>
<td>4/1/2004</td>
<td>JM</td>
</tr>
<tr>
<td>Pour Point</td>
<td>+35</td>
<td>Deg F</td>
<td>ASTM D-97</td>
<td>3/30/2004</td>
<td>VS</td>
</tr>
<tr>
<td>Reid Vapor Pressure, ASTM</td>
<td>0.95</td>
<td>psi</td>
<td>ASTM D-5191</td>
<td>3/26/2004</td>
<td>SAK</td>
</tr>
</tbody>
</table>
MARK LOCKHART  
COMMONWEALTH ENGINEERING  
10255 RICHMOND SUITE 300  
HOUSTON, TX 77042  

Sample Number: 141253-001  
Sample Date:  
Date Reported: 4/5/2004  
Date Received: 3/26/2004  
Sample ID: 02037-001 Crude Oil  
Description: Afghan Crude

Analytical Report

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Units</th>
<th>Method</th>
<th>Date</th>
<th>Analyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated Distillation-Crude</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>IBP</td>
<td>111</td>
<td>Deg F</td>
<td>ASTM D-5307</td>
<td>3/30/2004</td>
<td>DM</td>
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<tr>
<td>5 % off</td>
<td>283</td>
<td>Deg F</td>
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<td></td>
<td></td>
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<tr>
<td>10 % off</td>
<td>369</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>15 % off</td>
<td>434</td>
<td>Deg F</td>
<td></td>
<td></td>
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<tr>
<td>20 % off</td>
<td>488</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 % off</td>
<td>534</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 % off</td>
<td>578</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 % off</td>
<td>624</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 % off</td>
<td>668</td>
<td>Deg F</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>45 % off</td>
<td>713</td>
<td>Deg F</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>50 % off</td>
<td>758</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55 % off</td>
<td>805</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 % off</td>
<td>853</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65 % off</td>
<td>907</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70 % off</td>
<td>963</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 % off</td>
<td>1004</td>
<td>Deg F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Recovered</td>
<td>74.4</td>
<td>@ 1000 Deg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Residue</td>
<td>25.6</td>
<td>@ 1000 Deg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur, Total by X-Ray Fluoresc.</td>
<td>2.65</td>
<td>WT %</td>
<td>ASTM D-4294</td>
<td>4/1/2004</td>
<td>CB</td>
</tr>
<tr>
<td>Vanadium</td>
<td>7.1</td>
<td>ppm wt</td>
<td>ASTM D-5708</td>
<td>4/2/2004</td>
<td>KC</td>
</tr>
</tbody>
</table>

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MARK LOCKHART  
COMMONWEALTH ENGINEERING  
10255 RICHMOND SUITE 300  
HOUSTON, TX  77042  

Sample Number: 141253-001  
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Date Reported: 4/5/2004  
Date Received: 3/26/2004  
Sample ID: 02037-001  
Description: Afghan Crude

### Analytical Report

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Units</th>
<th>Method</th>
<th>Date</th>
<th>Analyst</th>
</tr>
</thead>
</table>

Approved By: Jean Waits  
Supervising Chemist

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E Environmental Guidelines
Summary of Air Emission and Effluent Discharge Requirements Presented in the Industry Guidelines

Terms Used in the following Tables 1–3

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADP</td>
<td>Air-dried pulp</td>
</tr>
<tr>
<td>Ag</td>
<td>Silver</td>
</tr>
<tr>
<td>AOX</td>
<td>Adsorbable organic halides</td>
</tr>
<tr>
<td>As</td>
<td>Arsenic</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical oxygen demand (understood as BOD measured over five days, BOD₅)</td>
</tr>
<tr>
<td>Cd</td>
<td>Cadmium</td>
</tr>
<tr>
<td>Cl</td>
<td>Chlorine</td>
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<tr>
<td>CN</td>
<td>Cyanide</td>
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<td>Cobalt</td>
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<tr>
<td>CO</td>
<td>Carbon monoxide</td>
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<tr>
<td>COD</td>
<td>Chemical oxygen demand</td>
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<tr>
<td>Cr₆⁺</td>
<td>Hexavalent chromium</td>
</tr>
<tr>
<td>Cr, total</td>
<td>Total chromium</td>
</tr>
<tr>
<td>CTMP</td>
<td>Chemical, thermal, mechanical process for producing pulp</td>
</tr>
<tr>
<td>Cu</td>
<td>Copper</td>
</tr>
<tr>
<td>F</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>g/mm Btu</td>
<td>Grams per million British thermal units</td>
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<tr>
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<td>Gigajoule</td>
</tr>
<tr>
<td>HC</td>
<td>Hydrocarbons</td>
</tr>
<tr>
<td>HCl</td>
<td>Hydrogen chloride/hydrochloric acid</td>
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<td>HF</td>
<td>Hydrogen fluoride/hydrofluoric acid</td>
</tr>
<tr>
<td>Hg</td>
<td>Mercury</td>
</tr>
<tr>
<td>H₂S</td>
<td>Hydrogen sulfide</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>kg/t</td>
<td>Kilograms per metric ton</td>
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<tr>
<td>mg/l</td>
<td>Milligrams per liter</td>
</tr>
<tr>
<td>µg/m³</td>
<td>Micrograms per cubic meter</td>
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<td>mg/Nm³</td>
<td>Milligrams per normal cubic meter</td>
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<td>MPN/100 ml</td>
<td>Coliform count expressed as most probable number per 100 milliliters</td>
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<tr>
<td>MWe</td>
<td>Megawatts of electricity</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>ng/J</td>
<td>Nanograms per joule</td>
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<tr>
<td>NH₃</td>
<td>Ammonia</td>
</tr>
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<td>NH₄</td>
<td>Ammonium nitrogen</td>
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<td>Ni</td>
<td>Nickel</td>
</tr>
<tr>
<td>NO₃</td>
<td>Nitrate nitrogen</td>
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<tr>
<td>NOₓ</td>
<td>Nitrogen oxides</td>
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<td>O&amp;G</td>
<td>Oil and grease</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>PAH</td>
<td>Polynuclear aromatic hydrocarbons</td>
</tr>
<tr>
<td>Pb</td>
<td>Lead</td>
</tr>
<tr>
<td>pH</td>
<td>Measure of acidity/alkalinity</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>Particulate matter with aerodynamic diameter less than 2.5 microns</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>Particulate matter with aerodynamic diameter less than 10 microns</td>
</tr>
<tr>
<td>ppm</td>
<td>Parts per million</td>
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<tr>
<td>S</td>
<td>Sulfur</td>
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<tr>
<td>Sb</td>
<td>Antimony</td>
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<tr>
<td>Se</td>
<td>Selenium</td>
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<td>Sn</td>
<td>Tin</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulfur dioxide</td>
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<tr>
<td>SO₃</td>
<td>Sulfur oxides</td>
</tr>
<tr>
<td>t</td>
<td>Metric ton</td>
</tr>
<tr>
<td>TCE</td>
<td>Trichloroethylene</td>
</tr>
<tr>
<td>Temp.</td>
<td>Temperature increase at the edge of the zone where initial mixing and dilution take place where the zone is not defined, 100 meters from the point of discharge is used</td>
</tr>
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O&G: up to 40 mg/l is acceptable for facilities producing ≤ 10,000
for any time; AOX: 1; organo-
not exceed 50 mg/l at any
clorines: 0.05;
organic chlorides: 0.05;
pyrethroids: 0.05;
phenoxy compounds:
0.05; active ingredients
each): 0.05
AOX: 1; active ingredi-
test to be done only
when no toxics to
are present
le 3°C
Benzenes: 0.05; vinyl
chloride: 0.05; sulfide: 1
Benzenes: 0.05;
benzo(a)pyrene: 0.05;
sulfide: 1
AOX: 1; active ingredi-
test to be done only
when no toxics to
are present

(Table continues on the following page.)
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- See column headed "Other comments".
Table 3. Effluent Discharge Requirements: Parameters and Maximum Values, Metals
(mg/l, unless otherwise specified)

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Effective Relocation of Existing Refining Units
Effective Relocation Of Existing Refinery Units

George Grame, P.E.  President - C&G Equipment Company, New York
Douglas W. Posey, P.E.  President - Cinco International, Houston

Can used refineries be moved and the quality of the installed plant be EQUIVALENT TO A NEW PLANT? If the project is handled correctly, the answer is most definitely YES.

Relocating existing refinery units has been a method of getting a refinery on-stream quickly and at a reduced cost for decades in the U.S. In fact, many of the major refinery companies in the U.S. today take advantage of this method. During the refinery boom years finding a shut down refinery unit for sale, however, was very difficult. This is not true today. There are many refineries in the U.S. that are shut down and for sale. Today’s market has changed. Companies outside the U.S. are planning many refinery relocation projects. They take advantage of the savings in cost and in schedule that the relocation of existing plants and equipment can facilitate.

Relocating existing plants can result in substantial savings in cost as well as a dramatic shortening of schedule without compromising the quality and functionality of the final plant. The first, and perhaps most important, concept to realize is that any project utilizing a used plant normally has a carefully selected mix of both new and used components. This raises the first and perhaps most important question of all. Which parts of an existing plant should be targeted as having maximum value to a relocation project?

To answer this question let’s first look at the approximate cost breakdown to build a new plant in the U.S. as shown in the table below.

| FIELD LABOR TO INSTALL PLUS BULK MATERIALS | 25 TO 35% |
| PIPING SYSTEM | 30 TO 40% |
| ENGINEERING | 8 TO 12% |
| MAJOR EQUIPMENT | 20 TO 30% |

FIELD LABOR TO INSTALL PLUS BULK MATERIALS for a plant consisting of all new components will not differ significantly from the cost of FIELD LABOR TO DISMANTLE & INSTALL PLUS BULK MATERIALS for a plant consisting of a mix of new and used components. Therefore, the 25 to 35 percent figure is approximately the same in both cases.

There will be some savings in the FIELD LABOR TO INSTALL for the used/new plant. This savings will be offset by the cost of dismantling the existing plant. ENGINEERING costs for a relocation project will most likely be in the same range or slightly higher. The savings in cost will therefore come from savings in MAJOR EQUIPMENT and the PIPING SYSTEM.

Primary target

NINETY PERCENT OF THE EQUIPMENT AND PIPING SYSTEM HAVE NO MOVING PARTS. THIS IS THE PRIMARY TARGET OF THE PURCHASE.

Value can be extracted from other components of the plant as well. This will depend on the age and condition of the plant. These components are discussed later on.

Price of used plant

The order of magnitude of the cost of a used plant will vary widely from plant to plant. An approximate rule of thumb to use is a figure in the range of 10 to 15% of the total cost of an all new plant. The basis of the purchase is normally on an "as is, where is - with all faults" basis. Pricing, however, is subject to negotiation and the factors involved would be too lengthy and complex to itemize here.
A good broker
The services provided by a good and experienced broker go much further than simply introducing a client to a plant which is for sale. An experienced broker can assure that the purchase proceeds in a very smooth and orderly manner.

The purchase price of the existing plant is easy to understand and define. The contractual terms of the purchase, however, are complex. The terms of this contract [which will also define the terms for the plant removal] are just as important, if not more, than the price paid for the plant. The overall cost of the project and the schedule can be seriously affected by this contract. An experienced broker can assure that many common errors are avoided and that the contract is structured properly.

Used car analogy
Let’s assume that a 1958 Chevrolet was offered to you for sale at a very reasonable price, and that after you purchased it, you are told that this car could be restored to its original “like new” condition. Remember, a car [unlike a refinery] has 90% moving parts. Body work is expensive. Older parts are not readily available. Refurbishing a 1958 Chevrolet may be fun but it is probably not a very good business decision. An old used car that looks like a piece of junk, is most likely just what it appears to be, an old piece of junk. In the end, you would still have a 1958 Chevrolet!

What’s that you say? You can afford a new Rolls Royce? In that case, just go down to your local dealership and order one. You’ll have one pretty quickly, if not immediately. I’m sure you’ll be very happy, but slightly lighter in your pocket book. A new Rolls Royce is a lot better than a re-built 1958 Chevrolet any day.

As stated earlier, 90% of a refinery has no moving parts. The sole purpose of these components is to contain process gas and liquids at high temperatures and pressures and not explode or leak. For these components, very little changes have been made over the years to improve their design. Pipes are still pipes [they are still round and come in all sizes]. Vessels are still vessels. Exchangers are still exchangers. etc.

What you can’t do, is go down to your local refinery dealership, buy a new one and be running it next week!

Process evaluation
Once an existing plant has been identified as a potential technical fit for a project, an engineering company should be retained to perform a process study to determine if the existing plant can be utilized to achieve the goals of the market feasibility study.

Plant inspection
Most existing refineries have 75% of all external surfaces of all equipment and piping covered by insulation which is in turn covered by shrouding. For this reason, a general “walk through” of a plant to view its external condition has little value other than being able to judge the quality of insulation and shrouding [which is going to be removed and discarded]. You cannot see the equipment and piping. They are totally packaged and hidden from view.

Some plants have made the decision to remove all insulation [and asbestos] from the plant prior to its sale. This is a real bonus for a prospective buyer. Not only has the asbestos issue been resolved, but the buyer can view and inspect all the exposed carbon steel surfaces. To the inexperienced eye, these exposed carbon steel surfaces will most likely look terrible. They will appear rusty and scaly and perhaps give the appearance of “old junk”. The experienced eye will realize that when these surfaces are sand blasted and painted and new insulation and new aluminum shrouding is attached the “new like” appearance will return. The primary concern is...... What are the wall thicknesses of the vessel shells, exchanger shells, and piping walls, etc.? This can only be determined by measuring wall thicknesses throughout the plant with U.T. thickness meters.

More valuable information can be obtained during this first plant visit by reviewing the layout of the plant and planning the “staging area” and the takedown of the units. This is also an opportunity to ask to see the latest operating records of the plant and also request a copy of the last plant inspection performed by the refinery. One word of caution, however, when reading these inspection reports. They were intended to be used as internal documents and they will be extremely critical of all the items that are deficient and require repair or replacement.

If the plant is a “technical fit” for your project, the services of a qualified and experienced engineering company or professional inspectors should be employed. Holes can be cut in the insulation throughout the plant and U.T. thickness gauges used to measure wall thicknesses externally of major vessel equipment, exchangers, and piping. These values can be compared to what the required thicknesses should be. All carbon steel items will have had “corrosion allowances” added to wall thicknesses when originally designed. In some cases you may have to reduce corrosion allowances or you may have to down rate the design pressure in some areas of the plant slightly. Please note that all equipment was originally designed with an original safety factor, i.e. wall thicknesses are up to four times...
A jobsite in the U.S. will have the various shops, parts, and technology available either locally or within a reasonable distance from the plant. This is where refurbishment and replacement of equipment should be performed.

**Think modular**

Structural steel should be used “as required” to brace the largest sections which are shippable. Each section will be removed and shipped whole as a module. A major effort should be made in the field and office to “think modular”. The size of sections removed should be as large and as intact as possible.

**ALL COMPONENTS ARRIVING AT THE NEW JOBSITE WILL BE EITHER REFURBISHED OR NEW.**

Guidelines for handling the various components are as follows:

- **Towers & pressure vessels**
  
  All equipment should be opened and undergo an internal inspection. Any repairs to the internals should be made. The external surfaces should be sandblasted and primer coats of paint applied. Any manways which have been opened, should have new bolts and gaskets installed and the vessel should be closed for shipment. It is not necessary to perform a hydrotest on any of this equipment unless cutting is required on the pressure shell.

  Temporary saddles should be welded to vertical vessels so that the tower or vessel can lie on its side during shipment. This bracing will be cut off when the “module” is re-erected in the field.

  Large diameter and relatively thin walled vessels such as cat cracker reactors and regenerators can have heavy rings welded to the outside of the vessel at two locations. These will hold the vessel round during handling. The vessel can be handled from these rings and the temporary shipping saddles can be attached to them.

  The internals of a cat cracker will probably look like a war zone. This is normal. A major bracing job will be required for these internals. The castable lining should be blocked and braced [wood bracing will suffice] or a decision can be made to remove this lining and apply a new lining in the field after the vessel is re-erected. The extra shipping weight of the existing lining and the possibility of damage to the lining during shipment must be evaluated.

- **Piping & valves**
  
  A decision should be made as to what size piping should be re-used. A good rule of thumb would be to save all flanged piping 4” and larger and discard all smaller piping. This smaller piping will then be fabricated and installed new in the field at the new jobsite. Large diameter butt welded piping should be re-used. These pipe sections should be moved to a separate section of the staging area and cleaned, sand blasted and painted. A final match marking number should be painted on each piece. Do not use any type of tagging system which attaches to equipment. These separate tags can break free from the item and be lost.

  Valves should be marked and sent to valve shops for rebuilding. The shops should furnish new valves for any that can not be re-built. These valves will arrive at the new jobsite crated and marked and ready for installation.

- **Exchangers**
  
  At the staging area [set up at the site of the used plant] all exchangers should first undergo hydrotesting of both sides. Those that pass hydrotesting should then have the bundles removed, the internals hydroblasted clean, new bolts, nuts and gaskets installed, reassembled, re-hydrotested, external surfaces sand blasted, and a primer coat of paint applied. Those that fail hydrotest, should be moved to a local exchanger shop for repair. In some cases, repair will be as minor as plugging a few tubes. In other cases, complete bundles may need replacing. In very bad cases, some exchangers will have to be discarded and new ones fabricated.

- **Structural steel**
  
  Once again, “think modular”. Can large sections of pipe racks be braced with the piping in place and a module created? Ingenuity in the field and the office will pay off. Re-use as much of the large structural steel as possible.
thicker than the thickness at which they would fail.

Internal inspections should be made of critical equipment such as large towers, reactors, cat crackers, etc.

Rotating equipment should be evaluated for either replacement or refurbishment. Since the owners [and your budget] at this stage will not allow equipment to be disassembled for internal inspection, “experience” is the key factor in this decision making “evaluation” process.

**BARE CARBON STEEL SURFACES CAN NOT BE ACCURATELY JUDGED BY VIEWING EXTERNAL APPEARANCE. WALL THICKNESS IS THE PRIMARY FACTOR.**

**Budget estimate**

After inspecting the plant, a budget estimate to dismantle, ship and construct the plant at the new site should be updated from the original estimate made at the start of the project.

**Engineering approach**

The amount of engineering and design work required for a relocation project will be slightly higher than the amount required for an all new plant. An engineering contractor experienced in handling plant relocations is highly desirable. A totally different approach and philosophy is required for these type of projects. Simply match marking, dismantling and moving the plant will result in a very poor quality installation and ultimately in a higher overall cost. Treating the project as if it was an all new installation would be equally detrimental to achieving your goal. Unlike a new design, you are not starting with a blank slate. Remember, this plant was running and functioning as designed when it was shut down. An extreme effort must be made to hold as much to the original design as possible. **Only changes which are required to adapt to the new site conditions should be made.** If too many changes are made to “improve the design”, the advantages to be gained in cost and schedule can very easily be lost.

Perhaps the most important principle to follow is the party responsible for the dismantling should also be responsible for the installation. The reason for this rule is obvious. The party handling the installation of the plant can not blame the dismantler for any problems and vice versa.

For plants being moved outside the U.S., the situation is more complex. This principle, however, must still be followed. If two different companies are handling the dismantling and the installation, a project management team from the company who will be handling the installation of the plant should be present in the U.S. during the engineering, match marking and dismantling of the plant. A project management team from the company who has handled the engineering, dismantling and shipping should be present during all phases of construction. Two good rules to follow are:

- **EMPLOY THE SERVICES OF ONE PRIME CONTRACTOR RESPONSIBLE FOR THE COMPLETE PROJECT.**
- **AVOID PURCHASING A PLANT WHICH HAS ALREADY BEEN DISMANTLED BY A THIRD PARTY.**

If you purchase a plant which has already been dismantled by another party, the complete piping system will have to be re-designed and its value will be severely reduced. Since the piping system accounts for approximately 40 percent of the value of the plant, the savings which should be achieved by utilizing an existing plant will be severely diminished. Any savings in schedule will also most likely be lost.

**Engineering**

In the best of all worlds, accurate “as built” original drawings of the plant would be available. Also, complete and up to date “as built” job books and plant specifications would be available. Unfortunately this is not a perfect world and this most likely will not be the case for the plant you purchase. It would be too lengthy for the purposes of this article to outline the complete engineering procedure.

Based on the circumstances for a given plant, “as built” drawings will have to be made [or existing drawings modified] with match marking numbers shown. If the plant is to be installed in a country in which the construction company and the plant operators must function in this other language, the drawings and specifications will have to be made bilingual. There are several ways of doing this. Once again “experience” is the key to a successful project.

**Dismantling & refurbishing**

The first step in the dismantling process will be the removal of all insulation and fireproofing material. If there is asbestos in the plant, the owner has “cradle to grave” responsibility for this asbestos. You will most likely be able to negotiate with the owner for him to either remove all insulation or, at a minimum, have the owner bear the cost of removal and abatement of any asbestos found in the plant.

If a refinery is being moved from the U.S. to a country outside the U.S., each jobsite has its own advantages.
**Instrumentation**

Unless the instrumentation system has recently been refurbished or replaced, it is advisable to discard the old system and replace it with all new components. Control valves which are adaptable to the new system, however, can be crated and sent to a shop for rebuilding.

**Electrical**

As a general rule, the entire existing electrical system should most likely be discarded and replaced with new. The larger and more costly equipment should be looked at and sent to a shop for refurbishment. In the case of a 60 hz plant being used in a 50 hz country [or vice versa] the larger electric motors can be re-wound or simply all electric motors replaced with new.

**Field fabricated equipment**

Large field fabricated equipment such as large heaters and storage tanks must be fabricated new in the field. Field fabricated storage tanks are 85% labor.

**Utilities**

In general, boiler feed water, compressed air, and steam production systems will be fabricated new. If the local utility can not furnish the power to the plant, good quality used generator sets and power plants are actively traded on the world market.

**Cost comparison - new vs. used**

Let's take a look at a hypothetical project that would cost $250 million to construct new in the U.S. today. For this comparison let's assume a project installation which includes the main process area only [i.e. no offsites included].

<table>
<thead>
<tr>
<th>NEW PLANT COST</th>
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<tbody>
<tr>
<td>MAJOR EQUIPMENT</td>
<td>$62,500,000</td>
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<tr>
<td>PIPING SYSTEM</td>
<td>$87,500,000</td>
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<td>ENGINEERING</td>
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<td>FIELD LABOR TO INSTALL PLUS BULK MATERIALS</td>
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<td><strong>TOTAL</strong></td>
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<table>
<thead>
<tr>
<th>COST UTILIZING USED PLANT</th>
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<tr>
<td>PURCHASE USED PLANT</td>
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<tr>
<td>ENGINEERING</td>
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<tr>
<td>REFURBISH AND SHIP TO $60,000,000</td>
<td>$155,000,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$185,000,000</td>
</tr>
</tbody>
</table>

The following tables show a very approximate example of the savings which may be achieved by utilizing a used plant.

Based upon an all new plant price of $250 million, a purchase price for the used plant of $25 million on an “as is”, where is” basis has been assumed. A cost range of $30 million to $60 million has been assumed for refurbishing [including the purchase of new components] plus shipping. Exactly which components should be refurbished and which should be replaced will vary widely from project to project. This is why such a wide range for this portion of the project has been assumed. Once again, it is advisable to utilize the services of an engineering contractor who has experience in making these decisions.

The same cost has been assumed for FIELD LABOR TO DISMANTLE & INSTALL PLUS BULK MATERIALS for the used/new plant as for the cost of FIELD LABOR PLUS BULK MATERIALS for an all new plant. This cost may be lower when labor rates are lower in the country where the plant is to be installed depending upon the productivity and experience of the construction contractor handling the installation.

**Schedule comparison - new vs. used**

Engineering for a project utilizing all new equipment will take 10 months to a year to complete. Vendor drawings are received and drawings are updated to “Approved for Construction” status after about 18 months after the start of the project. Equipment starts arriving at the job site around the end of year number 2. At this time work begins in earnest at the job site. Foundations and roads are started.

The length of the total project schedule for this hypothetical all new project will be between 4 and 5 years.

For a project which is based upon an existing plant design, most foundation dimensions are available at the start of the project. Work can commence at the job site after around 6 months [as compared to 2 years for new]. Components can start arriving at the new jobsite as early as 6 months after the start of the project and continue to arrive until the end of year 2.

The length of the total project schedule for this hypothetical project utilizing an existing plant can be between 2 and 3 years.

**THE BOTTOM LINE** is that the plant will be on stream and PRODUCING REVENUE 1 to 2 years sooner!

YOU MAY BE ABLE TO AFFORD AN ALL NEW PLANT. CAN YOU AFFORD TO WAIT FOR ONE?
G Calculations
Crude Assay Calculations

Yield and Property Calculations

Cost Curve Parameters

Hill International for the World Bank Group
Refinery and/or Power Plant
Shebergan, Afghanistan

CEC Project: 4009 01

Basis: Core Lab fax assay 5 Apr 2004, Sample No. 141253-001.
Afghanistan Crude. Angot.

Note: This revision of the calculations supports the clean-up of the draft report to the final report.
# Calculations

**Hill Int'l / Afghanistan Crude Utilization Study**  
By / Date: JTR 26 May 2004  
Job No.: 4009 01  
Assay, Yield, and Property Calculations  
Checked / Date: MWL 26 May 04  
App. / Date: 

```
<table>
<thead>
<tr>
<th>Index</th>
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<tbody>
<tr>
<td>Case Definition &amp; Assay</td>
<td>3</td>
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<tr>
<td>Simulated Distillation</td>
<td>3</td>
</tr>
<tr>
<td>Simulated and TBP Distillation Plot</td>
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<tr>
<td>Calculated Specific Gravity and LV%</td>
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<td>Specific Gravity Plot</td>
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<td>Wide Cut Diesel Summary</td>
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<td>Winter - Without Asphalt</td>
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<td>Jet from ADU</td>
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<tr>
<td>Hydrogen Plant</td>
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<td>Amine Regeneration</td>
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**Case Feed Rates**

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<tr>
<td>3C</td>
<td>Integrated Refinery</td>
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**Gravity**
- Gravity, °API: 23.6
- Specific Gravity: 0.9123
- Density, Lb/B: 319.1

**Simulated Crude Distillation and Conversion to TBP Distillation**
SD is ASTM D-5307

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<th>Wt%</th>
<th>SD Temperature °F</th>
<th>TBP Temperature °F</th>
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<tr>
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</table>


The conversion of the high temperature end is irrelevant and was not done.
TBP Distillation

Temperature, °F

LV%
Convert to TBP Distillation and Calculate LV%.

Assume TBP is the same as the simulated distillation. Modify the tail.
The assay does not have a gravity curve. Use the Exxon Arabian Heavy assay 7C-AN.66 as a go-by.
Interpolate for the cut temperatures from the AH assay.

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<td>TBP Cut Range EP °F</td>
<td>Angot Cut Wt%</td>
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<tr>
<td>---------------------</td>
<td>--------------</td>
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<tr>
<td>C3- 68</td>
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</tbody>
</table>

Crude - Calculated: 0.9123
Crude - Assay: 0.9123

Adjustment Factor to Match Sulfur in Crude from the Angot Assay: 1.0209

Note: C3- not included in calcs since it rounds to 0.
### Split Out the LSR
**Calculated Specific Gravity and LV%**

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<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Cumulative Wt%</th>
<th>Angot SG</th>
<th>Angot Cut Wt% / SG</th>
<th>Angot Cut LV%</th>
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### Split the Cut for the Naphtha End Point
**Calculated Specific Gravity and LV%**

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Calculated Specific Gravity and LV%

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Specific Gravity

Mid LV%
## Calculated Sulfur

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**Assay**

2.65

**Adjustment Factor to Match Sulfur in Crude from Angot Assay.**

1.0137
## Split Out the LSR
**Calculated Sulfur**

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## Split Out for the HSR End Point
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**Total / Avg.**

- Assay: 0.0588
- Adjustment Factor to Match Nitrogen in Crude from Angot Assay: 0.4902
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**Assay**

1.5

**Adjustment Factor to Match Iron in Crude from Angot Assay.**

0.2943
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**Angot Assay**

2.4

**Adjustment Factor to Match Nickel in Crude from Angot Assay.**

0.2515
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**Total / Avg.**

100.0 | 7.100 | 7.100

### Angot Assay

7.1

**Adjustment Factor to Match Vanadium in Crude from Angot Assay.**

0.2326
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**Total / Avg.**  
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8.4000

**Assay**  
8.4

**Adjustment Factor to Match Micro Carbon Residue in Crude from Angot Assay.**  
1.8610
## Breakout for Diesel End Point
### Micro Carbon Residue

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<td>AH Viscosity At 100 °F cSt</td>
<td>Angot Viscosity At 100 °F cSt</td>
<td>Angot VBI</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td>-------------------------------</td>
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<td>68</td>
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<td>0.16</td>
<td>-0.330</td>
</tr>
<tr>
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<td>2.2</td>
<td>0.30</td>
<td>0.54</td>
<td>-0.098</td>
</tr>
<tr>
<td>212</td>
<td>2.8</td>
<td>0.50</td>
<td>0.90</td>
<td>-0.015</td>
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<td>248</td>
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<td>0.85</td>
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<td>0.058</td>
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<td>1.10</td>
<td>1.98</td>
<td>0.090</td>
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<td>13.34</td>
<td>0.273</td>
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<td>0.323</td>
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</tbody>
</table>

Total / Avg. 100.0  33.880

Assay Viscosity AH Crude 19.1
Assay Viscosity Angot Crude 34.43
Factor 1.803
Calculated Viscosity Angot Crude 34.5
## Breakout of Diesel End Point
### Viscosity at 100 °F

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut LV%</th>
<th>Angot Cut Mid LV%</th>
<th>Angot Viscosity At 100 °F cSt</th>
<th>Angot VBI</th>
<th>Angot VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>650</td>
<td>3.9</td>
<td>40.3</td>
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<td>0.273</td>
<td>1.064</td>
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<td>1.620</td>
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<tr>
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<td>11.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case 1 - Power Plant Only
Fuel Oil Properties

In this case, the properties are those of the whole crude. Only the flash point and H of C need to be predicted.

Flash Point

Flash Point, °F = (0.57 x T) - 110
Use a rough conversion to ASTM distillation.
T, °F = (0% Pt. + 2 x 5% Pt. + 10% Pt.) / 4
T, °F 298
Flash Point, °F 60

Density

Gravity, °API 23.6
Specific Gravity 0.9123
Density, Lb/B 319.1

Heat of Combustion

Gravity, °API 23.6
Lower Heating Value, Blu/Lb (From Chart) 17,960
Case 1 - Power Plant Only
Fuel Oil Properties

<table>
<thead>
<tr>
<th>Rate Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
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<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tr>
<td>API Gravity at 60 °F, °API</td>
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<tr>
<td>Specific Gravity</td>
<td>0.9123</td>
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<tr>
<td>Density, Lb/B</td>
<td>319.1</td>
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<tr>
<td>Sulfur, Wt%</td>
<td>3.05</td>
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<tr>
<td>Nitrogen, wppm</td>
<td>588</td>
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<td>Reid Vapor Pressure, psia (Note 1)</td>
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<td>Acid Number, mg KOH/g</td>
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<td>Flash Point, °F (Note 1)</td>
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<td>Micro Carbon, Wt%</td>
<td>8.4</td>
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<tr>
<td>Pour Point, °F</td>
<td>35</td>
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<td>Lower Heating Value, Btu/Lb</td>
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<td>Kinematic Viscosity, cSt</td>
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<tr>
<td>At 60 °F</td>
<td>146.0</td>
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<tr>
<td>At 100 °F</td>
<td>34.4</td>
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<tr>
<td>Iron, wppm</td>
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<tr>
<td>Nickel, wppm</td>
<td>2.4</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>7.1</td>
</tr>
<tr>
<td>Salt, Lb/1000 B (Note 2)</td>
<td>?</td>
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</tbody>
</table>

Notes
1. It is suspected that light ends were lost from the assay sample and that the RVP will be higher. However, it will be suitable for tankage. The flash point may be lower.

2. The value is not available, but the crude will be desalted.
Case 1 - Power Plant Only
Power Plant Emissions

<table>
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<tr>
<th>Case</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Rate, Lb/Hr</td>
<td>132,961</td>
</tr>
</tbody>
</table>

The potential emissions are as follows. The flue gas scrubber will remove 90%+ of the SOx.

<table>
<thead>
<tr>
<th>Fuel S Content, Wt%</th>
<th>3.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Fe Content, wppm</td>
<td>1.5</td>
</tr>
<tr>
<td>Fuel Ni Content, wppm</td>
<td>2.4</td>
</tr>
<tr>
<td>Fuel V Content, wppm</td>
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<tr>
<td>SOx as SO2, Lb/Hr</td>
<td>7,843</td>
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<tr>
<td>SOx, LT/SD or metric t/d</td>
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</tr>
<tr>
<td>Iron, Lb/Hr</td>
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</tr>
<tr>
<td>Iron, LT/SD or metric t/d</td>
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</tr>
<tr>
<td>Nickel, Lb/Hr</td>
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</tr>
<tr>
<td>Nickel, LT/SD or metric t/d</td>
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<tr>
<td>Vanadium, Lb/Hr</td>
<td>0.9</td>
</tr>
<tr>
<td>Vanadium, LT/SD or metric t/d</td>
<td>0.010</td>
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</table>
### Case 1 - Power Plant Only

#### Overall Case Material Balance

#### Overall Material Balance - Case 1

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
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</thead>
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<tr>
<td>Feeds</td>
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<td></td>
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<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
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Case 2 - Atm. & Vac. Distillation
Pakistani Light Diesel Oil (Wide Cut Diesel)
This is the 302 - 650 Cut.

### Calculated Gravity, Sulfur, and Viscosity

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.0</td>
<td>-0.330</td>
<td></td>
</tr>
<tr>
<td>158</td>
<td>0.0</td>
<td>0.001</td>
<td>0.015</td>
<td>0.0</td>
<td>-0.098</td>
<td></td>
</tr>
<tr>
<td>212</td>
<td>1.7</td>
<td>0.005</td>
<td>0.011</td>
<td>2.2</td>
<td>-0.330</td>
<td></td>
</tr>
<tr>
<td>248</td>
<td>1.1</td>
<td>0.011</td>
<td>0.016</td>
<td>1.4</td>
<td>-0.098</td>
<td></td>
</tr>
<tr>
<td>302</td>
<td>2.3</td>
<td>0.026</td>
<td>0.037</td>
<td>2.8</td>
<td>-0.015</td>
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<tr>
<td>347</td>
<td>3.2</td>
<td>0.061</td>
<td>0.1946</td>
<td>3.7</td>
<td>0.058</td>
<td>0.2</td>
</tr>
<tr>
<td>401</td>
<td>4.0</td>
<td>0.132</td>
<td>0.5271</td>
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</tr>
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<td>0.124</td>
<td>0.6</td>
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<tr>
<td>509</td>
<td>5.4</td>
<td>0.811</td>
<td>4.3791</td>
<td>5.9</td>
<td>0.162</td>
<td>1.0</td>
</tr>
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<td>563</td>
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<td>0.198</td>
<td>1.3</td>
</tr>
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<td>0.273</td>
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<td>11.2</td>
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<td>851</td>
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<td>2.737</td>
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<td>10.2</td>
<td>0.389</td>
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<tr>
<td>950</td>
<td>9.0</td>
<td>2.990</td>
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<td>8.6</td>
<td>0.452</td>
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<td>9.0</td>
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<td>13.0</td>
<td>0.755</td>
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<td>35.4845</td>
<td>100.0</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cut Total 32.9 35.8
Cut Sulfur, Wt% 1.08
Cut VBI 0.17
Cut Viscosity, cSt (From Chart) 4.1

Specific Gravity 0.8384
Gravity, °API 37.3
Density, Lb/B 293.3

The specification for sulfur is 1.8 Wt% max.
The specification for viscosity at 100 °F is 14 max.
Both of these are easily met with a 650 °F cut point. It could be higher.

The 650 °F end cut point is OK. The initial cut point will be set by the flash point.

### Vacuum Tower

<table>
<thead>
<tr>
<th>Case</th>
<th>Rate, B/SD</th>
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<tbody>
<tr>
<td>2A</td>
<td>5,780</td>
</tr>
<tr>
<td>2B</td>
<td>2,890</td>
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</table>
Case 2 - Atm. & Vac. Distillation
Pakistan Light Diesel Oil (Wide Cut Diesel)

Calculation for Flash Point

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial TBP Cut Point, °F</td>
<td>347</td>
</tr>
<tr>
<td>Final TBP Cut Point, °F</td>
<td>650</td>
</tr>
<tr>
<td>5 LV% ASTM Point, °F</td>
<td>403</td>
</tr>
<tr>
<td>10 LV% ASTM Point, °F</td>
<td>413</td>
</tr>
<tr>
<td>Flash Point, °F = 0.64 x T - 100 - Correction</td>
<td>153 PMCC</td>
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<tr>
<td>Flash Point, °C</td>
<td>67</td>
</tr>
<tr>
<td>Specified Flash Point, °C (Min.)</td>
<td>54.5</td>
</tr>
</tbody>
</table>

OK. It could actually take a bit more lighter material, but leave as is.
Case 2 - Atm. & Vac. Distillation
Pakistan Light Diesel Oil (Wide Cut Diesel)

<table>
<thead>
<tr>
<th>Rate Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
</tr>
<tr>
<td>2A</td>
</tr>
<tr>
<td>2B</td>
</tr>
</tbody>
</table>

Wide-Cut Diesel - Case 2 (Summer & Winter)

<table>
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<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>37.3</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.8384</td>
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<tr>
<td>Sulfur, Wt%</td>
<td>1.08</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
<td></td>
</tr>
<tr>
<td>Flash Point, °F (Note 1)</td>
<td>67</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes
1. Pensky-Martens Closed Cup at 20°C
Case 2 - Atm. & Vac. Distillation  (Winter Without Asphalt Production)
Fuel Oil
The fuel oil is the blend of the IBP - 302 cut and the 650+ residuum.

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
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<td>0.0123</td>
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<td></td>
</tr>
<tr>
<td>401</td>
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<td>0.335</td>
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<tr>
<td>455</td>
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<td>0.811</td>
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<td>0.534</td>
<td>3.1</td>
</tr>
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<td>229.5316</td>
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</table>

Cut Total 67.1
Cut Sulfur, Wt% 3.42
Cut VBI at 100 °F 0.434
Cut Viscosity at 100 °F, cSt (From Chart) 200
Case 2 - Atm. & Vac. Distillation (Winter Without Asphalt Production)
Fuel Oil - Split Out of Naphtha for Alternate Case

Create an alternate case where high-octane blending component is purchased from the PSOCL to blend the straight run naphtha up to an 87 road octane gasoline.

Split the naphtha out of the fuel oil blend.
Recompute the reduced amount of fuel oil.

The alternate case will be an overall balance only.

<table>
<thead>
<tr>
<th>Item</th>
<th>Naphtha</th>
<th>Resid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate, LV% on Crude</td>
<td>6.4</td>
<td>57.8</td>
</tr>
<tr>
<td>Rate, Wt% on Crude</td>
<td>5.1</td>
<td>62.0</td>
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<tr>
<td>Summation Wt% x Sulfur</td>
<td>0.0815</td>
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<tr>
<td>Sulfur, Wt%</td>
<td>0.0150</td>
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<td>Rate, Case 2A, B/SD</td>
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<td>5,780</td>
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<tr>
<td>Rate, Case 2A, Lb/Hr</td>
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<td>82,436</td>
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<tr>
<td>Rate, Case 2B, B/SD</td>
<td>320</td>
<td>2,890</td>
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<tr>
<td>Rate, Case 2B, Lb/Hr</td>
<td>3,390</td>
<td>41,218</td>
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Case 2 - Atm. & Vac. Distillation (Winter Without Asphalt Production)
Fuel Oil - Split Out of Naphtha for Alternate Case

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut LV%</th>
<th>AH = Angot RON Index</th>
<th>Angot RON x Cut LV%</th>
<th>AH = Angot MON Index</th>
<th>Angot MON x Cut LV%</th>
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<tbody>
<tr>
<td>68</td>
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<td>77.0</td>
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<td>Cut MON</td>
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</table>

PSOCL High Octane Blending Component contains lead.

TEL, g/l 0.87
Specific Gravity 1.659
TEL, cc/l 0.52
TEL, cc/l 0.14

This is low enough that it may qualify as unleaded.
Case 2 - Atm. & Vac. Distillation  (Winter Without Asphalt Production)
Fuel Oil - Split Out of Naphtha for Alternate Case

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume Barrels</th>
<th>RON</th>
<th>RON Index</th>
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<tr>
<td>S. R. Naphtha</td>
<td>1.00</td>
<td>35.0</td>
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<tr>
<td>High Octane Blending Component</td>
<td>1.12</td>
<td>97.0</td>
<td>90.0</td>
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<tr>
<td>Total / Average</td>
<td>2.12</td>
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<td>76.6</td>
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<tr>
<td>Required Average</td>
<td></td>
<td>91.6</td>
<td>76.5</td>
</tr>
</tbody>
</table>

Road octane is (RON + MON)/2
The PSOCL specification does not give a motor octane.
It is assumed that a RON equal to our Case 3 is required. That is 91.6.
Case 2 - Atm. & Vac. Distillation (Winter Without Asphalt Production)
Fuel Oil - Split Out of Naphtha for Alternate Case

### Balances for Gasoline Pool for Alternate Cases 2A and 2B

<table>
<thead>
<tr>
<th></th>
<th>Rate Lb/Hr</th>
<th>Specific Gravity</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
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<tr>
<td><strong>Case 2A</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>S. R. Naphtha</td>
<td>6,781</td>
<td></td>
<td></td>
<td>640</td>
</tr>
<tr>
<td>PSOCL High Octane Blending Component</td>
<td>8,033</td>
<td>0.7690</td>
<td>52.5</td>
<td>717</td>
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<tr>
<td><strong>Total</strong></td>
<td>14,814</td>
<td>0.7492</td>
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<td>1,357</td>
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<tr>
<td><strong>Case 2B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. R. Naphtha</td>
<td>3,390</td>
<td></td>
<td></td>
<td>320</td>
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<tr>
<td>PSOCL High Octane Blending Component</td>
<td>4,017</td>
<td>0.7690</td>
<td>52.5</td>
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<tr>
<td><strong>Total</strong></td>
<td>7,407</td>
<td>0.7492</td>
<td>57.4</td>
<td>678</td>
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</table>

Gravity of the high octane blending component assumed to be the same as that of the Case 3 reformate.

Some purchased butanes may also be needed.
**Case 2 - Atm. & Vac. Distillation (Without Asphalt Production)**

**Fuel Oil**

### Calculated Nitrogen

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Nitrogen Wt%</th>
<th>Angot Nitrogen x Cut Wt%</th>
<th>Angot Cut LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>---</td>
<td>0.000</td>
<td>0.000</td>
<td>0.0</td>
</tr>
<tr>
<td>158</td>
<td>0.0</td>
<td>0.000</td>
<td>0.000</td>
<td>0.0</td>
</tr>
<tr>
<td>212</td>
<td>1.7</td>
<td>0.000</td>
<td>0.000</td>
<td>2.2</td>
</tr>
<tr>
<td>248</td>
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<td>0.000</td>
<td>0.000</td>
<td>1.4</td>
</tr>
<tr>
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<td>2.3</td>
<td>0.000</td>
<td>0.000</td>
<td>2.8</td>
</tr>
<tr>
<td>347</td>
<td>3.2</td>
<td>0.000</td>
<td>0.000</td>
<td>3.7</td>
</tr>
<tr>
<td>401</td>
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<td>0.000</td>
<td></td>
<td>4.6</td>
</tr>
<tr>
<td>455</td>
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<td>0.000</td>
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</tr>
<tr>
<td>509</td>
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<td>0.001</td>
<td></td>
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</tr>
<tr>
<td>563</td>
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</tr>
<tr>
<td>617</td>
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</tr>
<tr>
<td>650</td>
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<td>0.2216</td>
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<tr>
<td>851</td>
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<td>0.3088</td>
<td>10.2</td>
</tr>
<tr>
<td>950</td>
<td>9.0</td>
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<td>0.3530</td>
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</tr>
<tr>
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<td>9.6</td>
<td>0.059</td>
<td>0.5947</td>
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<tr>
<td>1126</td>
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<td>0.088</td>
<td>0.5559</td>
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<tr>
<td>1430</td>
<td>15.3</td>
<td>0.248</td>
<td>3.7876</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td><strong>5.7916</strong></td>
<td><strong>100.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

Cut Total: 67.1  
Cut Nitrogen, Wt%: 0.086  

64.2
Case 2 - Atm. & Vac. Distillation (Without Asphalt Production)

Fuel Oil

Gravity

Crude Specific Gravity 0.9123
Cut Specific Gravity 0.9535
Cut Gravity, °API 17.1
Density, Lb/B 333.5

Pour Point

Calculate the 65 LV% point of the blend.

<table>
<thead>
<tr>
<th>LV% on crude</th>
<th>LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV% on crude at 950 °F</td>
<td>41.7</td>
</tr>
<tr>
<td>LV% on crude at 1049 °F</td>
<td>950 36.4</td>
</tr>
<tr>
<td>TBP Temperature, °F at 41.7 LV%</td>
<td>41.7 1008</td>
</tr>
</tbody>
</table>

Pour Point, °F by Correlation 78

Based on 35 °F for whole crude.
The correlation probably does not handle this dumbell mixture well and the result could be off.
Case 2 - Atm. & Vac. Distillation (Without Asphalt Production)
Fuel Oil

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Nickel wppm</th>
<th>Angot Nickel x Cut Wt%</th>
<th>Angot Vanadium wppm</th>
<th>Angot Vanadium x Cut Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>___</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>158</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
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<tr>
<td>212</td>
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<tr>
<td>248</td>
<td>1.1</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.00</td>
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</tr>
<tr>
<td>302</td>
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<tr>
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</tr>
<tr>
<td>401</td>
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</tr>
<tr>
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</tr>
<tr>
<td>509</td>
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<td>0.00</td>
<td>0.0000</td>
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</tr>
<tr>
<td>563</td>
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Cut Total: 67.1
Cut Nickel, wppm: 3.58
Cut Vanadium, wppm: 10.58
Case 2 - Atm. & Vac. Distillation (Without Asphalt Production)
Fuel Oil

### Calculated Iron and MCR

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut %</th>
<th>Angot Iron wppm</th>
<th>Angot Iron x Cut Wt%</th>
<th>Angot Micro Carb. Wt%</th>
<th>Angot MCR x Cut Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
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<td></td>
<td></td>
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<td>0.00</td>
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<td></td>
<td>840.0000</td>
</tr>
</tbody>
</table>

Cut Total 67.1
Cut Iron, wppm 2.24
Cut Micro Carbon Residue, Wt% 12.5

### Flash Point

Call the same as the whole crude case since it is mainly influenced by the front end.

Flash Point, °F 60

### Heat of Combustion

Gravity, °API 17.1
Lower Heating Value, Btu/Lb (From Chart) 17,640
Case 2 - Atm. & Vac. Distillation (Without Asphalt Production) (Winter)

Fuel Oil

<table>
<thead>
<tr>
<th>Rate Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>2A</td>
</tr>
<tr>
<td>2B</td>
</tr>
</tbody>
</table>

**Fuel Oil - Case 2 (Winter)**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>17.1</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
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</tr>
<tr>
<td>Density, Lb/B</td>
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</tr>
<tr>
<td>Sulfur, Wt% (Note 4)</td>
<td>3.93</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>863</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Notes 1, 3)</td>
<td>0.95</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
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<tr>
<td>Flash Point, °F (Notes 1, 3)</td>
<td>60</td>
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<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>12.5</td>
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<tr>
<td>Pour Point, °F</td>
<td>78</td>
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<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>17,640</td>
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<tr>
<td>Kinematic Viscosity, cSt</td>
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<tr>
<td>At 100 °F</td>
<td>200</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>2.2</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td>3.6</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>10.6</td>
</tr>
<tr>
<td>Salt, Lb/1000 B (Note 2)</td>
<td>?</td>
</tr>
</tbody>
</table>

**Notes**

1. It is suspected that light ends were lost from the assay sample and that the RVP will be higher. However, it will be suitable for tankage. The flash point may be lower.
2. The value is not available, but the crude will be desalted.
3. Assumed to be the same as that of the whole crude.
4. Without the overdesign factor, this would meet the specification for fuel oil.
Case 2 - Atm. & Vac. Distillation  (Without Asphalt Production) (Winter)
Power Plant Emissions

<table>
<thead>
<tr>
<th>Case</th>
<th>2A</th>
<th>2B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Rate, Lb/Hr</td>
<td>89,215</td>
<td>44,606</td>
</tr>
</tbody>
</table>

The potential emissions are as follows. The flue gas scrubber will remove 90%+ of the SOx.

- Fuel S Content, Wt% | 3.93 | 3.93 |
- Fuel Fe Content, wppm | 2.2  | 2.2  |
- Fuel Ni Content, wppm | 3.6  | 3.6  |
- Fuel V Content, wppm | 10.6 | 10.6 |
- SOx as SO2, Lb/Hr | 6,794 | 3,397 |
- SOx, LT/SD or metric t/d | 73.9 | 37.0 |
- Iron, Lb/Hr | 0.2 | 0.1 |
- Iron, LT/SD or metric t/d | 0.002 | 0.001 |
- Nickel, Lb/Hr | 0.3 | 0.2 |
- Nickel, LT/SD or metric t/d | 0.003 | 0.002 |
- Vanadium, Lb/Hr | 0.9 | 0.5 |
- Vanadium, LT/SD or metric t/d | 0.010 | 0.005 |

These strictly apply to the base cases not to the alternate cases.
### Case 2 - Atm. & Vac. Distillation (Without Asphalt Production) (Winter)

#### Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>13</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Wide-Cut Diesel</td>
<td>43,733</td>
<td>37.3</td>
<td>3,580</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>89,215</td>
<td>17.1</td>
<td>6,420</td>
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<tr>
<td>Total</td>
<td>132,961</td>
<td></td>
<td>10,000</td>
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Case 2 - Atm. & Vac. Distillation (Without Asphalt Production) (Winter)
Overall Case Material Balance

### Overall Material Balance - Alternate Case 2A (Winter)

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSOCL H. Octane Comp.</td>
<td>8,033</td>
<td>52.5</td>
<td>717</td>
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<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
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<tr>
<td><strong>Total</strong></td>
<td>140,994</td>
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<td>10,717</td>
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<td><strong>Products</strong></td>
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<td></td>
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<tr>
<td>Fuel Gas (Used Internally)</td>
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<td>---</td>
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<tr>
<td>Gasoline (87 Octane)</td>
<td>14,814</td>
<td>57.4</td>
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<td>3,580</td>
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<td>10,717</td>
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Case 2 - Atm. & Vac. Distillation (Without Asphalt Production) (Winter)
Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
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<td>Feeds</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
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<td>Total</td>
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<td>5,000</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fuel Gas (Used Internally)</td>
<td>7</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Wide-Cut Diesel</td>
<td>21,866</td>
<td>37.3</td>
<td>1,790</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
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</table>

This case was calculated by dividing the 10,000 B/SD case by 2.0.
Case 2 - Atm. & Vac. Distillation  (Without Asphalt Production) (Winter)
Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeds</strong></td>
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<td></td>
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<tr>
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<td><strong>Total</strong></td>
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<td>5,358</td>
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<tr>
<td><strong>Products</strong></td>
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<td></td>
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</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
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<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Gasoline (87 Octane)</td>
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<td>678</td>
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<tr>
<td>Wide-Cut Diesel</td>
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<td>1,790</td>
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<td>Fuel Oil (to Power)</td>
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<td><strong>Total</strong></td>
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<td>5,358</td>
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</table>

This case was calculated by dividing the 10,000 B/SD case by 2.0.
Case 2 - Distillation Only (With Asphalt Production)
Asphalt

There is no assay information. Use the Arabian Heavy assay.

Choose the 950+

<table>
<thead>
<tr>
<th>AH Yield</th>
<th>Cut point</th>
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</thead>
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<tr>
<td>PEN Wt%</td>
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<tr>
<td>100</td>
<td>35.4</td>
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<tr>
<td>164</td>
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</tr>
<tr>
<td>200</td>
<td>38.7</td>
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</tbody>
</table>

Use the 950+ cut point on Angot. PEN should be lower.
# Calculations

**Case 2 - Atm. & Vac. Distillation (With Asphalt Production)**

## Asphalt

### Calculated Sulfur and Viscosity

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
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<tr>
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<td>0.001</td>
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</tr>
<tr>
<td>248</td>
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<td>-0.015</td>
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<td>302</td>
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<tr>
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<td>0.061</td>
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<td>0.090</td>
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<tr>
<td>401</td>
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<td>0.132</td>
<td>4.6</td>
<td>0.124</td>
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<td>0.162</td>
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<td>509</td>
<td>5.4</td>
<td>0.811</td>
<td>5.9</td>
<td>0.198</td>
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</tr>
<tr>
<td>563</td>
<td>6.0</td>
<td>1.521</td>
<td>6.4</td>
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</tr>
<tr>
<td>617</td>
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<td>1.926</td>
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<td>0.273</td>
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</tr>
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<td>3.9</td>
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<tr>
<td>752</td>
<td>11.3</td>
<td>2.737</td>
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<tr>
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<tr>
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<td>5.575</td>
<td>85.3003</td>
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<td>0.755</td>
</tr>
</tbody>
</table>

**Total**

| 100.0               | 142.8726         | 100.0                   | 17.3          |

- **Cut Total**: 31.2
- **Cut Sulfur, Wt%**: 4.58
- **Cut VBI at 100 °F**: 0.622
- **Cut Viscosity at 100 °F, cSt (From Chart)**: 86,000

### Gravity

- **Crude Specific Gravity**: 0.9123
- **Cut Specific Gravity**: 1.0239
- **Cut Gravity, °API**: 6.9
- **Density, Lb/B**: 358.1
Case 2 - Atm. & Vac. Distillation  (With Asphalt Production)
Fuel Oil
The fuel oil is the blend of the IBP - 302 cut and the 650 - 950 VGO

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<td>0</td>
</tr>
<tr>
<td>158</td>
<td>0.0</td>
<td>0.001</td>
<td>0.0000</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>212</td>
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<td>0.005</td>
<td>0.0066</td>
<td>2.2</td>
<td>-0.330</td>
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</tbody>
</table>

Cut Total 35.9
Cut Sulfur, Wt% 2.41
Cut VBI at 100 °F 0.290
Cut Viscosity at 100 °F, cSt (From Chart) 16.5

Gravity

Crude Specific Gravity 0.9123
Cut Specific Gravity 0.8998
Cut Gravity, °API 26.0
Density, Lb/B 314.7
Case 2 - Atm. & Vac. Distillation  (With Asphalt Production)
Fuel Oil

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Nitrogen Wt%</th>
<th>Angot Nitrogen x Cut Wt%</th>
<th>Angot Cut LV%</th>
</tr>
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<tbody>
<tr>
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<td>0.0</td>
</tr>
<tr>
<td>158</td>
<td>1.7</td>
<td>0.000</td>
<td>0.0000</td>
<td>2.2</td>
</tr>
<tr>
<td>212</td>
<td>1.1</td>
<td>0.000</td>
<td>0.0000</td>
<td>1.4</td>
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<tr>
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</tr>
<tr>
<td>1126</td>
<td>15.3</td>
<td>0.248</td>
<td>0.248</td>
<td>13.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>0.8834</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

Cut Total 35.9 36.4
Cut Nitrogen, Wt% 0.025

Pour Point

Calculate the 65 LV% point of the blend.

<table>
<thead>
<tr>
<th>°F</th>
<th>LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV% on crude</td>
<td>23.7</td>
</tr>
<tr>
<td>LV% on crude at 950 °F</td>
<td>752 17.6</td>
</tr>
<tr>
<td>LV% on crude at 1049 °F</td>
<td>1049 27.8</td>
</tr>
<tr>
<td>TBP Temperature, °F at 41.7 LV%</td>
<td>928 23.7 by interpolation</td>
</tr>
</tbody>
</table>

Pour Point, °F by correlation 57

Based on 35 °F for whole crude.
The correlation probably does not handle this dumbbell mixture well and the result could be off.
### Calculated Pour Point for Distillate Blend

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut %</th>
<th>Angot Cut LV%</th>
<th>AH $\text{Pour Pt.} ^\circ$F</th>
<th>AH $\text{Pour Pt.} ^\circ$R</th>
<th>Angot Pour Pt. Index</th>
<th>Angot Pour Pt. Index x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>---</td>
<td>0.0</td>
<td>0.0</td>
<td>-130</td>
<td>330</td>
<td>1.590</td>
</tr>
<tr>
<td>158</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>-130</td>
<td>330</td>
<td>1.590</td>
</tr>
<tr>
<td>212</td>
<td>1.7</td>
<td>2.2</td>
<td>-120</td>
<td>340</td>
<td>1.594</td>
<td>2.2</td>
</tr>
<tr>
<td>248</td>
<td>1.1</td>
<td>1.4</td>
<td>-120</td>
<td>340</td>
<td>1.594</td>
<td>2.2</td>
</tr>
<tr>
<td>302</td>
<td>2.3</td>
<td>2.8</td>
<td>-100</td>
<td>360</td>
<td>1.601</td>
<td>4.5</td>
</tr>
<tr>
<td>347</td>
<td>2.3</td>
<td>2.8</td>
<td>-100</td>
<td>360</td>
<td>1.601</td>
<td>4.5</td>
</tr>
<tr>
<td>401</td>
<td>11.3</td>
<td>11.2</td>
<td>60</td>
<td>520</td>
<td>1.649</td>
<td>18.5</td>
</tr>
<tr>
<td>455</td>
<td>10.5</td>
<td>10.2</td>
<td>85</td>
<td>545</td>
<td>1.655</td>
<td>16.9</td>
</tr>
<tr>
<td>509</td>
<td>9.0</td>
<td>8.6</td>
<td>100</td>
<td>560</td>
<td>1.659</td>
<td>14.3</td>
</tr>
<tr>
<td>563</td>
<td>11.3</td>
<td>11.2</td>
<td>60</td>
<td>520</td>
<td>1.649</td>
<td>18.5</td>
</tr>
<tr>
<td>617</td>
<td>10.5</td>
<td>10.2</td>
<td>85</td>
<td>545</td>
<td>1.655</td>
<td>16.9</td>
</tr>
<tr>
<td>650</td>
<td>9.0</td>
<td>8.6</td>
<td>100</td>
<td>560</td>
<td>1.659</td>
<td>14.3</td>
</tr>
<tr>
<td>752</td>
<td>11.3</td>
<td>11.2</td>
<td>60</td>
<td>520</td>
<td>1.649</td>
<td>18.5</td>
</tr>
<tr>
<td>851</td>
<td>10.5</td>
<td>10.2</td>
<td>85</td>
<td>545</td>
<td>1.655</td>
<td>16.9</td>
</tr>
<tr>
<td>950</td>
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<td>8.6</td>
<td>100</td>
<td>560</td>
<td>1.659</td>
<td>14.3</td>
</tr>
<tr>
<td>1049</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1126</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1430</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total / Avg.</td>
<td>35.9</td>
<td>36.4</td>
<td></td>
<td></td>
<td></td>
<td>59.8</td>
</tr>
</tbody>
</table>

Calculated Pour Point Index: 1.644
Calculated Pour Point, °R: 498
Calculated Pour Point, °F: 38
Case 2 - Atm. & Vac. Distillation  (With Asphalt Production)
Fuel Oil

### Calculated Nickel and Vanadium

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut WI%</th>
<th>Angot Nickel wppm</th>
<th>Angot Nickel x Cut WI%</th>
<th>Angot Vanadium wppm</th>
<th>Angot Vanadium x Cut WI%</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td>---</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.000</td>
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<tr>
<td>158</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>212</td>
<td>1.7</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>248</td>
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<td>0.0000</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
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<td>0.0000</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>347</td>
<td>3.2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>401</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>455</td>
<td>4.6</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>509</td>
<td>5.4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>563</td>
<td>6.0</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>617</td>
<td>5.9</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>650</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>752</td>
<td>11.3</td>
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<td>0.0000</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>851</td>
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<td>0.000</td>
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<tr>
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<td>0.000</td>
</tr>
<tr>
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<td>0.27</td>
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<tr>
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<td>46.56</td>
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</tbody>
</table>

Total: 100.0 0.0000 46.56 0.0000

Cut Total: 35.9
Cut Nickel, wppm: 0.00
Cut Vanadium, wppm: 0.00
Case 2 - Atm. & Vac. Distillation  (With Asphalt Production)
Fuel Oil

## Calculated Iron

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut WI%</th>
<th>Angot Iron wppm</th>
<th>Angot Iron x Cut WI%</th>
<th>Angot Micro Carb. WI%</th>
<th>Angot MCR x Cut WI%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>--</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>158</td>
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<td>0.0</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>212</td>
<td>1.7</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
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<td>0.00</td>
<td>0.0000</td>
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<tr>
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<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>347</td>
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<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>401</td>
<td>4.0</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>455</td>
<td>4.6</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>509</td>
<td>5.4</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>563</td>
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<td>0.0</td>
<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>617</td>
<td>5.9</td>
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<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
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<td>0.0000</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>752</td>
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<td>0.0000</td>
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<td>0.210</td>
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<td>851</td>
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<td>0.0</td>
<td>0.0000</td>
<td>0.04</td>
<td>0.301</td>
</tr>
<tr>
<td>950</td>
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<td>0.0000</td>
<td>0.37</td>
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<td>0.0000</td>
<td>2.48</td>
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</tr>
<tr>
<td>1126</td>
<td>6.3</td>
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<td>6.90</td>
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</tr>
<tr>
<td>1430</td>
<td>15.3</td>
<td>0.0</td>
<td>50.25</td>
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<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td><strong>0.0000</strong></td>
<td><strong>3.9510</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Cut Total**: 35.9
- **Cut Iron, wppm**: 0.00
- **Cut Micro Carbon Residue, WI%**: 0.1

### Flash Point

Call the same as the whole crude case since it is mainly influenced by the front end.

**Flash Point, °F**: 60

### Heat of Combustion

- **Gravity, °API**: 26.0
- **Lower Heating Value, Btu/Lb (From Chart)**: 18,050
Case 2 - Atm. & Vac. Distillation (With Asphalt Production)(Summer)
Fuel Oil

Rate Summary

<table>
<thead>
<tr>
<th>Case</th>
<th>Fuel Oil Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A</td>
<td>3,640</td>
</tr>
<tr>
<td>2B</td>
<td>1,820</td>
</tr>
</tbody>
</table>

Fuel Oil - Case 2 (Summer)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>26.0</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.8998</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>314.7</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>2.78</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>25</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Notes 1, 2)</td>
<td>0.95</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g</td>
<td></td>
</tr>
<tr>
<td>Flash Point, °F (Notes 1, 2)</td>
<td>60</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>0.1</td>
</tr>
<tr>
<td>Pour Point, °F</td>
<td>38</td>
</tr>
<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>18,050</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>At 100 °F</td>
<td>16.5</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Salt, Lb/1000 B</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Notes
1. It is suspected that light ends were lost from the assay sample and that the RVP will be higher. However, it will be suitable for tankage. The flash point may be lower.
2. Assumed the same as the whole crude.
Case 2 - Atm. & Vac. Distillation  (With Asphalt Production)(Summer)
Power Plant Emissions

<table>
<thead>
<tr>
<th>Case</th>
<th>Fuel Rate, Lb/HR</th>
<th>2A</th>
<th>2B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>47,732</td>
<td>23,866</td>
</tr>
</tbody>
</table>

The potential emissions are as follows. The flue gas scrubber will remove 90%+ of the SOx.

<table>
<thead>
<tr>
<th></th>
<th>2A</th>
<th>2B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel S Content, Wt%</td>
<td>2.78</td>
<td>2.78</td>
</tr>
<tr>
<td>Fuel Fe Content, ppm</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Fuel Ni Content, ppm</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Fuel V Content, ppm</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SOx as SO2, Lb/HR</td>
<td>2,565</td>
<td>1,282</td>
</tr>
<tr>
<td>SOx, LT/SD or metric t/d</td>
<td>27.9</td>
<td>14.0</td>
</tr>
<tr>
<td>Iron, Lb/HR</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Iron, LT/SD or metric t/d</td>
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<td>0.000</td>
</tr>
<tr>
<td>Nickel, Lb/HR</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nickel, LT/SD or metric t/d</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Vanadium, Lb/HR</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Vanadium, LT/SD or metric t/d</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

These strictly apply to the base cases not to the alternate cases.
### Case 2 - Atm. & Vac. Distillation (With Asphalt Production) (Summer)

#### Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/HR</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>132,961</td>
<td>23.6</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>132,961</td>
<td></td>
<td>10,000</td>
</tr>
</tbody>
</table>

| Products                |            |              |           |
| Fuel Gas (Used Internally) | 13        | ---          | ---       |
| Wide-Cut Diesel         | 43,733     | 37.3         | 3,580     |
| Fuel Oil (to Power)     | 47,732     | 26.0         | 3,640     |
| Asphalt                 | 41,483     | 6.9          | 2,780     |
| Total                   | 132,961    |              | 10,000    |
Case 2 - Atm. & Vac. Distillation (With Asphalt Production)(Summer)
Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>66,480</td>
<td>23.6</td>
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</tr>
<tr>
<td>Total</td>
<td>66,480</td>
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<td>5,000</td>
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<tr>
<td>Products</td>
<td></td>
<td></td>
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<tr>
<td>Fuel Gas (Used Internally)</td>
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<td></td>
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<tr>
<td>Wide-Cut Diesel</td>
<td>21,866</td>
<td>37.3</td>
<td>1,790</td>
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<tr>
<td>Fuel Oil (to Power)</td>
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<td>1,820</td>
</tr>
<tr>
<td>Asphalt</td>
<td>20,742</td>
<td>6.9</td>
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</tr>
<tr>
<td>Total</td>
<td>66,480</td>
<td></td>
<td>5,000</td>
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</table>

This case was calculated by dividing the 10,000 B/SD case by 2.0.
Case 3 - Integrated Refinery  (With or Without Asphalt Production)
Light Ends from ADU

<table>
<thead>
<tr>
<th></th>
<th>3A</th>
<th>3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate, Wt.% on Crude</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Rate, LV.% on Crude</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.5075</td>
<td></td>
</tr>
<tr>
<td>MW (as C3)</td>
<td>44.097</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case</th>
<th>3A</th>
<th>3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Rate, B/SD</td>
<td>10,000</td>
<td>15,000</td>
</tr>
<tr>
<td>Crude Density, Lb/B</td>
<td>319.1</td>
<td>319.1</td>
</tr>
<tr>
<td>Crude Rate, Lb/Hr</td>
<td>132,961</td>
<td>199,441</td>
</tr>
<tr>
<td>Light Ends, Lb/Hr</td>
<td>13.3</td>
<td>19.9</td>
</tr>
<tr>
<td>Light Ends, Mol/Hr</td>
<td>0.30</td>
<td>0.45</td>
</tr>
<tr>
<td>Light Ends, MM SCF/D</td>
<td>0.0027</td>
<td>0.0041</td>
</tr>
</tbody>
</table>
Case 3 - Integrated Refinery (With or Without Asphalt Production)
Light Straight Run Naphtha

The LSR needs to include the cyclohexane (BP 177.3) to keep from making benzene in the reformer.

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut %</th>
<th>Angot Sulfur %</th>
<th>Angot Sulfur x Cut %</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>158</td>
<td>0.0</td>
<td>0.001</td>
<td></td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>0.7</td>
<td>0.005</td>
<td></td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.7</strong></td>
<td><strong>0.0000</strong></td>
<td></td>
<td><strong>0.9</strong></td>
<td></td>
<td><strong>0.0</strong></td>
</tr>
</tbody>
</table>

Cut Total: 0.7
Cut Sulfur, %: 0.005

Specific Gravity: 0.7055
Gravity, °API: 69.1

RON, Clear: 60
MON, Clear: 57
MW: 75

<table>
<thead>
<tr>
<th>Rates</th>
<th>3A</th>
<th>3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate, Lb/Hr</td>
<td>931</td>
<td>1,396</td>
</tr>
<tr>
<td>Rate, B/SD</td>
<td>90</td>
<td>135</td>
</tr>
</tbody>
</table>
Case 3 - Integrated Refinery  (With or Without Asphalt Production)
Heavy Straight Run Naphtha

### Calculated Gravity, Sulfur, and Viscosity

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>1.0</td>
<td>0.007</td>
<td>0.0070</td>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>212</td>
<td>1.1</td>
<td>0.011</td>
<td>0.0123</td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>248</td>
<td>2.3</td>
<td>0.026</td>
<td>0.0606</td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>302</td>
<td>3.2</td>
<td>0.061</td>
<td>0.1946</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>375</td>
<td>2.1</td>
<td>0.114</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9.7</strong></td>
<td><strong>0.2745</strong></td>
<td><strong>11.4</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cut Total 7.6
Cut Sulfur, Wt% 0.04
Cut VBI
Cut Viscosity, cSt (From Chart)
Specific Gravity 0.7537
Gravity, °API 56.3
Density, Lb/B 263.6
MW 119
Case 3 - Integrated Refinery  (With or Without Asphalt Production)
Jet Fuel

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>347</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>375</td>
<td>2.1</td>
<td>0.114</td>
<td>0.2394</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>401</td>
<td>1.9</td>
<td>0.151</td>
<td>0.2877</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 4.0  0.5271  4.6

Cut Total: 4.0  4.6
Cut Sulfur, Wt%: 0.13
Cut VBI
Cut Viscosity, cSt (From Chart)
Specific Gravity: 0.7933
Gravitty, "API: 46.9
MW: 155
Case 3 - Integrated Refinery (With or Without Asphalt Production)
Diesel from ADU

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>401</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>455</td>
<td>4.6</td>
<td>0.335</td>
<td>1.5387</td>
<td>5.1</td>
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<td></td>
</tr>
<tr>
<td>509</td>
<td>5.4</td>
<td>0.811</td>
<td>4.3791</td>
<td>5.9</td>
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<td></td>
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<tr>
<td>563</td>
<td>6.0</td>
<td>1.521</td>
<td>9.1230</td>
<td>6.4</td>
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<tr>
<td>617</td>
<td>5.9</td>
<td>1.926</td>
<td>11.3632</td>
<td>6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>650</td>
<td>3.8</td>
<td>2.200</td>
<td>8.3587</td>
<td>3.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25.7</strong></td>
<td></td>
<td><strong>34.7628</strong></td>
<td>27.5</td>
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</tr>
</tbody>
</table>

Cut Total 25.7 27.5
Cut Sulfur, Wt% 1.35
Cut VBI
Cut Viscosity, cSt (From Chart)

Specific Gravity 0.8526
Gravity, °API 34.5
MW 222
Case 3 - Integrated Refinery  (With Asphalt Production)

Diesel from VDU

The stream is a single cut. No calculations necessary.

<table>
<thead>
<tr>
<th>Cut</th>
<th>WT% on Crude</th>
<th>LV% on Crude</th>
</tr>
</thead>
<tbody>
<tr>
<td>650 - 710</td>
<td>6.6</td>
<td>6.5</td>
</tr>
</tbody>
</table>

| Specific Gravity | 0.9264 |
| Gravity, °API    | 21.3   |

| Cut Sulfur, WT%  | 2.540  |
| Cut Nitrogen, WT%| 0.017  |
Case 3 - Integrated Refinery (With Asphalt Production)
Vacuum Gas Oil  (= Fuel Oil for This Case)

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>710</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>752</td>
<td>4.7</td>
<td>3.01</td>
<td>14.1630</td>
<td>4.7</td>
<td>0.307</td>
<td>1.4</td>
</tr>
<tr>
<td>851</td>
<td>10.5</td>
<td>2.74</td>
<td>28.7375</td>
<td>10.2</td>
<td>0.389</td>
<td>4.0</td>
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<tr>
<td>950</td>
<td>9.0</td>
<td>2.99</td>
<td>26.9129</td>
<td>8.6</td>
<td>0.452</td>
<td>3.9</td>
</tr>
<tr>
<td>Total</td>
<td>24.2</td>
<td>69.8135</td>
<td>23.5</td>
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<td></td>
</tr>
</tbody>
</table>

Cut Total 24.2 23.5
Cut Sulfur, Wt% 2.88
Cut VBI 0.396
Cut Viscosity, cSt (From Chart) 93
Specific Gravity 0.9395
Gravity, °API 19.1
Density, Lb/B 328.6

Flash Point
ASTM 5 LV% Point, °F 730
Flash Point, °F 367
Case 3 - Integrated Refinery (With Asphalt Production)
Vacuum Gas Oil (= Fuel Oil for This Case)

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Nitrogen Wt%</th>
<th>Angot Nitrogen x Cut Wt%</th>
<th>Angot Cut LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>710</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>752</td>
<td>4.7</td>
<td>0.017</td>
<td>0.0778</td>
<td>4.7</td>
</tr>
<tr>
<td>851</td>
<td>10.5</td>
<td>0.029</td>
<td>0.3088</td>
<td>10.2</td>
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<tr>
<td>950</td>
<td>9.0</td>
<td>0.039</td>
<td>0.3530</td>
<td>8.6</td>
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<tr>
<td>Total</td>
<td>24.2</td>
<td>0.7396</td>
<td>23.5</td>
<td></td>
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</tbody>
</table>

Cut Total
Cut Nitrogen, Wt%  0.031

23.5
Case 3 - Integrated Refinery  (With Asphalt Production)
Vacuum Gas Oil  (= Fuel Oil for This Case)

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>AH = Angot Pour Pt. °F</th>
<th>AH = Angot Pour Pt. °R</th>
<th>Angot Pour Pt. Index x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>710</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>752</td>
<td>4.7</td>
<td>4.7</td>
<td>67</td>
<td>527</td>
<td>1.651</td>
</tr>
<tr>
<td>851</td>
<td>10.5</td>
<td>10.2</td>
<td>85</td>
<td>545</td>
<td>1.655</td>
</tr>
<tr>
<td>950</td>
<td>9.0</td>
<td>8.5</td>
<td>100</td>
<td>550</td>
<td>1.659</td>
</tr>
<tr>
<td>1049</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1126</td>
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<td></td>
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<tr>
<td>1430</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total / Avg.</td>
<td>24.2</td>
<td>23.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculated Pour Point Index: 1.656
Calculated Pour Point, °R: 544
Calculated Pour Point, °F: 85
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Vacuum Gas Oil (= Fuel Oil for This Case)

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Iron wppm</th>
<th>Angot Iron x Cut Wt%</th>
<th>Angot Micro Carb. Wt%</th>
<th>Angot MCR x Cut Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>710</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>752</td>
<td>4.7</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.03</td>
<td>0.142</td>
</tr>
<tr>
<td>851</td>
<td>10.5</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.04</td>
<td>0.391</td>
</tr>
<tr>
<td>950</td>
<td>9.0</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.37</td>
<td>3.350</td>
</tr>
<tr>
<td>Total</td>
<td>24.2</td>
<td></td>
<td>0.0000</td>
<td></td>
<td>3.8829</td>
</tr>
</tbody>
</table>

Cut Total 24.2
Cut Iron, wppm 0.00
Cut Micro Carbon Residue, Wt% 0.2

Heat of Combustion
Gravty. °API 19.1
Lower Heating Value, Btu/Lb (From Chart) 17,740
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Vacuum Gas Oil (= Fuel Oil for This Case)

<table>
<thead>
<tr>
<th>Case</th>
<th>Fuel Oil Rate B/SD</th>
<th>Fuel Oil Rate Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A</td>
<td>2,350</td>
<td>32,176</td>
</tr>
<tr>
<td>3B</td>
<td>3,525</td>
<td>48,265</td>
</tr>
</tbody>
</table>

Fuel Oil - Case 3A or 3B (Summer)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>19.1</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.9395</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>328.6</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
<td>3.32</td>
</tr>
<tr>
<td>Nitrogen, wppm</td>
<td>306</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Acid Number, mg KOH/g (Note 1)</td>
<td></td>
</tr>
<tr>
<td>Flash Point, °F</td>
<td>367</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
<td>0.2</td>
</tr>
<tr>
<td>Pour Point, °F (Note 2)</td>
<td>85</td>
</tr>
<tr>
<td>Lower Heating Value, Btu/Lb</td>
<td>17,740</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>At 100 °F</td>
<td>93</td>
</tr>
<tr>
<td>Iron, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Nickel, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
<td>0.0</td>
</tr>
<tr>
<td>Salt, Lb/1000 B</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Notes
1. An assay breakdown is not available.
2. An assay breakdown is not available. The estimate is based on Arabian Heavy and could be off.
Case 3 - Integrated Refinery  (With Asphalt Production) (Summer)
Power Plant Potential Emissions

<table>
<thead>
<tr>
<th>Case</th>
<th>3A</th>
<th>3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Rate, Lb/Hr</td>
<td>32,176</td>
<td>48,265</td>
</tr>
</tbody>
</table>

The potential emissions are as follows. The flue gas scrubber will remove 90%+ of the SOx.

<table>
<thead>
<tr>
<th>Fuel S Content, Wi%</th>
<th>3.32</th>
<th>3.32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Fe Content, wppm</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Fuel Ni Content, wppm</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Fuel V Content, wppm</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SOx as SO2, Lb/Hr</td>
<td>2,066</td>
<td>3,100</td>
</tr>
<tr>
<td>SOx, LT/SD or metric t/d</td>
<td>22.5</td>
<td>33.7</td>
</tr>
<tr>
<td>Iron, Lb/Hr</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Iron, LT/SD or metric t/d</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Nickel, Lb/Hr</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nickel, LT/SD or metric t/d</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Vanadium, Lb/Hr</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Vanadium, LT/SD or metric t/d</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
**Case 3 - Integrated Refinery (With Asphalt Production) (Summer)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Yield Wt% FF</th>
<th>MW Lb/Mol</th>
<th>Density °API</th>
<th>Specific Gravity</th>
<th>Yield LV% FF</th>
<th>Sulfur Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td></td>
<td>2.016</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>H2S</td>
<td>1.373</td>
<td>34.076</td>
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<tr>
<td>C1</td>
<td>0.167</td>
<td>16.043</td>
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<td></td>
<td></td>
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<tr>
<td>C2</td>
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<td>30.07</td>
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<tr>
<td>C3</td>
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<tr>
<td>nC4</td>
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<td>58.124</td>
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</tr>
<tr>
<td>rC4</td>
<td>0.660</td>
<td>58.124</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>C5 - 180</td>
<td>0.054</td>
<td>73.0</td>
<td>70.1</td>
<td>0.7020</td>
<td>0.066</td>
<td>0.001</td>
</tr>
<tr>
<td>180 - 347</td>
<td>0.590</td>
<td>115.0</td>
<td>57.3</td>
<td>0.7497</td>
<td>0.675</td>
<td>0.005</td>
</tr>
<tr>
<td>347 - 401</td>
<td>11.226</td>
<td>149.0</td>
<td>47.9</td>
<td>0.7889</td>
<td>12.209</td>
<td>0.013</td>
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<tr>
<td>401 - 710</td>
<td>84.366</td>
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<td>Total</td>
<td>100.511</td>
<td></td>
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<td></td>
<td>98.357</td>
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<td>Check Total</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

Specific Gravity: 0.8580
Density, °API: 33.4
Density, Lb/B: 300.1

H/T Percent HDS: 90

**Nitrogen**: Negligible
# Case 3 - Integrated Refinery (With Asphalt Production) (Summer)

Jet / Diesel Hydrotreater Yields

## Case 3A

<table>
<thead>
<tr>
<th></th>
<th>Yield Lb/HR</th>
<th>Yield Lb Mol/HR</th>
<th>H2 Lb Mol/HR</th>
<th>Yield B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>662</td>
<td>19.4</td>
<td>58.3</td>
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<tr>
<td>H2S</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>81</td>
<td>5.0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>84</td>
<td>2.8</td>
<td>2.8</td>
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<tr>
<td>C3</td>
<td>297</td>
<td>6.7</td>
<td>6.7</td>
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<tr>
<td>lC4</td>
<td>620</td>
<td>10.7</td>
<td>10.7</td>
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<tr>
<td>nC4</td>
<td>319</td>
<td>5.5</td>
<td>5.5</td>
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</tr>
<tr>
<td>C5 - 180</td>
<td>26</td>
<td>0.4</td>
<td>0.5</td>
<td>3</td>
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<tr>
<td>180 - 347</td>
<td>285</td>
<td>2.5</td>
<td>2.8</td>
<td>26</td>
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<tr>
<td>347 - 401</td>
<td>5,418</td>
<td>36.4</td>
<td>11.1</td>
<td>471</td>
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<tr>
<td>401 - 710</td>
<td>40,719</td>
<td>190.3</td>
<td>18.8</td>
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<td>Total</td>
<td>48,511</td>
<td>229.5</td>
<td>122.3</td>
<td>3,797</td>
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Chem H2: 246.5
Chem H2, SCF/Hr, SCF/D, SCF/B: 46,396 1,113,511 288
H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B: 4,825 115,800 30
Total: 1,229,311

The H2 rates are as pure H2.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Jet / Diesel Hydrotreater Yields

<table>
<thead>
<tr>
<th>Case 3B</th>
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<tbody>
<tr>
<td>Crude Rate, B/SD</td>
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<tr>
<td>Density, Lb/B</td>
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<tr>
<td>Crude Rate, Lb/Hr</td>
</tr>
<tr>
<td>H/T Feed Rate, Lb/Hr</td>
</tr>
<tr>
<td>H/T Feed Rate + H2, Lb/Hr</td>
</tr>
<tr>
<td>H/T Feed Rate, B/SD</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>Yield Lb/Hr</th>
<th>Yield Lb Mol/Hr</th>
<th>H2 Lb Mol/Hr</th>
<th>Yield B/SD</th>
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<td>H2</td>
<td>994</td>
<td>29.2</td>
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<td>H2S</td>
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<td>C1</td>
<td>121</td>
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<td>125</td>
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<td>10.1</td>
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<td>tC4</td>
<td>930</td>
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<td>16.0</td>
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<td>C5 - 180</td>
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<td>0.5</td>
<td>0.7</td>
<td>4</td>
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<tr>
<td>180 - 347</td>
<td>427</td>
<td>3.7</td>
<td>4.3</td>
<td>39</td>
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<td>347 - 401</td>
<td>8,127</td>
<td>54.5</td>
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<td>707</td>
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<td>61,079</td>
<td>285.4</td>
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<td>Total</td>
<td>72,767</td>
<td>419.4</td>
<td>183.4</td>
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Chem H2 369.7
Chem H2, SCF/Hr, SCF/D, SCF/B 69,594 1,670,287 288
H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B 7,238 173,700 30
Total 1,843,987

The H2 rates are as pure H2.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Naphtha Hydrotreater Feed

<table>
<thead>
<tr>
<th></th>
<th>Rate on Crude Wt%</th>
<th>Rate on Crude LV%</th>
<th>Sulfur Wt%</th>
<th>Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha from ADU</td>
<td>7.6</td>
<td>9.2</td>
<td>0.036</td>
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<tr>
<td>Naphtha from Diesel H/T</td>
<td>0.2</td>
<td>0.3</td>
<td>0.005</td>
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<tr>
<td>Total / Average</td>
<td>7.8</td>
<td>9.5</td>
<td>0.035</td>
<td>Negligible</td>
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Specific Gravity: 0.7535
Density, °API: 56.3
Density, Lb/B: 263.6

H/T Percent HDS: 99.95

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<tr>
<th>Component</th>
<th>Yield Wt% FF</th>
<th>MW Lb/Mol</th>
<th>Density °API</th>
<th>Specific Gravity</th>
<th>Yield LV% FF</th>
<th>Sulfur Wt%</th>
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</thead>
<tbody>
<tr>
<td>H2</td>
<td></td>
<td>2.016</td>
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<td>H2S</td>
<td>0.037</td>
<td>34.076</td>
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<tr>
<td>C1</td>
<td>0.033</td>
<td>16.043</td>
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<tr>
<td>C2</td>
<td>0.035</td>
<td>30.07</td>
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<td>C3</td>
<td>0.123</td>
<td>44.097</td>
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<tr>
<td>iC4</td>
<td>0.257</td>
<td>58.124</td>
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</tr>
<tr>
<td>nC4</td>
<td>0.132</td>
<td>58.124</td>
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<td></td>
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<tr>
<td>C5 - 180</td>
<td>0.011</td>
<td>73.0</td>
<td>70.1</td>
<td>0.7020</td>
<td>0.012</td>
<td>0.00005</td>
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<td>180 - 347</td>
<td>99.526</td>
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<td>Total</td>
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Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Naphtha Hydrotreater

<table>
<thead>
<tr>
<th>Case 3A</th>
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</thead>
<tbody>
<tr>
<td>Crude Rate, B/SD</td>
</tr>
<tr>
<td>Density, Lb/B</td>
</tr>
<tr>
<td>Crude Rate, Lb/Hr</td>
</tr>
<tr>
<td>H/T Feed Rate, Lb/Hr</td>
</tr>
<tr>
<td>H/T Feed Rate + H2, Lb/Hr</td>
</tr>
<tr>
<td>H/T Feed Rate, B/SD</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Yield Lb/Hr</th>
<th>Yield Lb Mol/Hr</th>
<th>H2 Lb Mol/Hr</th>
<th>Yield B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>4</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>H2S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>C2</td>
<td>4</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>C3</td>
<td>13</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>iC4</td>
<td>27</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>nC4</td>
<td>14</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>C5 - 180</td>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>180 - 347</td>
<td>10,341</td>
<td>89.9</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>10,406</td>
<td>89.9</td>
<td>8.0</td>
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Chem H2
16.1
Chem H2, SCF/Hr, SCF/D, SCF/B
3,028 72,674 77
H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B
1,183 26,382 30
101,055

The H2 rates are as pure H2.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Naphtha Hydrotreater

**Case 3B**

<table>
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<tr>
<th></th>
<th>Crude Rate, B/SD</th>
<th>Density, Lb/B</th>
<th>Crude Rate, Lb/Hr</th>
<th>H/T Feed Rate, Lb/Hr</th>
<th>H/T Feed Rate + H2, Lb/Hr</th>
<th>H/T Feed Rate, B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15,000</td>
<td>319.1</td>
<td>199,441</td>
<td>15,585</td>
<td>15,609</td>
<td>1,419</td>
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<table>
<thead>
<tr>
<th>Yield</th>
<th>Yield</th>
<th>H2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lb/Hr</td>
<td>Lb Mol/Hr</td>
</tr>
<tr>
<td>H2</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>H2S</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>C1</td>
<td>5</td>
<td>0.2</td>
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<tr>
<td>C2</td>
<td>19</td>
<td>0.4</td>
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<tr>
<td>C3</td>
<td>40</td>
<td>0.7</td>
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<tr>
<td>nC4</td>
<td>21</td>
<td>0.4</td>
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<tr>
<td>C5 - 160</td>
<td>2</td>
<td>0.0</td>
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<tr>
<td>160 - 347</td>
<td>15,511</td>
<td>134.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>15,609</strong></td>
<td><strong>137.1</strong></td>
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</table>

Chem H2 24.1
Chem H2, SCF/Hr, SCF/D, SCF/B 4,539 108,947 77
H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B 1,774 42,573 30
**Total** 151,520

The H2 rates are as pure H2.
### Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
#### Light Naphtha (Merifiner Feed)

<table>
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<tr>
<th></th>
<th>Rate on Crude Wt%</th>
<th>Rate on Crude LV%</th>
<th>Sulfur Wt%</th>
<th>RONC</th>
<th>MONC</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSR Naphtha from ADU</td>
<td>0.70</td>
<td>0.90</td>
<td>0.005</td>
<td>67.4</td>
<td>63.0</td>
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<tr>
<td>Light Naphtha from Diesel H/T</td>
<td>0.02</td>
<td>0.03</td>
<td>0.001</td>
<td></td>
<td></td>
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<tr>
<td>Total / Average</td>
<td>0.72</td>
<td>0.93</td>
<td>0.005</td>
<td>67.4</td>
<td>63.0</td>
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- Specific Gravity: 0.7094
- Density, °API: 68.0
- Density, Lb/B: 248.1

<p>| | |</p>
<table>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Case 3A Rate, B/SD</td>
<td>93</td>
</tr>
<tr>
<td>Case 3A Rate, Lb/Hr</td>
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<tr>
<td>Case 3B Rate, B/SD</td>
<td>139</td>
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<tr>
<td>Case 3B Rate, Lb/Hr</td>
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Case 3 - Integrated Refinery (With Asphalt Production) (Summer) Refiner

<table>
<thead>
<tr>
<th></th>
<th>Rate on Crude</th>
<th>Rate on Crude</th>
<th>Sulfur</th>
<th>Nitrogen</th>
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<tbody>
<tr>
<td></td>
<td>Wt%</td>
<td>LV%</td>
<td>Wt%</td>
<td></td>
</tr>
<tr>
<td>Naphtha from H/T</td>
<td>7.8</td>
<td>9.5</td>
<td>0.00005</td>
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</tr>
<tr>
<td>Total / Average</td>
<td>7.8</td>
<td>9.5</td>
<td>0.00005</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

Specific Gravity: 0.7497
Density, °API: 57.3
Density, Lb/B: 262.2

Octane, RONC: 96
Octane, MONC: 86
H2, SCFB: 410

<table>
<thead>
<tr>
<th>Component</th>
<th>Yield Wt% FF</th>
<th>MW Lb/Mol</th>
<th>Density °API</th>
<th>Specific Gravity</th>
<th>Yield LV% FF</th>
<th>Sulfur Wt%</th>
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<tr>
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<td>34.076</td>
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<td>0.787</td>
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<td></td>
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<td>C1</td>
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<td>16.043</td>
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<td>30.07</td>
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<td>0.3563</td>
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<td>C3</td>
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<td>0.5075</td>
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<td>iC4</td>
<td>4.506</td>
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<td>115.041</td>
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**Case 3 - Integrated Refinery (With Asphalt Production) (Summer)**

**Reformer**

### Check of Gasoline Pool Octane

<table>
<thead>
<tr>
<th></th>
<th>Rate on Crude LV%</th>
<th>RONC</th>
<th>MONC</th>
<th>Road Octane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Naphtha Reformate</td>
<td>0.9</td>
<td>67.4</td>
<td>63.0</td>
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</tr>
<tr>
<td></td>
<td>6.6</td>
<td>96.0</td>
<td>86.0</td>
<td></td>
</tr>
<tr>
<td>Total / Average</td>
<td>7.5</td>
<td>92.5</td>
<td>83.2</td>
<td>87.8</td>
</tr>
</tbody>
</table>
Case 3 - Integrated Refinery (With Asphalt Production) (Summer) Refiner

<table>
<thead>
<tr>
<th>Case 3A</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Rate, B/SD</td>
<td>10,000</td>
<td>Density, Lb/B</td>
<td>319.1</td>
</tr>
<tr>
<td>Crude Rate, Lb/HR</td>
<td>132,961</td>
<td>Refiner Feed Rate, Lb/HR</td>
<td>10,341</td>
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<tr>
<td>Refiner Feed Rate, B/SD</td>
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<table>
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<th>Yield B/SD</th>
<th>Yield Lb Moli/Hr</th>
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<tbody>
<tr>
<td>H2</td>
<td>86</td>
<td>0</td>
<td>43</td>
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<tr>
<td>H2S</td>
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<tr>
<td>C1</td>
<td>298</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>580</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>847</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>iC4</td>
<td>466</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>645</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>C5 - 347</td>
<td>7,419</td>
<td>662</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10,341</td>
<td>1,089</td>
<td></td>
</tr>
</tbody>
</table>

H2, SCF/Hr, SCF/D 16,169 388,047
Check H2, SCF/B 410
H2 Solubility Loss, SCF/Hr, SCF/D SCF/B 1,183 28,394 30

The H2 rates are as pure H2.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer) Refiner

### Hydrogen Balance - Case 3A (Summer)

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen Requirement SCF/D</th>
<th>Hydrogen Production SCF/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha Hydrotreater</td>
<td>101,055</td>
<td></td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
<td>1,229,311</td>
<td>388,047</td>
</tr>
<tr>
<td>Reformer</td>
<td>28,394</td>
<td></td>
</tr>
<tr>
<td>Hydrogen Plant</td>
<td>970,713</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,358,761</strong></td>
<td><strong>1,358,761</strong></td>
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</table>

By difference.

### Case 3A - Gasoline Pool RVP

<table>
<thead>
<tr>
<th></th>
<th>Rate</th>
<th>RVP Blending Index</th>
<th>Rate x BI</th>
<th>Rate Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B/SD</td>
<td>PSIA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>92</td>
<td>52.0</td>
<td>139.6</td>
<td>12,906</td>
</tr>
<tr>
<td>Light Naphtha</td>
<td>93</td>
<td>11.1</td>
<td>20.3</td>
<td>1,875</td>
</tr>
<tr>
<td>Reformate</td>
<td>662</td>
<td>2.5</td>
<td>3.3</td>
<td>2,186</td>
</tr>
<tr>
<td><strong>Total / Average</strong></td>
<td><strong>847</strong></td>
<td><strong>11.0</strong></td>
<td><strong>20.0</strong></td>
<td><strong>20</strong></td>
</tr>
</tbody>
</table>

nC4 in Crude
Net nC4 Required

Specific Gravity 0.7423
Gravity, °API 59.1
Density, Lb/B 259.7
Case 3 - Integrated Refinery (With Asphalt Production) (Summer) Refomer

<table>
<thead>
<tr>
<th>Case 3B</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Rate, B/SD</td>
<td>15,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>319.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude Rate, Lb/Hr</td>
<td>199,441</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reformer Feed Rate, Lb/Hr</td>
<td>15,511</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reformer Feed Rate, B/SD</td>
<td>1,420</td>
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<table>
<thead>
<tr>
<th></th>
<th>Yield</th>
<th>Yield</th>
<th>Yield</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Lb/Hr</td>
<td>B/SD</td>
<td>Lb Mol/Hr</td>
</tr>
<tr>
<td>H2</td>
<td>129</td>
<td></td>
<td>64</td>
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<td>H2S</td>
<td>0</td>
<td></td>
<td>0</td>
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<tr>
<td>C1</td>
<td>447</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>870</td>
<td>168</td>
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<tr>
<td>C3</td>
<td>1,271</td>
<td>172</td>
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<tr>
<td>iC4</td>
<td>699</td>
<td>85</td>
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<tr>
<td>nC4</td>
<td>967</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td>C5 - 347</td>
<td>11,129</td>
<td>993</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15,511</td>
<td>1,633</td>
<td></td>
</tr>
</tbody>
</table>

|                  |       |       |       |
| H2, SCF/Hr       | 24,253| 582,071|       |
| Check H2, SCF/B  |       | 410   |       |
| H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B | 1,775 | 42,591 | 30 |

The H2 rates are as pure H2.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Reformer

### Hydrogen Balance - Case 3B (Summer)

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen Requirement SCF/D</th>
<th>Hydrogen Production SCF/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha Hydrotreater</td>
<td>151,520</td>
<td></td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
<td>1,843,967</td>
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</tr>
<tr>
<td>Reformer</td>
<td>42,591</td>
<td>582,071</td>
</tr>
<tr>
<td>Hydrogen Plant</td>
<td></td>
<td>1,456,007</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>2,038,078</strong></td>
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By difference.

### Case 3B - Gasoline Pool RVP

<table>
<thead>
<tr>
<th></th>
<th>Rate</th>
<th>RVP</th>
<th>RVP Blending Index</th>
<th>Rate x BI</th>
<th>Rate Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B/SD</td>
<td>PSIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>139</td>
<td>52.0</td>
<td>139.6</td>
<td>19,356</td>
<td>1,180</td>
</tr>
<tr>
<td>Light Naphtha</td>
<td>139</td>
<td>11.1</td>
<td>20.3</td>
<td>2,813</td>
<td>1,435</td>
</tr>
<tr>
<td>Reformate</td>
<td>993</td>
<td>2.6</td>
<td>3.3</td>
<td>3,278</td>
<td>11,129</td>
</tr>
<tr>
<td><strong>Total / Average</strong></td>
<td><strong>1,270</strong></td>
<td><strong>11.0</strong></td>
<td><strong>20.0</strong></td>
<td><strong>20</strong></td>
<td><strong>13,744</strong></td>
</tr>
<tr>
<td>nC4 in Crude</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net nC4 Required</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Specific Gravity
Gravity, °API
Density, Lb/B

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.7423</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity, °API</td>
<td>59.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>259.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case 3 - Integrated Refinery (With Asphalt Production) (Summer) Refiner

Note that Case 3A will be the same.

<table>
<thead>
<tr>
<th>Case 3B - Gasoline Pool Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate Lb/Hr</td>
</tr>
<tr>
<td>nC4</td>
</tr>
<tr>
<td>Light Naphtha</td>
</tr>
<tr>
<td>Reformate</td>
</tr>
<tr>
<td>Total / Average</td>
</tr>
</tbody>
</table>

Distilations

Reformer Feed TBP Cut Range, °F 180 - 347

<table>
<thead>
<tr>
<th>Feed Point</th>
<th>Feed ASTM D-86 °F</th>
<th>Reformate Point</th>
<th>Reformate ASTM D-86 °F</th>
<th>Pool Point</th>
<th>Pool ASTM D-86 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV%</td>
<td></td>
<td>LV%</td>
<td></td>
<td>LV%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>231</td>
<td>6</td>
<td>158</td>
<td>10.9</td>
<td>31</td>
</tr>
<tr>
<td>10</td>
<td>236</td>
<td>10</td>
<td>180</td>
<td>20.0</td>
<td>132</td>
</tr>
<tr>
<td>20</td>
<td>244</td>
<td>21</td>
<td>212</td>
<td>29.7</td>
<td>180</td>
</tr>
<tr>
<td>50</td>
<td>271</td>
<td>50</td>
<td>260</td>
<td>38.3</td>
<td>212</td>
</tr>
<tr>
<td>70</td>
<td>293</td>
<td>90</td>
<td>320</td>
<td>50.0</td>
<td>240</td>
</tr>
<tr>
<td>90</td>
<td>298</td>
<td>97</td>
<td>338</td>
<td>60.9</td>
<td>260</td>
</tr>
<tr>
<td>95</td>
<td>308</td>
<td>100</td>
<td>355</td>
<td>90.0</td>
<td>315</td>
</tr>
<tr>
<td>100</td>
<td>323</td>
<td></td>
<td></td>
<td>92.2</td>
<td>320</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>97.7</td>
<td>338</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.0</td>
<td>355</td>
</tr>
</tbody>
</table>
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Reformer

Reformate Distillation

![Graph showing Reformate Distillation with temperature in °F on the y-axis and LV% on the x-axis.](chart.png)
Gasoline Pool Distillation

Temperature, °F

LV%
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Gasoline Property Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>59.1</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.7423</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>259.7</td>
</tr>
<tr>
<td>Sulfur, wppm</td>
<td>5.6</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Note 1)</td>
<td>11</td>
</tr>
<tr>
<td>Research Octane Number</td>
<td>92.5</td>
</tr>
<tr>
<td>Motor Octane Number</td>
<td>83.2</td>
</tr>
<tr>
<td>Road Octane Number (Note 2)</td>
<td>87.8</td>
</tr>
<tr>
<td>ASTM D-86 Distillation</td>
<td></td>
</tr>
<tr>
<td>10 LV%</td>
<td>31</td>
</tr>
<tr>
<td>50 LV%</td>
<td>240</td>
</tr>
<tr>
<td>90 LV%</td>
<td>315</td>
</tr>
<tr>
<td>100 LV%</td>
<td>355</td>
</tr>
</tbody>
</table>

Notes

1. RVP is controlled by blending butane.
2. The octane number can be controlled by adjusting the reformer severity.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Hydrogen Plant

<table>
<thead>
<tr>
<th>Hydrogen Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choose</td>
</tr>
<tr>
<td>Product H2 Purity, Mol%</td>
</tr>
<tr>
<td>Steam Factor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>MW Lb/Mol</th>
<th>Composition Mol%</th>
<th>Rate MM SCF/SD</th>
<th>Rate LbMol/HR</th>
<th>Rate Lb/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case 3A -- 1.04 MM SCF/SD Plant</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>2.016</td>
<td>93.0</td>
<td>0.97</td>
<td>106.6</td>
<td>215</td>
</tr>
<tr>
<td>C1</td>
<td>16.043</td>
<td>7.0</td>
<td>0.07</td>
<td>8.0</td>
<td>129</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>100.0</td>
<td>1.04</td>
<td>114.6</td>
</tr>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>16.043</td>
<td>100.0</td>
<td></td>
<td></td>
<td>34.7</td>
</tr>
<tr>
<td>Steam Feed Factor</td>
<td>18.015</td>
<td>100.0</td>
<td></td>
<td></td>
<td>69.3</td>
</tr>
<tr>
<td><strong>Case 3B -- 1.57 MM SCF/SD Plant</strong></td>
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<td></td>
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</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>2.016</td>
<td>93.0</td>
<td>1.46</td>
<td>159.9</td>
<td>322</td>
</tr>
<tr>
<td>C1</td>
<td>16.043</td>
<td>7.0</td>
<td>0.11</td>
<td>12.0</td>
<td>193</td>
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<td>Total</td>
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<td></td>
<td>100.0</td>
<td>1.57</td>
<td>171.9</td>
</tr>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>16.043</td>
<td>100.0</td>
<td></td>
<td></td>
<td>52.0</td>
</tr>
<tr>
<td>Steam Feed Factor</td>
<td>18.015</td>
<td>100.0</td>
<td></td>
<td></td>
<td>103.9</td>
</tr>
</tbody>
</table>

Overall reaction is:

\[ \text{CH}_4 + 2 \text{H}_2\text{O} = \text{CO}_2 + 4 \text{H}_2 \]

The CO2 is vented and not accounted for in the table above.

High purity hydrogen is not particularly required. No PSA with the hydrogen plant.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Gas Plant - Light Ends

### Case 3A

<table>
<thead>
<tr>
<th>Crude Rate, B/SD</th>
<th>10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, Lb/B</td>
<td>319.1</td>
</tr>
<tr>
<td>Crude Rate, Lb/Hr</td>
<td>132,961</td>
</tr>
</tbody>
</table>

### Gas Plant Feeds - Light Ends

<table>
<thead>
<tr>
<th>Component</th>
<th>Atmospheric Distillation Lb/Hr</th>
<th>Visbreaker Lb/Hr</th>
<th>Jet / Diesel Hydrotreater Lb/Hr</th>
<th>Naphtha Hydrotreater Lb/Hr</th>
<th>Reformer Lb/Hr</th>
<th>Hydrogen Plant Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td></td>
<td></td>
<td>25</td>
<td>6</td>
<td>6</td>
<td>129</td>
</tr>
<tr>
<td>H₂S</td>
<td>0</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>C₁</td>
<td>81</td>
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<td>3</td>
<td>298</td>
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<td></td>
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<tr>
<td>C₂</td>
<td>5</td>
<td>84</td>
<td>4</td>
<td>580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₃</td>
<td>8</td>
<td>297</td>
<td>13</td>
<td>847</td>
<td></td>
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</tr>
<tr>
<td>C₄</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>iC₄</td>
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<td>nC₄</td>
<td></td>
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</tbody>
</table>

### Component

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Rate Lb/Hr</th>
<th>MW Lb/Mol</th>
<th>SG</th>
<th>Vapor Rate SCF/SD</th>
<th>Recovered LPG Ratio to Vapor Feed Gal/ M SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>38</td>
<td>2.016</td>
<td>0.7870</td>
<td>172,576</td>
<td></td>
</tr>
<tr>
<td>H₂S</td>
<td>0</td>
<td>34.076</td>
<td>0.3000</td>
<td>289,938</td>
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<tr>
<td>C₁</td>
<td>511</td>
<td>16.043</td>
<td>0.3563</td>
<td>203,795</td>
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<tr>
<td>C₂</td>
<td>0</td>
<td>28.054</td>
<td>0.5217</td>
<td>0</td>
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</tr>
<tr>
<td>C₃</td>
<td>673</td>
<td>30.070</td>
<td>0.5075</td>
<td>240,644</td>
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<tr>
<td>C₄</td>
<td>0</td>
<td>56.108</td>
<td>0.6271</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>iC₄</td>
<td>1,113</td>
<td>58.124</td>
<td>0.5630</td>
<td>174,379</td>
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<td>nC₄</td>
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<td>58.124</td>
<td>0.5842</td>
<td>153,079</td>
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<td>1,234,411</td>
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<tr>
<td>Total ex H₂S</td>
<td>4,477</td>
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<td>1,234,411</td>
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Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Gas Plant - Liquid Feed & Products

### Case 3A - Gas Plant Liquid Feeds

<table>
<thead>
<tr>
<th>Feed</th>
<th>Rate B/SD</th>
<th>Rate Gal/SD</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Light Naphtha</td>
<td>93</td>
<td>3,887</td>
<td>Merfiner Feed</td>
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<td>Heavy Naphtha</td>
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<td>Naphtha H/T Feed</td>
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<td>1,039</td>
<td>43,622</td>
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</tr>
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</table>

This tabulation is for the feed parameter to the gas plant cost curve only. It may double count a little light naphtha.

### Case 3A - Fuel Gas Product

<table>
<thead>
<tr>
<th>Component</th>
<th>Rate Lb/Hr</th>
<th>Lower Heating Value Btu/Lb</th>
<th>Fuel Value MM Btu/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>38</td>
<td>51,600</td>
<td>1.97</td>
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<td>H2S</td>
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</tr>
<tr>
<td>C₁</td>
<td>511</td>
<td>21,500</td>
<td>10.98</td>
</tr>
<tr>
<td>C₂=</td>
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<td>20,290</td>
<td>0.00</td>
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<td>673</td>
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### Case 3A - LPG Product

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<tr>
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<th>Total Rate Lb/Hr</th>
<th>Rate to Gasoline Rate Lb/Hr</th>
<th>Net Rate Lb/Hr</th>
<th>SG</th>
<th>Net Rate B/SD</th>
<th>Net Rate GPM</th>
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</thead>
<tbody>
<tr>
<td>C₃=</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>C₃</td>
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<td>1,165</td>
<td>1,165</td>
<td>0.5075</td>
<td>158</td>
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</tr>
<tr>
<td>C₄=</td>
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<td>0.6271</td>
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<tr>
<td>tC₄</td>
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<td>1,113</td>
<td>1,113</td>
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<td>668</td>
<td>309</td>
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Case 3 - Integrated Refinery  (With Asphalt Production) (Summer)
Gas Plant - Light Ends

<table>
<thead>
<tr>
<th>Case 3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Rate, B/SD</td>
</tr>
<tr>
<td>Density, Lb/B</td>
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<tr>
<td>Crude Rate, Lb/Hr</td>
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### Gas Plant Feeds - Light Ends

<table>
<thead>
<tr>
<th>Component</th>
<th>Atmospheric Distillation Lb/Hr</th>
<th>Visbreaker Lb/Hr</th>
<th>Jet / Diesel Hydrotreater Lb/Hr</th>
<th>Naphtha Hydrotreater Lb/Hr</th>
<th>Reformer Lb/Hr</th>
<th>Hydrogen Plant Lb/Hr</th>
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</thead>
<tbody>
<tr>
<td>H2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>H2S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>193</td>
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<tr>
<td>C1</td>
<td>121</td>
<td>5</td>
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<td>447</td>
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<tr>
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<td>5</td>
<td></td>
<td></td>
<td>447</td>
<td>870</td>
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<tr>
<td>C2</td>
<td>126</td>
<td>5</td>
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<td></td>
<td>1,271</td>
<td>1,271</td>
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<td>C3=</td>
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<td>699</td>
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<tr>
<td>C4=</td>
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### Component Properties

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Rate Lb/Hr</th>
<th>MW Lb/Mol</th>
<th>SG</th>
<th>Vapor Rate SCF/SD</th>
<th>Recovered LPG Ratio to Vapor Feed Gal/M SCF</th>
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<tbody>
<tr>
<td>H2</td>
<td>57</td>
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<td>0.7870</td>
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<tr>
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<td>0.3000</td>
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<td>766</td>
<td>16.043</td>
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<td>305,693</td>
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<tr>
<td>C2=</td>
<td>0</td>
<td>28.054</td>
<td>0.3563</td>
<td>305,693</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>1,009</td>
<td>30.070</td>
<td>0.3563</td>
<td>305,693</td>
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<tr>
<td>C3=</td>
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<td>0.5217</td>
<td>305,693</td>
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<tr>
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<tr>
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<td>1,851,611</td>
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<td>1,851,611</td>
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Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Gas Plant - Liquid Feed & Products

### Case 3B - Gas Plant Liquid Feeds

<table>
<thead>
<tr>
<th>Feed</th>
<th>Rate B/SD</th>
<th>Rate Gal/SD</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Naphtha</td>
<td>139</td>
<td>5,830</td>
<td>Merfiner Feed</td>
</tr>
<tr>
<td>Heavy Naphtha</td>
<td>1,419</td>
<td>59,602</td>
<td>Naphtha H/T Feed</td>
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<td><strong>Total</strong></td>
<td>1,558</td>
<td>65,433</td>
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This tabulation is for the feed parameter to the gas plant cost curve only. It may double count a little light naphtha.

### Case 3B - Fuel Gas Product

<table>
<thead>
<tr>
<th>Component</th>
<th>Rate Lb/HR</th>
<th>Lower Heating Value Btu/Lb</th>
<th>Fuel Value MM Btu/HR</th>
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<tbody>
<tr>
<td>H₂</td>
<td>57</td>
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<tr>
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<tr>
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### Case 3B - LPG Product

<table>
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<tr>
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<th>Total Rate Lb/HR</th>
<th>Rate to Gasoline Lb/HR</th>
<th>Net Rate Lb/HR</th>
<th>SG</th>
<th>Net Rate B/SD</th>
<th>Net Rate GPM</th>
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<tbody>
<tr>
<td>C₃⁺</td>
<td>0</td>
<td>0</td>
<td>0.5217</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>1,748</td>
<td>0.5075</td>
<td>236</td>
<td>7</td>
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<td>0.5630</td>
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<td><strong>Total</strong></td>
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<td>14</td>
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Case 3 - Integrated Refinery (With Asphalt Production) (Summer) Amine Regenerator

**Case 3A - Amine Regenerator**

<table>
<thead>
<tr>
<th>Component</th>
<th>Visbreaker</th>
<th>Jet / Diesel Hydrotreater</th>
<th>Naphtha Hydrotreater</th>
<th>Gas Plant</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>H2S, Lb/HR</td>
<td></td>
<td>662</td>
<td>4</td>
<td>0</td>
<td>666</td>
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<tr>
<td>MW H2S, Lb Mol/HR</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Loading, Mol/Mol</td>
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<td></td>
<td>19.6</td>
</tr>
<tr>
<td>MDEA, Mol/HR</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDEA, Lb/HR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2O, Lb/HR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, Lb/HR</td>
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<td></td>
<td></td>
<td>15,034</td>
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<tr>
<td>Density, Lb/Gal</td>
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<td>8.73</td>
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<td>Solution Rate, GPM</td>
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**Case 3B - Amine Regenerator**

<table>
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<tr>
<th>Component</th>
<th>Visbreaker</th>
<th>Jet / Diesel Hydrotreater</th>
<th>Naphtha Hydrotreater</th>
<th>Gas Plant</th>
<th>Total</th>
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<tr>
<td>H2S, Lb/HR</td>
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<td></td>
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<tr>
<td>Loading, Mol/Mol</td>
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</tr>
<tr>
<td>MW</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MDEA, Lb/HR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2O, Lb/HR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, Lb/HR</td>
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<tr>
<td>Density, Lb/Gal</td>
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<td>Solution Rate, GPM</td>
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Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Sulfur Plant

Case 3A

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<th></th>
<th>Sulfur Rate</th>
<th>Sulfur Rate</th>
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<tbody>
<tr>
<td></td>
<td>LT/Hr</td>
<td>LT/SD</td>
</tr>
<tr>
<td>Sulfur Plant</td>
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</tr>
<tr>
<td>Tail Gas Unit</td>
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</tbody>
</table>

Case 3B

<table>
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<tr>
<th></th>
<th>Sulfur Rate</th>
<th>Sulfur Rate</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>LT/Hr</td>
<td>LT/SD</td>
</tr>
<tr>
<td>Sulfur Plant</td>
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<td>0.51</td>
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</table>
Case 3 - Integrated Refinery  (With Asphalt Production) (Summer)

Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
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<tr>
<td>Crude</td>
<td>132,961</td>
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<tr>
<td>Total</td>
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<td>10,000</td>
</tr>
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<td>Products</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
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<td>---</td>
</tr>
<tr>
<td>LPG</td>
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<td>Gasoline</td>
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<td>847</td>
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</tr>
<tr>
<td>Total</td>
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<td>10,074</td>
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</tbody>
</table>

Notes
1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the hydrogen plant and is not accounted for.
Case 3 - Integrated Refinery  (With Asphalt Production) (Summer)
Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
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<td>Feeds</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Total</td>
<td>200,275</td>
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<td>15,000</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>1,833</td>
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<td>---</td>
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<tr>
<td>LPG</td>
<td>3,881</td>
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<td>494</td>
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<td>Gasoline</td>
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</table>

Notes
1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown.
   Some carbon dioxide is vented from the hydrogen plant and is not accounted for.
Case 3 - Integrated Refinery (With Asphalt Production) (Summer)
Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
<td>278</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>66,480</td>
<td>23.6</td>
<td>5,000</td>
</tr>
<tr>
<td>Total</td>
<td>66,758</td>
<td></td>
<td>5,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Products</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Gas (Used Internally)</td>
<td>611</td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td>1,294</td>
<td>131.1</td>
</tr>
<tr>
<td>Gasoline</td>
<td>4,581</td>
<td>59.1</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>2,709</td>
<td>47.9</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>20,360</td>
<td>35.5</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>16,088</td>
<td>19.1</td>
</tr>
<tr>
<td>Asphalt</td>
<td>20,742</td>
<td>6.9</td>
</tr>
<tr>
<td>Sulfur</td>
<td>313</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>66,698</td>
<td></td>
</tr>
</tbody>
</table>

Notes
1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the plant and is not accounted for.

The rates for this table are those of Case 3A divided by 2.

This case will not be used.
Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
Visbreaker Feed - 650+

## Calculated Sulfur and Viscosity

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Sulfur Wt%</th>
<th>Angot Sulfur x Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.0</td>
<td>-0.330</td>
<td>---</td>
</tr>
<tr>
<td>158</td>
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<td>2.2</td>
<td>-0.098</td>
<td>0.002</td>
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<tr>
<td>212</td>
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<td>1.4</td>
<td>0.015</td>
<td>0.004</td>
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<tr>
<td>248</td>
<td>1.1</td>
<td>0.011</td>
<td>1.1</td>
<td>0.008</td>
<td>4.6</td>
<td>0.090</td>
</tr>
<tr>
<td>302</td>
<td>2.3</td>
<td>0.026</td>
<td>2.8</td>
<td>3.7</td>
<td>0.058</td>
<td>0.090</td>
</tr>
<tr>
<td>347</td>
<td>3.2</td>
<td>0.061</td>
<td>3.7</td>
<td>4.6</td>
<td>0.124</td>
<td>0.090</td>
</tr>
<tr>
<td>401</td>
<td>4.0</td>
<td>0.132</td>
<td>5.1</td>
<td>6.4</td>
<td>0.198</td>
<td>0.090</td>
</tr>
<tr>
<td>455</td>
<td>4.6</td>
<td>0.335</td>
<td>5.1</td>
<td>6.2</td>
<td>0.236</td>
<td>0.090</td>
</tr>
<tr>
<td>509</td>
<td>5.4</td>
<td>0.811</td>
<td>5.9</td>
<td>6.2</td>
<td>0.236</td>
<td>0.090</td>
</tr>
<tr>
<td>563</td>
<td>6.0</td>
<td>1.521</td>
<td>6.4</td>
<td>6.2</td>
<td>0.236</td>
<td>0.090</td>
</tr>
<tr>
<td>617</td>
<td>5.9</td>
<td>1.926</td>
<td>6.2</td>
<td>3.9</td>
<td>0.273</td>
<td>0.090</td>
</tr>
<tr>
<td>650</td>
<td>3.8</td>
<td>2.200</td>
<td>3.9</td>
<td>11.2</td>
<td>0.323</td>
<td>3.6</td>
</tr>
<tr>
<td>752</td>
<td>11.3</td>
<td>2.737</td>
<td>10.2</td>
<td>30.927</td>
<td>0.323</td>
<td>3.6</td>
</tr>
<tr>
<td>851</td>
<td>10.5</td>
<td>2.737</td>
<td>10.2</td>
<td>28.737</td>
<td>0.389</td>
<td>4.0</td>
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<tr>
<td>950</td>
<td>9.0</td>
<td>2.990</td>
<td>8.6</td>
<td>26.9129</td>
<td>0.452</td>
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</tr>
<tr>
<td>1049</td>
<td>9.6</td>
<td>3.416</td>
<td>9.0</td>
<td>32.7942</td>
<td>0.488</td>
<td>4.4</td>
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<tr>
<td>1126</td>
<td>6.3</td>
<td>3.933</td>
<td>5.8</td>
<td>24.7781</td>
<td>0.534</td>
<td>3.1</td>
</tr>
<tr>
<td>1430</td>
<td>15.3</td>
<td>5.575</td>
<td>13.0</td>
<td>85.3003</td>
<td>0.755</td>
<td>9.82</td>
</tr>
</tbody>
</table>

Total

|                      | 100.0        | 229.4501       | 100.0                  | 28.8         |

### Cut Total

<table>
<thead>
<tr>
<th>Cut Sulfur, Wt%</th>
<th>62.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut VBI at 100 °F</td>
<td>57.8</td>
</tr>
<tr>
<td>Cut Viscosity at 100 °F, cSt (From Chart)</td>
<td>0.498</td>
</tr>
</tbody>
</table>

Note: Blending resid and distillates is not very accurate.

## Gravity

| Crude Specific Gravity | 0.9123 |
| Cut Specific Gravity   | 0.9786 |
| Cut Gravity, °API      | 13.3   |
Case 3 - Integrated Refinery  (Winter - Without Asphalt Production)
Visbreaker Feed - 650+

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Nitrogen Wt%</th>
<th>Angot Nitrogen x Cut Wt%</th>
<th>Angot Cut LV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>650</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>752</td>
<td>11.3</td>
<td>0.020</td>
<td>0.2216</td>
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<tr>
<td>851</td>
<td>10.5</td>
<td>0.029</td>
<td>0.3088</td>
<td>10.2</td>
</tr>
<tr>
<td>950</td>
<td>9.0</td>
<td>0.039</td>
<td>0.3530</td>
<td>8.6</td>
</tr>
<tr>
<td>1049</td>
<td>9.6</td>
<td>0.059</td>
<td>0.5547</td>
<td>9.0</td>
</tr>
<tr>
<td>1126</td>
<td>6.3</td>
<td>0.088</td>
<td>0.5559</td>
<td>5.8</td>
</tr>
<tr>
<td>1430</td>
<td>15.3</td>
<td>0.248</td>
<td>3.7876</td>
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</tr>
<tr>
<td>Total</td>
<td>62.0</td>
<td>5.7916</td>
<td>57.8</td>
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</tbody>
</table>

Cut Total 30.8 30.0
Cut Nitrogen, Wt% 0.188
Case 3 - Integrated Refinery (Without Asphalt Production)
Visbreaker Yields

<table>
<thead>
<tr>
<th></th>
<th>Yield on Crude Wt%</th>
<th>Yield on Crude LV%</th>
<th>SG</th>
<th>Sulfur Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>62.0</td>
<td>57.8</td>
<td>0.9786</td>
<td>3.7</td>
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</tbody>
</table>

Set severity for stable bottoms at yield of 5.1 LV% 300°F EP Naphtha.

<table>
<thead>
<tr>
<th></th>
<th>Yield on Feed Wt%</th>
<th>Yield on Feed LV%</th>
<th>SG</th>
<th>Gravity °API</th>
<th>MW Lb/Mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2S</td>
<td>0.34</td>
<td>0.42</td>
<td>0.787</td>
<td>34.076</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>0.39</td>
<td>1.27</td>
<td>0.3000</td>
<td>16.043</td>
<td></td>
</tr>
<tr>
<td>C2=</td>
<td>0.05</td>
<td>0.14</td>
<td>0.3563</td>
<td>28.054</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>0.56</td>
<td>1.54</td>
<td>0.3563</td>
<td>30.070</td>
<td></td>
</tr>
<tr>
<td>Subtotal C2s</td>
<td>0.61</td>
<td>1.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3=</td>
<td>0.15</td>
<td>0.28</td>
<td>0.5217</td>
<td>42.081</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>0.42</td>
<td>0.81</td>
<td>0.5075</td>
<td>44.097</td>
<td></td>
</tr>
<tr>
<td>Subtotal C3s</td>
<td>0.57</td>
<td>1.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4=</td>
<td>0.24</td>
<td>0.37</td>
<td>0.6271</td>
<td>56.108</td>
<td></td>
</tr>
<tr>
<td>iC4</td>
<td>0.10</td>
<td>0.17</td>
<td>0.5630</td>
<td>58.124</td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>0.27</td>
<td>0.45</td>
<td>0.5842</td>
<td>58.124</td>
<td></td>
</tr>
<tr>
<td>Subtotal C4s</td>
<td>0.61</td>
<td>0.99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5 - 300 °F</td>
<td>3.89</td>
<td>5.10</td>
<td>0.7459</td>
<td>56.2</td>
<td></td>
</tr>
<tr>
<td>300 - 400 °F Naphtha</td>
<td>3.25</td>
<td>3.80</td>
<td>0.8373</td>
<td>37.5</td>
<td></td>
</tr>
<tr>
<td>400+</td>
<td>90.34</td>
<td>90.78</td>
<td>0.9739</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>103.44</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case 3 - Integrated Refinery  (Without Asphalt Production)
Visbreaker Yields

<table>
<thead>
<tr>
<th></th>
<th>Yield on Feed Wt%</th>
<th>Yield on Feed LV%</th>
<th>SG</th>
<th>Gravity °API</th>
<th>MW Lb/Mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split C5-300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5 - 300 °F</td>
<td>3.89</td>
<td>5.10</td>
<td>0.7459</td>
<td>58.2</td>
<td></td>
</tr>
<tr>
<td>C5 - 180</td>
<td>1.59</td>
<td>2.24</td>
<td>0.6953</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>180 - 300</td>
<td>2.30</td>
<td>2.86</td>
<td>0.7864</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split 300 - 400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 - 400</td>
<td>3.25</td>
<td>3.80</td>
<td>0.8373</td>
<td>37.5</td>
<td></td>
</tr>
<tr>
<td>300 - 347</td>
<td>1.53</td>
<td>1.82</td>
<td>0.8230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>347 - 400</td>
<td>1.72</td>
<td>1.98</td>
<td>0.8504</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split 400+</td>
<td>90.34</td>
<td>90.78</td>
<td>0.9739</td>
<td>13.8</td>
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<tr>
<td>400 - 700</td>
<td>9.94</td>
<td>11.19</td>
<td>0.8593</td>
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</tr>
<tr>
<td>700+</td>
<td>80.40</td>
<td>79.59</td>
<td>0.9885</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

However, there was some 650 - 710 in the feed. Ignore the 700 / 710 difference. Add this to the predicted 400 - 700 yield at the expense of 700+.

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>650 - 710 Wt% on Crude</td>
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<td></td>
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</tr>
<tr>
<td>650 - 710 LV% on Crude</td>
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<tr>
<td>SG</td>
<td>0.9264</td>
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<tr>
<td>Wt% on VB Feed</td>
<td>10.65</td>
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<td></td>
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</tr>
<tr>
<td>LV% on VB Feed</td>
<td>11.25</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 - 700</td>
<td>20.59</td>
<td>22.44</td>
<td>0.8979</td>
<td></td>
<td></td>
</tr>
<tr>
<td>700+</td>
<td>69.76</td>
<td>68.34</td>
<td>0.9988</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case 3 - Integrated Refinery (Without Asphalt Production)
Visbreaker Yields

<table>
<thead>
<tr>
<th>Mid Wt%</th>
<th>SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>138</td>
<td>0.6953</td>
</tr>
<tr>
<td>198</td>
<td>0.7459</td>
</tr>
<tr>
<td>240</td>
<td>0.7864</td>
</tr>
<tr>
<td>350</td>
<td>0.8373</td>
</tr>
</tbody>
</table>

SG

Mid Temperature, °F

0.6000  0.6500  0.7000  0.7500  0.8000  0.8500  0.9000

100  200  300  400  500  600
Case 3 - Integrated Refinery. (Without Asphalt Production)
Visbreaker Yields
Note that the yields are stated as a percent of the visbreaker feed and not of the crude.

<table>
<thead>
<tr>
<th></th>
<th>Yield on Feed Wt%</th>
<th>Yield on Feed LV%</th>
<th>SG</th>
<th>Gravity °API</th>
<th>MW Lb/Mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2S</td>
<td>0.34</td>
<td>0.42</td>
<td>0.7870</td>
<td></td>
<td>34.076</td>
</tr>
<tr>
<td>C1</td>
<td>0.39</td>
<td>1.27</td>
<td>0.3000</td>
<td></td>
<td>16.043</td>
</tr>
<tr>
<td>C2</td>
<td>0.05</td>
<td>0.14</td>
<td>0.3563</td>
<td></td>
<td>28.054</td>
</tr>
<tr>
<td>C2</td>
<td>0.56</td>
<td>1.54</td>
<td>0.3563</td>
<td></td>
<td>30.070</td>
</tr>
<tr>
<td>Subtotal C2s</td>
<td>0.61</td>
<td>1.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>0.15</td>
<td>0.28</td>
<td>0.5217</td>
<td></td>
<td>42.081</td>
</tr>
<tr>
<td>C3</td>
<td>0.42</td>
<td>0.91</td>
<td>0.5075</td>
<td></td>
<td>44.097</td>
</tr>
<tr>
<td>Subtotal C3s</td>
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</tr>
<tr>
<td>C4</td>
<td>0.24</td>
<td>0.37</td>
<td>0.5271</td>
<td></td>
<td>56.108</td>
</tr>
<tr>
<td>IC4</td>
<td>0.10</td>
<td>0.17</td>
<td>0.5630</td>
<td></td>
<td>58.124</td>
</tr>
<tr>
<td>nC4</td>
<td>0.27</td>
<td>0.45</td>
<td>0.5842</td>
<td></td>
<td>58.124</td>
</tr>
<tr>
<td>Subtotal C4s</td>
<td>0.61</td>
<td>0.99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5 - 180 ºF Lt. Naphtha</td>
<td>1.59</td>
<td>2.24</td>
<td>0.8953</td>
<td></td>
<td>72.0</td>
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<tr>
<td>180 - 347 ºF Hvy. Naphtha</td>
<td>3.83</td>
<td>4.68</td>
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<td>45.2</td>
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<tr>
<td>347 - 400 ºF Jet</td>
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<td>1.98</td>
<td>0.8504</td>
<td></td>
<td>34.9</td>
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<tr>
<td>400 - 700 ºF Diesel</td>
<td>20.59</td>
<td>22.44</td>
<td>0.8979</td>
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<td>26.1</td>
</tr>
<tr>
<td>700+ Fuel Oil</td>
<td>69.76</td>
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<td>0.9988</td>
<td></td>
<td>10.2</td>
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<tr>
<td>Total</td>
<td>100.00</td>
<td>103.44</td>
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</tr>
</tbody>
</table>

Naphtha and Lighter 12.37
Case 3 - Integrated Refinery (Without Asphalt Production)
Visbreaker Yields - Restated as % on Crude

<table>
<thead>
<tr>
<th></th>
<th>Yield on Crude Wt%</th>
<th>Yield on Crude LV%</th>
<th>SG</th>
<th>Gravity °API</th>
<th>MW Lb/Mol</th>
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<tbody>
<tr>
<td>H2S</td>
<td>0.21</td>
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<td>0.8504</td>
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<td>400 - 700 °F Diesel</td>
<td>12.76</td>
<td>12.97</td>
<td>0.8979</td>
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<td>39.51</td>
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<tr>
<td>Total</td>
<td>62.00</td>
<td>59.80</td>
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</tbody>
</table>

Dry Gas
Subtotal C3-      | 1.18               | 2.58               | 0.4191 |             | 28.190    |

Case 3A Rate, MM SCF/D 0.51
Case 3A Rate, Lb/Hr  1,574
Case 3B Rate, MM SCF/D 0.76
Case 3B Rate, Lb/Hr  2,361
Case 3 - Integrated Refinery  (Without Asphalt Production)
Visbreaker Yields

<table>
<thead>
<tr>
<th></th>
<th>Yield on Crude</th>
<th>Yield on Crude</th>
<th>Sulfur</th>
<th>Sulfur x Wt%</th>
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<tbody>
<tr>
<td></td>
<td>Wt%</td>
<td>LV%</td>
<td>Wt%</td>
<td>Wt%</td>
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<tr>
<td>H2S</td>
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<td>0.24</td>
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<td>C2</td>
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<tr>
<td>C3</td>
<td>0.09</td>
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<td></td>
</tr>
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<td>C3</td>
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<td>0.47</td>
<td></td>
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</tr>
<tr>
<td>Subtotal C3s</td>
<td>0.35</td>
<td>0.63</td>
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<tr>
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<tr>
<td>iC4</td>
<td>0.06</td>
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</tr>
<tr>
<td>nC4</td>
<td>0.17</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal C4s</td>
<td>0.38</td>
<td>0.57</td>
<td></td>
<td></td>
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<tr>
<td>C5 - 180 °F Lt. Naphtha</td>
<td>0.99</td>
<td>1.29</td>
<td>0.77</td>
<td>0.76</td>
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<tr>
<td>180 - 347 °F Hvy. Naphtha</td>
<td>2.37</td>
<td>2.71</td>
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<td>347 - 400 °F Jet</td>
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Case 3 - Integrated Refinery  (Without Asphalt Production)
Visbreaker Yields

<table>
<thead>
<tr>
<th></th>
<th>Yield on Crude Wt%</th>
<th>Mid TBP °F</th>
<th>Nitrogen Wt%</th>
<th>Nitrogen x Wt% Wt%</th>
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<tbody>
<tr>
<td>H2S</td>
<td>0.21</td>
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<td></td>
</tr>
<tr>
<td>C1</td>
<td>0.24</td>
<td></td>
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</tr>
<tr>
<td>C2=</td>
<td>0.03</td>
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<td></td>
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<tr>
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<td>Subtotal C2s</td>
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<tr>
<td>C3=</td>
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<td></td>
<td></td>
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<tr>
<td>C3</td>
<td>0.26</td>
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<td></td>
<td></td>
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<tr>
<td>Subtotal C3s</td>
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<td></td>
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<tr>
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<tr>
<td>iC4</td>
<td>0.06</td>
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<td></td>
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<tr>
<td>nC4</td>
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<td></td>
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<tr>
<td>Subtotal C4s</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>C5 - 180 °F Lt. Naphtha</td>
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<td>0.000</td>
<td>0.00</td>
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<td>180 - 347 °F Hvy. Naphtha</td>
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### Visbreaker Yields - Bromine Number

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<th>Bromine Number g/100g</th>
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<tr>
<td>Subtotal C3s</td>
<td>0.35</td>
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<td></td>
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<tr>
<td>C4=</td>
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<td></td>
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<tr>
<td>iC4</td>
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<tr>
<td>nC4</td>
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<td>C5 - 180 °F Lt. Naphtha</td>
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Total / Average: 62.00

Feed for Check

### Visbreaker Yields - Octane Number

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<th>RON</th>
<th>MON</th>
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<td>1.29</td>
<td>78.3</td>
<td>71.2</td>
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Case 3 - Integrated Refinery  (Without Asphalt Production)
Visbreaker Yields  (700+ Bottoms = Fuel Oil)

<table>
<thead>
<tr>
<th>TBP Cut Range EP °F</th>
<th>Angot Cut Wt%</th>
<th>Angot Cut LV%</th>
<th>Angot VBI</th>
<th>VBI x LV%</th>
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<tbody>
<tr>
<td>710</td>
<td>4.7</td>
<td>4.7</td>
<td>0.345</td>
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<tr>
<td>752</td>
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<td>10.2</td>
<td>0.389</td>
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<tr>
<td>851</td>
<td>9.0</td>
<td>8.6</td>
<td>0.452</td>
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<tr>
<td>950</td>
<td>9.6</td>
<td>9.0</td>
<td>0.488</td>
<td>4.4</td>
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<tr>
<td>1049</td>
<td>6.3</td>
<td>5.8</td>
<td>0.534</td>
<td>3.1</td>
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<tr>
<td>1126</td>
<td>15.3</td>
<td>13.0</td>
<td>0.755</td>
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<td><strong>Total</strong></td>
<td><strong>55.4</strong></td>
<td><strong>51.3</strong></td>
<td></td>
<td><strong>26.8</strong></td>
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</tbody>
</table>

Cut Total

- **Cut VBI at 100 °F**: 0.522
- **Crude Cut Viscosity at 100 °F, cSt (From Chart)**: 1,900
- **VB Bottoms Viscosity at 100 °F, cSt (From Chart)**: 1,463
- **Call VB Bottoms Viscosity at 100 °F, cSt**: 1,460

**Density**

- **Density, Lb/B**: 349.4
Case 3 - Integrated Refinery (Without Asphalt Production)
Visbreaker Yields (700+ Bottoms = Fuel Oil)

Flash Point
ASTM 5% Point
Flash Point, °F

Micro Carbon Residue
All MCR ends up in the bottoms.

Total MCR x Wt% in Crude
VB Bottoms, Wt% on Crude
Micro Carbon Residue, Wt%

Iron, Nickel, and Vanadium
These will also all end up in the bottoms.

Iron
Nickel
Vanadium

Pour Point
Conversion (Naphtha and Lighter), LV%
Pour Point Improvement, °C
Feed TBP 65% Point, °F
Feed ASTM 65% Point, °F
Predicted Pour Point of Crude Cut, °F
Predicted Pour Point of VB Bottoms, °F
Call Predicted Pour Point of VB Bottoms, °F

Heat of Combustion
Gravity, °API
Heat of Combustion, Btu/Lb
Lower Heating Value (From Chart)
Case 3 - Integrated Refinery (Without Asphalt Production) (Winter)
Fuel Oil = VB Bottoms

<table>
<thead>
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<th>Rate Summary</th>
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<tbody>
<tr>
<td>Case</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>3A</td>
</tr>
<tr>
<td>3B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel Oil - Case 3A &amp; 3B (Winter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
</tr>
<tr>
<td>Gravity at 60 °F, °API</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
</tr>
<tr>
<td>Density, Lb/B</td>
</tr>
<tr>
<td>Sulfur, Wt%</td>
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<tr>
<td>Nitrogen, wppm</td>
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<tr>
<td>Reid Vapor Pressure, psia</td>
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<tr>
<td>Acid Number, mg KOH/g</td>
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<tr>
<td>Flash Point, °F</td>
</tr>
<tr>
<td>Micro Carbon Residue, Wt%</td>
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<tr>
<td>Pour Point, °F</td>
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<tr>
<td>Lower Heating Value, Btu/Lb</td>
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<tr>
<td>Kinematic Viscosity, cSt</td>
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<tr>
<td>At 100 °F</td>
</tr>
<tr>
<td>Iron, wppm</td>
</tr>
<tr>
<td>Nickel, wppm</td>
</tr>
<tr>
<td>Vanadium, wppm</td>
</tr>
<tr>
<td>Salt, Lb/1000 B (Note 1)</td>
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</table>

Notes
1. The value is not available, but the crude will be desalted.
Case 3 - Integrated Refinery (Without Asphalt Production) (Winter)

Power Plant Potential Emissions

<table>
<thead>
<tr>
<th>Case</th>
<th>3A</th>
<th>3B</th>
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</thead>
<tbody>
<tr>
<td>Fuel Rate, Lb/Hr</td>
<td>57,506</td>
<td>86,259</td>
</tr>
</tbody>
</table>

The potential emissions are as follows. The flue gas scrubber will remove 90%+ of the SOx.

- Fuel S Content, Wt%: 4.85, 4.85
- Fuel Fe Content, wppm: 3.5, 3.5
- Fuel Ni Content, wppm: 5.5, 5.5
- Fuel V Content, wppm: 16.4, 16.4
- SOx as SO2, Lb/Hr: 5,402, 8,103
- SOx, LT/SD or metric t/d: 58.8, 88.2
- Iron, Lb/Hr: 0.2, 0.3
- Iron, LT/SD or metric t/d: 0.002, 0.003
- Nickel, Lb/Hr: 0.3, 0.5
- Nickel, LT/SD or metric t/d: 0.003, 0.005
- Vanadium, Lb/Hr: 0.9, 1.4
- Vanadium, LT/SD or metric t/d: 0.010, 0.015
### Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
**Jet / Diesel Hydrotreater Feed**

<table>
<thead>
<tr>
<th></th>
<th>Rate on Crude Wt%</th>
<th>Rate on Crude LV%</th>
<th>Sulfur Wt%</th>
<th>Olefin Mol/Lb</th>
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</thead>
<tbody>
<tr>
<td>Jet from ADU</td>
<td>4.0</td>
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<td>0.13</td>
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<tr>
<td>Diesel from ADU</td>
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<td>1.35</td>
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<tr>
<td>Diesel from VDU</td>
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</tr>
<tr>
<td>Jet from VB</td>
<td>1.07</td>
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<td>0.77</td>
<td>0.0026</td>
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<tr>
<td>Diesel from VB</td>
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<td>12.97</td>
<td>1.80</td>
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<tr>
<td>Total / Average</td>
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<td>1.36</td>
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</table>

- **Specific Gravity**: 0.8594
- **Density, °API**: 33.2
- **Density, Lb/B**: 300.6

### H/T Percent HDS

<table>
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<tr>
<th>Component</th>
<th>Yield Wt% FF</th>
<th>MW Lb/Mol</th>
<th>Density °API</th>
<th>Specific Gravity</th>
<th>Yield LV% FF</th>
<th>Sulfur Wt%</th>
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</thead>
<tbody>
<tr>
<td>H2</td>
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<td>34.076</td>
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**AssayCalcsRev09_02.xls**

CalcSheet Version 4.05 Dated 4 Mar 2004
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Jet / Diesel Hydrotreater Yields

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<thead>
<tr>
<th>Case 3A</th>
<th>Yield Lb/HR</th>
<th>Yield Lb Mol/HR</th>
<th>H2 Lb Mol/HR</th>
<th>Yield B/SD</th>
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Chem H2, SCF/Hr, SCF/D, SCF/B 76,923 1,846,148 399
H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B 5,777 138,638 30

1,984,786

The H2 rates are as pure H2.
Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
Jet / Diesel Hydrotreater Yields

### Case 3B

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<th>Yield B/SD</th>
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Chem H2: 613.0
Chem H2, SCF/Hr, SCF/D, SCF/B: 115,384, 2,769,222, 399
H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B: 8,665, 207,957, 30

The H2 rates are as pure H2.
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)  
Naphtha Hydrotreater Feed and Yields

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<th>Rate on Crude Wt%</th>
<th>Rate on Crude LV%</th>
<th>Sulfur Wt%</th>
<th>Olefin Mol/Lb</th>
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H/T Percent HDS 99.95

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<th>Specific Gravity</th>
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Total: 102.786
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Naphtha Hydrotreater Yields

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<td>0.3</td>
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<td>0.2</td>
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<td>0.0</td>
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<tr>
<td>180 - 347</td>
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Chem H2, Lb/Hr         32.8
Chem H2, SCF/Hr, SCF/D, SCF/B     6,172 148,118 123
H2 Solubility Loss, SCF/Hr, SCF/D, SCF/B 1,499 35,980 30

The H2 rates are as pure H2.
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Naphtha Hydrotreater Yields

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<th>H2 Lb Mol/HR</th>
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Chem H2

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<td>222,176</td>
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The H2 rates are as pure H2.
### Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
#### Light Naphtha (Melfiner Feed)

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<th>Sulfur</th>
<th>RONC</th>
<th>MONC</th>
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<td>LV%</td>
<td>Wt%</td>
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<td><strong>67.6</strong></td>
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- **Specific Gravity**: 0.7012
- **Density, °API**: 70.3
- **Density, Lb/B**: 245.3

- **Case 3A Rate, B/SD**: 222
- **Case 3A Rate, Lb/Hr**: 2,273
- **Case 3B Rate, B/SD**: 334
- **Case 3B Rate, Lb/Hr**: 3,409
**Case 3 - Integrated Refinery (Without Asphalt Production - Winter) Refiner**

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<th>Rate on Crude LV%</th>
<th>Sulfur Wt%</th>
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- Specific Gravity: 0.7497
- Density, °API: 57.3
- Density, Lb/B: 262.2

- Octane, RONC: 96.2
- Octane, MONC: 86.2
- H2, SCFB: 410

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<td>12.100</td>
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</tr>
<tr>
<td>iC4</td>
<td>4.506</td>
<td>58.124</td>
<td>0.5630</td>
<td></td>
<td>6.000</td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>6.234</td>
<td>58.124</td>
<td>0.5842</td>
<td></td>
<td>8.000</td>
<td></td>
</tr>
<tr>
<td>C5 - 347</td>
<td>71.748</td>
<td>73.000</td>
<td>52.5</td>
<td>0.7690</td>
<td>69.941</td>
<td>0.00005</td>
</tr>
</tbody>
</table>

**Total** 100.000 115.041
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Reformer

<table>
<thead>
<tr>
<th></th>
<th>Rate on Crude LV%</th>
<th>RONC</th>
<th>MONC</th>
<th>Road Octane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Naphtha</td>
<td>2.2</td>
<td>73.7</td>
<td>67.8</td>
<td></td>
</tr>
<tr>
<td>Reformate</td>
<td>8.6</td>
<td>96.2</td>
<td>86.2</td>
<td></td>
</tr>
<tr>
<td>Total / Average</td>
<td>10.8</td>
<td>91.6</td>
<td>82.4</td>
<td>87.0</td>
</tr>
</tbody>
</table>
**Case 3 - Integrated Refinery (Without Asphalt Production - Winter) Reformer**

### Case 3A

<table>
<thead>
<tr>
<th></th>
<th>Yield Lb/Hr</th>
<th>Yield B/SD</th>
<th>Yield Lb Mol/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>112</td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>H₂S</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₁</td>
<td>388</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>C₂</td>
<td>755</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>C₃</td>
<td>1,103</td>
<td>149</td>
<td></td>
</tr>
<tr>
<td>iC₄</td>
<td>607</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>nC₄</td>
<td>840</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>C₅ - 347</td>
<td>9,662</td>
<td>862</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13,467</strong></td>
<td><strong>1,418</strong></td>
<td></td>
</tr>
</tbody>
</table>

H₂, SCF/Hr, SCF/D  21,057  505,374
Check H₂, SCF/B  410
H₂ Solubility Loss, SCF/Hr, SCF/D SCF/B  1,541  36,979  30

The H₂ rates are as pure H₂.
### Case 3 - Integrated Refinery (Without Asphalt Production - Winter) Reformer

**Hydrogen Balance - Case 3A (Winter)**

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen Requirement SCF/D</th>
<th>Hydrogen Production SCF/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha Hydrotreater</td>
<td>184,098</td>
<td></td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
<td>1,984,785</td>
<td></td>
</tr>
<tr>
<td>Reformer</td>
<td>36,979</td>
<td>505,374</td>
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<tr>
<td>Hydrogen Plant</td>
<td>1,700,489</td>
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<tr>
<td><strong>Total</strong></td>
<td>2,205,863</td>
<td>2,205,863</td>
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</tbody>
</table>

*By difference.*

### Case 3A - Gasoline Pool RVP

<table>
<thead>
<tr>
<th></th>
<th>Rate</th>
<th>RVP</th>
<th>RVP Blending Index</th>
<th>Rate x Bl</th>
<th>Rate Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B/SD</td>
<td>PSIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>95</td>
<td>52.0</td>
<td>139.6</td>
<td>13,323</td>
<td>812</td>
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<tr>
<td>Light Naphtha</td>
<td>222</td>
<td>11.1</td>
<td>20.3</td>
<td>4,506</td>
<td>2,273</td>
</tr>
<tr>
<td>Reformate</td>
<td>862</td>
<td>4.6</td>
<td>6.7</td>
<td>5,808</td>
<td>9,662</td>
</tr>
<tr>
<td><strong>Total / Average</strong></td>
<td><strong>1,180</strong></td>
<td><strong>11.0</strong></td>
<td><strong>20.0</strong></td>
<td><strong>23,637</strong></td>
<td><strong>12,747</strong></td>
</tr>
</tbody>
</table>

- **nC4 in Crude**
- **Net nC4 Required**

In the cases with the visbreaker, the visbreaker naphtha is defined as 10 RVP. Therefore the Reformate has a higher RVP than it does in the cases without the VB.
**Case 3 - Integrated Refinery (Without Asphalt Production - Winter) Reformer**

**Case 3B**

<table>
<thead>
<tr>
<th></th>
<th>Yield Lb/Hr</th>
<th>Yield B/SD</th>
<th>Yield Lb Mol/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>168</td>
<td></td>
<td>83</td>
</tr>
<tr>
<td>H2S</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>582</td>
<td>133</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>1,133</td>
<td>218</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>1,655</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>IC4</td>
<td>910</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>1,259</td>
<td>148</td>
<td></td>
</tr>
<tr>
<td>C5 - 347</td>
<td>14,493</td>
<td>1,293</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20,201</strong></td>
<td><strong>2,127</strong></td>
<td></td>
</tr>
</tbody>
</table>

H2, SCF/Hr, SCF/D: 31,586 758,060
Check H2, SCF/B: 410
H2 Solubility Loss, SCF/Hr, SCF/D SCF/B: 2,311 55,468 30

The H2 rates are as pure H2.
Case 3 - Integrated Refinery (Without Asphalt Production - Winter) Reformer

### Hydrogen Balance - Case 3B (Winter)

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen Requirement SCF/D</th>
<th>Hydrogen Production SCF/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphtha Hydrotreater</td>
<td>276,147</td>
<td></td>
</tr>
<tr>
<td>Jet / Diesel Hydrotreater</td>
<td>2,977,179</td>
<td></td>
</tr>
<tr>
<td>Reformer</td>
<td>55,468</td>
<td>758,060</td>
</tr>
<tr>
<td>Hydrogen Plant</td>
<td>2,550,734</td>
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</tr>
<tr>
<td>Total</td>
<td>3,308,794</td>
<td>3,308,794</td>
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</tbody>
</table>

By difference.

### Case 3B - Gasoline Pool RVP

<table>
<thead>
<tr>
<th></th>
<th>Rate</th>
<th>RVP</th>
<th>RVP Blending Index</th>
<th>Rate x BI</th>
<th>Rate Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B/SD</td>
<td>PSIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>143</td>
<td>52.0</td>
<td>139.6</td>
<td>19,984</td>
<td>1,218</td>
</tr>
<tr>
<td>Light Naphtha</td>
<td>334</td>
<td>11.1</td>
<td>20.3</td>
<td>6,759</td>
<td>3,409</td>
</tr>
<tr>
<td>Reformate</td>
<td>1,293</td>
<td>4.6</td>
<td>6.7</td>
<td>8,712</td>
<td>14,493</td>
</tr>
<tr>
<td>Total / Average</td>
<td>1,770</td>
<td>11.0</td>
<td>20.0</td>
<td>35,454</td>
<td>19,121</td>
</tr>
</tbody>
</table>

In the cases with the visbreaker, the visbreaker naphtha is defined as 10 RVP. Therefore the Reformate has a higher RVP than it does in the cases without the VB.
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter) Reformer

Note that Case 3A will be the same.

<table>
<thead>
<tr>
<th>Case 3B - Gasoline Pool Sulfur</th>
<th>Rate x Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate Lb/Hr</td>
<td>Sulfur wppm</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>nC4</td>
<td>1,218</td>
</tr>
<tr>
<td>Light Naphtha</td>
<td>3,409</td>
</tr>
<tr>
<td>Reformate</td>
<td>14,493</td>
</tr>
<tr>
<td>Total / Average</td>
<td>19,121</td>
</tr>
</tbody>
</table>

Distillations

Reformer Feed TBP Cut Range, °F  180 - 347

<table>
<thead>
<tr>
<th>Feed Point</th>
<th>Feed ASTM D-86 °F</th>
<th>Reformate Point</th>
<th>Reformate ASTM D-86 °F</th>
<th>Pool Point</th>
<th>Pool ASTM D-86 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV%</td>
<td></td>
<td>LV%</td>
<td>LV%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>231</td>
<td>6</td>
<td>158</td>
<td>8.1</td>
<td>31</td>
</tr>
<tr>
<td>10</td>
<td>236</td>
<td>10</td>
<td>180</td>
<td>20.0</td>
<td>120</td>
</tr>
<tr>
<td>20</td>
<td>244</td>
<td>21</td>
<td>212</td>
<td>34.2</td>
<td>180</td>
</tr>
<tr>
<td>50</td>
<td>271</td>
<td>50</td>
<td>260</td>
<td>38.3</td>
<td>212</td>
</tr>
<tr>
<td>70</td>
<td>293</td>
<td>90</td>
<td>320</td>
<td>50.0</td>
<td>240</td>
</tr>
<tr>
<td>90</td>
<td>298</td>
<td>97</td>
<td>338</td>
<td>60.9</td>
<td>260</td>
</tr>
<tr>
<td>95</td>
<td>308</td>
<td>100</td>
<td>355</td>
<td>90.0</td>
<td>315</td>
</tr>
<tr>
<td>100</td>
<td>323</td>
<td></td>
<td></td>
<td>92.2</td>
<td>320</td>
</tr>
</tbody>
</table>

Calculation Spreadsheet: AssayCalcsRev09_02.xls
Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
Reformer

Gasoline Pool Distillation
Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
Reformer

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity at 60 °F, °API</td>
<td>57.3</td>
</tr>
<tr>
<td>Specific Gravity at 60 °F</td>
<td>0.7497</td>
</tr>
<tr>
<td>Density, Lb/B</td>
<td>262.2</td>
</tr>
<tr>
<td>Sulfur, wppm</td>
<td>9.3</td>
</tr>
<tr>
<td>Reid Vapor Pressure, psia (Note 1)</td>
<td>11</td>
</tr>
<tr>
<td>Research Octane Number</td>
<td>91.6</td>
</tr>
<tr>
<td>Motor Octane Number</td>
<td>82.4</td>
</tr>
<tr>
<td>Road Octane Number (Note 2)</td>
<td>87.0</td>
</tr>
<tr>
<td>ASTM D-86 Distillation</td>
<td></td>
</tr>
<tr>
<td>10 LV%</td>
<td>31</td>
</tr>
<tr>
<td>50 LV%</td>
<td>240</td>
</tr>
<tr>
<td>90 LV%</td>
<td>315</td>
</tr>
<tr>
<td>100 LV%</td>
<td>355</td>
</tr>
</tbody>
</table>

Notes

1. RVP is controlled by blending butane.
2. The octane number can be controlled by adjusting the reformer severity.
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Hydrogen Plant

### Hydrogen Plant

<table>
<thead>
<tr>
<th>Choose</th>
<th>Product H2 Purity, Mol%</th>
<th>93.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steam Factor</td>
<td>1.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>MW Lb/Mol</th>
<th>Composition Mol%</th>
<th>Rate MM SCF/SD</th>
<th>Rate LbMol/Hr</th>
<th>Rate Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case 3A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>2.016</td>
<td>93.0</td>
<td>1.70</td>
<td>186.7</td>
<td>376</td>
</tr>
<tr>
<td>C1</td>
<td>16.043</td>
<td>7.0</td>
<td>0.13</td>
<td>14.1</td>
<td>225</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100.0</td>
<td>1.83</td>
<td>200.8</td>
<td>602</td>
</tr>
<tr>
<td><strong>Feeds</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>16.043</td>
<td>100.0</td>
<td></td>
<td>60.7</td>
<td>974</td>
</tr>
<tr>
<td>Steam Feed Factor</td>
<td>18.015</td>
<td>100.0</td>
<td></td>
<td>121.4</td>
<td>2,186</td>
</tr>
</tbody>
</table>

| **Case 3B** |           |                  |                |               |            |
| Products    |           |                  |                |               |            |
| H2          | 2.016     | 93.0             | 2.55           | 280.1         | 585        |
| C1          | 16.043    | 7.0              | 0.19           | 21.1          | 338        |
| Total       |           | 100.0            | 2.74           | 301.1         | 903        |
| **Feeds**   |           |                  |                |               |            |
| C1          | 16.043    | 100.0            |                | 91.1          | 1,461      |
| Steam Feed Factor | 18.015 | 100.0           |                | 182.0         | 3,279      |

Overall reaction is:

\[ \text{CH}_4 + 2 \text{H}_2\text{O} = \text{CO}_2 + 4 \text{H}_2 \]

The CO2 is vented and not accounted for in the table above.

High purity hydrogen is not particularly required. No PSA with the hydrogen plant.
### Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
Gas Plant - Light Ends

#### Case 3A

<table>
<thead>
<tr>
<th>Crude Rate, B/SD</th>
<th>10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, Lb/B</td>
<td>319.1</td>
</tr>
<tr>
<td>Crude Rate, Lb/Hr</td>
<td>132,961</td>
</tr>
</tbody>
</table>

#### Gas Plant Feeds - Light Ends

<table>
<thead>
<tr>
<th>Component</th>
<th>Atmospheric Distillation Lb/Hr</th>
<th>Visbreaker Lb/Hr</th>
<th>Jet / Diesel Hydrotreater Lb/Hr</th>
<th>Naphtha Hydrotreater Lb/Hr</th>
<th>Reformer Lb/Hr</th>
<th>Hydrogen Plant Lb/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>31</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td>225</td>
</tr>
<tr>
<td>H2S</td>
<td>280</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>321</td>
<td>97</td>
<td>5</td>
<td>388</td>
<td>755</td>
<td>1,103</td>
</tr>
<tr>
<td>C2=</td>
<td>41</td>
<td>124</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>5</td>
<td>101</td>
<td>5</td>
<td>755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3=</td>
<td>8</td>
<td>357</td>
<td>17</td>
<td>1,103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>346</td>
<td>382</td>
<td>18</td>
<td>840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4=</td>
<td>198</td>
<td>744</td>
<td>35</td>
<td>607</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iC4</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>223</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Component Properties

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Rate Lb/Hr</th>
<th>MW Lb/Mol</th>
<th>SG</th>
<th>Vapor Rate SCF/SD</th>
<th>Recovered LPG Ratio to Vapor Feed Gal/ M SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>47</td>
<td>2.016</td>
<td>0.7870</td>
<td>211,597</td>
<td></td>
</tr>
<tr>
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<td>280</td>
<td>34.076</td>
<td>0.7870</td>
<td>74,968</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>1,035</td>
<td>16.043</td>
<td>0.3000</td>
<td>567,771</td>
<td></td>
</tr>
<tr>
<td>C2=</td>
<td>41</td>
<td>28.054</td>
<td>0.3563</td>
<td>13,381</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>1,328</td>
<td>30.070</td>
<td>0.3563</td>
<td>402,127</td>
<td></td>
</tr>
<tr>
<td>C3=</td>
<td>124</td>
<td>42.081</td>
<td>0.5217</td>
<td>26,783</td>
<td></td>
</tr>
<tr>
<td>C3</td>
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<td>44.097</td>
<td>0.5075</td>
<td>378,082</td>
<td></td>
</tr>
<tr>
<td>C4=</td>
<td>198</td>
<td>56.108</td>
<td>0.6271</td>
<td>32,115</td>
<td></td>
</tr>
<tr>
<td>iC4</td>
<td>1,456</td>
<td>58.124</td>
<td>0.5830</td>
<td>229,999</td>
<td></td>
</tr>
<tr>
<td>nC4</td>
<td>1,462</td>
<td>58.124</td>
<td>0.5842</td>
<td>229,093</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7,813</td>
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<td>2,185,897</td>
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<td>Total ex H2S</td>
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<td>2,110,929</td>
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Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Gas Plant - Liquid Feed & Products

## Case 3A - Gas Plant Liquid Feeds

<table>
<thead>
<tr>
<th>Feed</th>
<th>Rate B/SD</th>
<th>Rate Gal/SD</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Naphtha</td>
<td>222</td>
<td>9,341</td>
<td>Merfiner Feed</td>
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<tr>
<td>Heavy Naphtha</td>
<td>1,199</td>
<td>50,373</td>
<td>Naphtha H/T Feed</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>1,422</strong></td>
<td><strong>59,713</strong></td>
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</table>

This tabulation is for the feed parameter to the gas plant cost curve only. It may double count a little light naphtha.

## Case 3A - Fuel Gas Product

<table>
<thead>
<tr>
<th>Component</th>
<th>Rate Lb/HR</th>
<th>Lower Heating Value Btu/Lb</th>
<th>Fuel Value MM Btu/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>47</td>
<td>51,600</td>
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## Case 3A - LPG Product

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<th>Component</th>
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<th>Rate to Gasoline Lb/HR</th>
<th>Net Rate Lb/HR</th>
<th>SG</th>
<th>Net Rate B/SD</th>
<th>Net Rate GPM</th>
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</thead>
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<tr>
<td>C3=</td>
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<td>124</td>
<td>0.5217</td>
<td>16</td>
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<td></td>
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<tr>
<td>C3</td>
<td>1,831</td>
<td>1,831</td>
<td>0.5075</td>
<td>247</td>
<td>7</td>
<td></td>
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<tr>
<td>C4=</td>
<td>198</td>
<td>198</td>
<td>0.6271</td>
<td>22</td>
<td>1</td>
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</tr>
<tr>
<td>IC4</td>
<td>1,468</td>
<td>1,468</td>
<td>0.5630</td>
<td>179</td>
<td>5</td>
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<tr>
<td>nC4</td>
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<td>693</td>
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<td>90</td>
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<td><strong>4,389</strong></td>
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Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Gas Plant - Light Ends

Case 3A - LPG Product RVP

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<tr>
<th>Component</th>
<th>Net Rate Lb/Hr</th>
<th>SG</th>
<th>Net Rate B/SD</th>
<th>RVP PSIA</th>
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<tr>
<td>C3=</td>
<td>124</td>
<td>0.5217</td>
<td>16</td>
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<td>C3</td>
<td>1,831</td>
<td>0.5075</td>
<td>247</td>
<td>151</td>
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<tr>
<td>C4=</td>
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<td>0.6271</td>
<td>22</td>
<td>71</td>
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<td>0.5842</td>
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<td>5,082</td>
<td>636</td>
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C3 & C4= are approximate

RVP will obviously meet the specification of 208 PSIG if the C2 content is OK.
Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
Gas Plant - Light Ends

### Case 3B

<table>
<thead>
<tr>
<th>Crude Rate, B/SD</th>
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<tr>
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<td>Crude Rate, Lb/Hr</td>
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#### Gas Plant Feeds - Light Ends

<table>
<thead>
<tr>
<th>Component</th>
<th>Atmospheric Distillation Lb/HR</th>
<th>Visbreaker Lb/HR</th>
<th>Jet / Diesel Hydrotreater Lb/HR</th>
<th>Naphtha Hydrotreater Lb/HR</th>
<th>Reformer Lb/HR</th>
<th>Hydrogen Plant Lb/HR</th>
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</thead>
<tbody>
<tr>
<td>H2</td>
<td></td>
<td></td>
<td>46</td>
<td>12</td>
<td>12</td>
<td>338</td>
</tr>
<tr>
<td>H2S</td>
<td></td>
<td>421</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
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<td>481</td>
<td>145</td>
<td>7</td>
<td>582</td>
<td></td>
</tr>
<tr>
<td>C2=</td>
<td></td>
<td>62</td>
<td>692</td>
<td>151</td>
<td>7</td>
<td>1,133</td>
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<tr>
<td>C3=</td>
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<td>8</td>
<td>185</td>
<td>535</td>
<td>25</td>
<td>1,655</td>
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<tr>
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<td></td>
<td>12</td>
<td>519</td>
<td>1,116</td>
<td>52</td>
<td>910</td>
</tr>
<tr>
<td>C4=</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iC4</td>
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<td>124</td>
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<td></td>
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<tr>
<td>nC4</td>
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<td>334</td>
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<td>1,259</td>
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#### Component Table

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Rate Lb/HR</th>
<th>MW Lb/Mol</th>
<th>SG</th>
<th>Vapor Rate SCF/SD</th>
<th>Recovered LPG Ratio to Vapor Feed Gal/ M SCF</th>
</tr>
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<tbody>
<tr>
<td>H2</td>
<td>70</td>
<td>2.016</td>
<td>0.7870</td>
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<tr>
<td>H2S</td>
<td>421</td>
<td>34.076</td>
<td>0.3000</td>
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<tr>
<td>C1</td>
<td>1,553</td>
<td>16.043</td>
<td>0.3563</td>
<td>881,657</td>
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<td>C2=</td>
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<td>28.054</td>
<td>0.3563</td>
<td>20,072</td>
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</tr>
<tr>
<td>C2</td>
<td>1,991</td>
<td>30.070</td>
<td>0.5217</td>
<td>603,191</td>
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<tr>
<td>C3=</td>
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<td>0.5075</td>
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<tr>
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<td>0.5842</td>
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<tr>
<td>Total</td>
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<td>3,278,846</td>
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</table>
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Gas Plant - Liquid Feed & Products

### Case 3B - Gas Plant Liquid Feeds

<table>
<thead>
<tr>
<th>Feed</th>
<th>Rate B/SD</th>
<th>Rate Gal/SD</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Naphtha</td>
<td>334</td>
<td>14,011</td>
<td>Merlifier Feed</td>
</tr>
<tr>
<td>Heavy Naphtha</td>
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<td>75,559</td>
<td>Naphtha H/T Feed</td>
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<tr>
<td>Total</td>
<td>2,133</td>
<td>89,570</td>
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</table>

This tabulation is for the feed parameter to the gas plant cost curve only. It may double count a little light naphtha.

### Case 3B - Fuel Gas Product

<table>
<thead>
<tr>
<th>Component</th>
<th>Rate Lb/Hr</th>
<th>Lower Heating Value Blt/Lb</th>
<th>Fuel Value MM Blt/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>70</td>
<td>51,600</td>
<td>3.63</td>
</tr>
<tr>
<td>H₂S</td>
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</tr>
<tr>
<td>C1</td>
<td>1,553</td>
<td>21,500</td>
<td>33.39</td>
</tr>
<tr>
<td>C2=</td>
<td>62</td>
<td>20,290</td>
<td>1.25</td>
</tr>
<tr>
<td>C2</td>
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<td>40.67</td>
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<td>75.31</td>
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</table>

### Case 3B - LPG Product

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Rate Lb/Hr</th>
<th>Rate to Gasoline Lb/Hr</th>
<th>Net Rate Lb/Hr</th>
<th>SG</th>
<th>Net Rate B/SD</th>
<th>Net Rate GPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3=</td>
<td>185</td>
<td>185</td>
<td>0.5217</td>
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<tr>
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<td>nC4</td>
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Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Amine Regenerator

### Case 3A - Amine Regenerator

<table>
<thead>
<tr>
<th>Component</th>
<th>Visbreaker</th>
<th>Jet / Diesel Hydrotreater</th>
<th>Naphtha Hydrotreater</th>
<th>Gas Plant</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2S, Lb/Hr</td>
<td></td>
<td>752</td>
<td>33</td>
<td>280</td>
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<tr>
<td>MW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34.076</td>
</tr>
<tr>
<td>H2S, Lb Mol/Hr</td>
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<td></td>
<td></td>
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<tr>
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### Case 3B - Amine Regenerator

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<th>Jet / Diesel Hydrotreater</th>
<th>Naphtha Hydrotreater</th>
<th>Gas Plant</th>
<th>Total</th>
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<tbody>
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<tr>
<td>H2O, Lb/Hr</td>
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<td></td>
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</tr>
<tr>
<td>Total, Lb/Hr</td>
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<td></td>
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<tr>
<td>Density, Lb/Gal</td>
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<td></td>
<td></td>
<td></td>
<td>8.73</td>
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<tr>
<td>Solution Rate, GPM</td>
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Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Sulfur Plant

**Case 3A**

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<th>Sulfur Rate</th>
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<tr>
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<td>LT/SD</td>
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<tr>
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</tr>
<tr>
<td>Sulfur Rate, Lb Mol/HR</td>
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<tr>
<td>Sulfur MW, Lb/Mol</td>
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**Case 3B**

<table>
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<th>Sulfur Rate</th>
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<tbody>
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<td>LT/SD</td>
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Case 3 - Integrated Refinery (Without Asphalt Production - Winter)
Overall Case Material Balance

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<th>Gravity °API</th>
<th>Rate B/SD</th>
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</tr>
<tr>
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<tr>
<td><strong>Total</strong></td>
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<td>10,000</td>
</tr>
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<td><strong>Products</strong></td>
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<td></td>
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</tr>
<tr>
<td>Fuel Gas (Used Internally)</td>
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<td>---</td>
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<tr>
<td>LPG</td>
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</tr>
<tr>
<td>Gasoline</td>
<td>12,747</td>
<td>59.4</td>
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</tr>
<tr>
<td>Jet Fuel</td>
<td>6,515</td>
<td>47.9</td>
<td>567</td>
</tr>
<tr>
<td>Diesel Fuel</td>
<td>48,967</td>
<td>35.5</td>
<td>3,964</td>
</tr>
<tr>
<td>Fuel Oil (to Power)</td>
<td>57,506</td>
<td>10.2</td>
<td>3,951</td>
</tr>
<tr>
<td>Asphalt</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1,002</td>
<td>---</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td>133,577</td>
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<td>10,217</td>
</tr>
</tbody>
</table>

Notes
1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the hydrogen plant and is not accounted for.
## Case 3 - Integrated Refinery (Without Asphalt Production - Winter)

### Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
<td>1,461</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Crude</td>
<td>199,441</td>
<td>23.6</td>
<td>15,000</td>
</tr>
<tr>
<td>Total</td>
<td>200,903</td>
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<td>15,000</td>
</tr>
<tr>
<td>Products</td>
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<td></td>
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<tr>
<td>Fuel Gas (Used Internally)</td>
<td>3,677</td>
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<td>--</td>
</tr>
<tr>
<td>LPG</td>
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<td>5,927</td>
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<tr>
<td>Sulfur</td>
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</tr>
<tr>
<td>Total</td>
<td>200,366</td>
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<td>15,325</td>
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</tbody>
</table>

### Notes
1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown. Some carbon dioxide is vented from the hydrogen plant and is not accounted for.
Case 3 - Integrated Refinery  (Without Asphalt Production - Winter)
Overall Case Material Balance

<table>
<thead>
<tr>
<th>Stream</th>
<th>Rate Lb/Hr</th>
<th>Gravity °API</th>
<th>Rate B/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeds</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas (Note 1)</td>
<td>487</td>
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<td>---</td>
</tr>
<tr>
<td>Crude</td>
<td>66,480</td>
<td>23.6</td>
<td>5,000</td>
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<tr>
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<td>66,968</td>
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<td>5,000</td>
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<tr>
<td>Products</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>Total</td>
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<td>5,108</td>
</tr>
</tbody>
</table>

Notes
1. The natural gas feed goes to the hydrogen plant. There is also a steam feed that is not shown.
   Some carbon dioxide is vented from the hydrogen plant and is not accounted for.

This case was calculated by dividing case 3A by 2.0.
Case will not be used.