Basics of Refining and Optimization

February 6, 2015
Statements contained in this presentation that state the company’s or management’s expectations or predictions of the future are forward-looking statements intended to be covered by the safe harbor provisions of the Securities Act of 1933 and the Securities Exchange Act of 1934. The words “believe,” “expect,” “should,” “estimates,” “intend,” and other similar expressions identify forward-looking statements. It is important to note that actual results could differ materially from those projected in such forward-looking statements. For more information concerning factors that could cause actual results to differ from those expressed or forecasted, see Valero’s annual reports on Form 10-K and quarterly reports on Form 10-Q, filed with the Securities and Exchange Commission, and available on Valero’s website at www.valero.com.
Lane Riggs
Executive Vice President
Refining Operations and Engineering
• Crude oil overview
• Refining basics
• Refinery optimization
• Crude oil valuation and relative discounts
Crude oils are blends of hydrocarbon molecules

- Classified and priced by density, sulfur content, and acidity

Density is commonly measured in API gravity (relative density of crude oil to water)

- API > 10: lighter, floats on water
- API < 10: heavier, sinks in water

Sulfur content is measured in weight percent

- Less than 0.7% sulfur content = sweet
- Greater than 0.7% sulfur content = sour

Acidity is measured by Total Acid Number (TAN)

- High acid crudes are those with TAN greater than 0.7
- Acidic crudes are corrosive to refinery equipment, require greater investment to process significant volumes or higher TAN levels

Light, sweet, low TAN crudes are easier to process and tend to trade at premiums to heavier, higher sulfur, more acidic crudes which require additional conversion capacity to upgrade
Crude Oil Basics

Estimated 1.65 Trillion Barrels of Oil Reserves (2013)

- Majority of global crude oil reserves are sour
- Most quoted benchmarks are light sweet crude oils (WTI, Brent, Tapis)

Crude Oil Quality

- Source: Industry reports

- Source: EIA
What’s in a Barrel of Crude Oil?

**Crude Oil Types**
- **Light Sweet** (e.g. WTI, LLS, Brent)
  - > 34 API Gravity
  - < 0.7 % Sulfur
  - 35% Demand
  - Most Expensive
- **Medium Sour** (e.g. Mars, WTS, Arab Medium, Basrah)
  - 24 to 34 API Gravity
  - > 0.7 % Sulfur
  - 50% Demand
  - Less Expensive
- **Heavy Sour** (e.g. Maya, Cold Lake, Western Canadian Select)
  - < 24 API Gravity
  - > 0.7 % Sulfur
  - 15% Demand
  - Least Expensive

**Characteristics**
- > 34 API Gravity
- < 0.7 % Sulfur
- 35% Demand
- Most Expensive
- 24 to 34 API Gravity
- > 0.7 % Sulfur
- 50% Demand
- Less Expensive
- < 24 API Gravity
- > 0.7 % Sulfur
- 15% Demand
- Least Expensive

**Inherent Yields**
- 3%
- 32%
- 30%
- 35%
- 2%
- 24%
- 26%
- 48%
- 1%
- 15%
- 21%
- 63%

**2014 U.S. Refinery Production**
- **4%** Refinery Gases
- **46%** Gasoline
  - RBOB
  - CBOB
  - Conventional
  - CARB
  - Premium
- **39%** Distillate
  - Jet Fuel
  - Diesel
  - Heating Oil
- **11%** Heavy Fuel
  - Oil & Other

Source: EIA refinery yield through Oct 2014

Refineries upgrade crude oil into higher value gasoline and distillates.
Basic Refining Concepts

Basic Refining Units:
- Crude Distillation Unit
- Furnace
- Vacuum Distillation Unit
- Hydrotreater
- FCC
- Hydrocracker
- Refiner
- Isomerization
- Blending
- Hydrocracker
- Coker
- Resid Hydrocracker
- Lube stocks

Basic Refining Concepts:
- Crude Oil
- Furnace
- Vacuum Distillation Unit
- Hydrotreater
- FCC
- Hydrocracker
- Refiner
- Isomerization
- Blending
- Hydrocracker
- Coker
- Resid Hydrocracker
- Lube stocks

Crude Distillation Unit:
- Crude Oil
- Furnace
- Vacuum Distillation Unit
- Hydrotreater
- FCC
- Hydrocracker
- Refiner
- Isomerization
- Blending
- Hydrocracker
- Coker
- Resid Hydrocracker
- Lube stocks

Basic Refining Process Flow:
- Crude Oil
- Furnace
- Vacuum Distillation Unit
- Hydrotreater
- FCC
- Hydrocracker
- Refiner
- Isomerization
- Blending
- Hydrocracker
- Coker
- Resid Hydrocracker
- Lube stocks
Hydroskimming (Topping) Refinery

Low complexity refineries run sweet crude
Crude and Vacuum Distillation Towers

Crude Tower

Vacuum Tower
Medium Conversion: Catalytic Cracking

Moderate complexity refineries tend to run more sour crudes, yield more high value products, and achieve higher volume gain.
Fluid Catalytic Cracker
High Conversion: Coking/Resid Destruction

High complexity refineries can run heavier, more sour crudes while achieving the highest light product yields and volume gain.
Cokers

Delayed Coker
Superstructure holds the drill and drill stem while the coke is forming in the drum

Fluid Coker
Hydrocracker

- Enables capture of arbitrage between natural gas and crude oil
- Upgrades high sulfur gasoil into low sulfur gasoline, jet, and diesel
- Increases volumetric yield of products through hydrogen saturation
Gary Simmons
Senior Vice President
Supply, International Operations and Systems Optimization
Maximizing Refinery Profit

Feedstocks (100+)
- Prices
- Qualities
- Availabilities (purchase volumes)

Products (30+)
- Prices
- Specifications
- Market demand (sales volumes)

Refinery
- 10 to 25+ individual process units
- Unit hardware constraints
- Operating parameters
- Operating costs

Relationship between variables modeled in series of linear equations
Linear program used to find combination of feed and product slates, operating rates and parameters that delivers highest profit
**LP Example: What’s for Breakfast?**

<table>
<thead>
<tr>
<th></th>
<th>Serving Size</th>
<th>$/Serving</th>
<th>Protein (g)</th>
<th>Total Fat (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagel</td>
<td>1 large bagel</td>
<td>$2.00</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Oatmeal</td>
<td>1 cup</td>
<td>$2.50</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Eggs</td>
<td>2 large eggs</td>
<td>$3.50</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Bacon</td>
<td>3 slices</td>
<td>$4.00</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Orange juice</td>
<td>1 cup</td>
<td>$2.50</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

*Your goal is to consume at least 18 grams of protein, but not more than 10 grams of total fat for the lowest COST.*
Optimizing Breakfast from an Engineer’s Point of View

<table>
<thead>
<tr>
<th>Food</th>
<th>Servings</th>
<th>Protein</th>
<th>Total Fat</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagel</td>
<td>3</td>
<td>3 g</td>
<td></td>
<td>$2.00</td>
</tr>
<tr>
<td>Oatmeal</td>
<td>4</td>
<td>4 g</td>
<td></td>
<td>$2.50</td>
</tr>
<tr>
<td>Eggs</td>
<td>6</td>
<td>6 g</td>
<td></td>
<td>$3.50</td>
</tr>
<tr>
<td>Bacon</td>
<td>8</td>
<td>8 g</td>
<td></td>
<td>$4.00</td>
</tr>
<tr>
<td>Juice</td>
<td>2</td>
<td>2 g</td>
<td></td>
<td>$2.50</td>
</tr>
</tbody>
</table>

**Consume at least 18 grams of protein**

\[3 \times 3 + 4 \times 4 + 6 \times 6 \geq 18 \text{ grams protein}\]

**Consume no more than 15 grams of total fat**

\[1 \times 1 + 1 \times 1 + 5 \times 5 + 8 \times 8 + 0 \times 0 \leq 15 \text{ grams total fat}\]

**Minimize the cost of breakfast**

\[2.00 + 2.50 + 3.50 + 4.00 + 2.50 = \text{Minimum}\]

Even with only five food choices, there are so many possible combinations that using trial and error to find the one with the lowest cost isn’t efficient.
# What’s Best?

<table>
<thead>
<tr>
<th>Servings</th>
<th>Unit Cost</th>
<th>Protein (g)</th>
<th>Total Fat (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagel</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oatmeal</td>
<td>2.7</td>
<td>X $2.50 = $6.75</td>
<td>X 4 = 10.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X 1 = 2.7</td>
</tr>
<tr>
<td>Eggs</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacon</td>
<td>0.9</td>
<td>X $4.00 = $3.60</td>
<td>X 8 = 7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X 8 = 7.2</td>
</tr>
<tr>
<td>Orange juice</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total meal</strong></td>
<td></td>
<td><strong>$10.35</strong></td>
<td><strong>18</strong></td>
</tr>
</tbody>
</table>

GOAL = Lowest cost  
Min 18 g protein  
Max 10 g fat

- Linear programming is a branch of applied mathematics concerned with problems of constrained optimization
- Started in 1947 and used by the US Air Force to optimize logistics
- Price and “quality” of each variable drive the optimum solution
• Linear programs are used to calculate relative refining values (quality differentials) for crude oils versus a benchmark, such as Brent or WTI
• Relative value for a crude is largely determined by its yields
• Wider discounts ($/bbl) are needed for medium and heavy sour crudes to break even with light sweets in a higher flat price environment than at lower flat prices
• Percentage discount required for medium and heavy sours to break even with light sweets stays about the same at low and high flat prices
### Crude Break Even Values

<table>
<thead>
<tr>
<th>Yields</th>
<th>“Reference Crude” Light Sweet$^{(1)}$</th>
<th>“Alternate Crude” Medium Sour</th>
<th>“Alternate Crude” Heavy Sour</th>
<th>Prices $99/bbl crude$^{(1)}$</th>
<th>Prices $51/bbl crude$^{(1)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery gases</td>
<td>3%</td>
<td>2%</td>
<td>1%</td>
<td>$49</td>
<td>$31</td>
</tr>
<tr>
<td>Gasoline$^{(2)}$</td>
<td>32%</td>
<td>24%</td>
<td>15%</td>
<td>$109</td>
<td>$60</td>
</tr>
<tr>
<td>Distillate$^{(3)}$</td>
<td>30%</td>
<td>26%</td>
<td>21%</td>
<td>$118</td>
<td>$69</td>
</tr>
<tr>
<td>Heavy fuel oil$^{(4)}$</td>
<td>35%</td>
<td>48%</td>
<td>63%</td>
<td>$80</td>
<td>$41</td>
</tr>
</tbody>
</table>

Note: Prices do not crossfoot due to rounding.

1. Reference crude
2. Gasoline crack: $9/bbl
3. Distillate crack: $18/bbl
4. Heavy fuel oil: 80% of reference crude value

#### Break Even Value (BEV) = Alternate Crude Total Product Value - Reference Crude Total Product Value

<table>
<thead>
<tr>
<th>Break Even Versus Light Sweet Crude</th>
<th>$99/bbl Crude</th>
<th>$51/bbl Crude</th>
<th>BEV as % of Crude Value @ $99/bbl</th>
<th>BEV as % of Crude Value @ $51/bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium sour</td>
<td>-$3.55</td>
<td>-$2.58</td>
<td>96%</td>
<td>95%</td>
</tr>
<tr>
<td>Heavy sour</td>
<td>-$7.76</td>
<td>-$5.65</td>
<td>92%</td>
<td>89%</td>
</tr>
</tbody>
</table>

BEV for alternate crude as a percentage of reference crude value is relatively insensitive to flat price environment.
Crude Oil Differentials Versus ICE Brent

Source: Argus; 2015 through Jan 30. LLS prices are roll adjusted
Q & A
Appendix
Major Refining Processes – Crude Processing

• Definition
  – Separating crude oil into different hydrocarbon groups
  – The most common means is through distillation

• Process
  – Desalting – Prior to distillation, crude oil is often desalted to remove corrosive salts as well as metals and other suspended solids.
  – Atmospheric distillation – Used to separate the desalted crude into specific hydrocarbon groups (straight run gasoline, naphtha, light gas oil, etc.) or fractions.
  – Vacuum distillation – Heavy crude residue ("bottoms") from the atmospheric column is further separated using a lower-pressure distillation process. Means to lower the boiling points of the fractions and permit separation at lower temperatures, without decomposition and excessive coke formation.
**Major Refining Processes – Cracking**

- **Definition**
  - “Cracking” or breaking down large, heavy hydrocarbon molecules into smaller hydrocarbon molecules through application of heat (thermal) or the use of catalysts.

- **Process**
  - **Coking** – Thermal non-catalytic cracking process that converts low value oils to higher value gasoline, gas oils and marketable coke. Residual fuel oil from vacuum distillation column is typical feedstock.
  - **Visbreaking** – Thermal non-catalytic process used to convert large hydrocarbon molecules in heavy feedstocks to lighter products such as fuel gas, gasoline, naphtha and gas oil. Produces sufficient middle distillates to reduce the viscosity of the heavy feed.
  - **Catalytic cracking** – A central process in refining where heavy gas oil range feeds are subjected to heat in the presence of catalyst and large molecules crack into smaller molecules in the gasoline and lighter boiling ranges.
  - **Catalytic hydrocracking** – Like cracking, used to produce blending stocks for gasoline and other fuels from heavy feedstocks. Introduction of hydrogen in addition to a catalyst allows the cracking reaction to proceed at lower temperatures than in catalytic cracking, although pressures are much higher.
• Definition
  – Linking two or more hydrocarbon molecules together to form a large molecule (e.g. converting gases to liquids) or rearranging to improve the quality of the molecule

• Process
  – Alkylation – Important process to upgrade light olefins to high-value gasoline components. Used to combine small molecules into large molecules to produce a higher octane product for blending into gasoline.
  – Catalytic reforming – The process whereby naphthas are changed chemically to increase their octane numbers. Octane numbers are measures of whether a gasoline will knock in an engine. The higher the octane number, the more resistance to pre or self-ignition.
  – Polymerization – Process that combines smaller molecules to produce high octane blendstock.
  – Isomerization – Process used to produce compounds with high octane for blending into the gasoline pool. Also used to produce isobutene, an important feedstock for alkylation.
Major Refining Processes – Treating

• Definition
  – Processing of petroleum products to remove some of the sulfur, nitrogen, heavy metals, and other impurities

• Process
  – **Catalytic hydrotreating, hydroprocessing, sulfur/metals removal** – Used to remove impurities (e.g. sulfur, nitrogen, oxygen and halides) from petroleum fractions. Hydrotreating further “upgrades” heavy feeds by converting olefins and diolefins to paraffins, which reduces gum formation in fuels. Hydroprocessing also cracks heavier products to lighter, more saleable products.
# List of Refining Acronyms

- AGO – Atmospheric Gas Oil
- ATB – Atmospheric Tower Bottoms
- B–B – Butane-Butylene Fraction
- BBLS – Barrels
- BPD – Barrels Per Day
- BTX – Benzene, Toluene, Xylene
- CARB – California Air Resource Board
- CCR – Continuous Catalytic Regenerator
- DAO – De–Asphalted Oil
- DCS – Distributed Control Systems
- DHT – Diesel Hydrotreater
- DSU – Desulfurization Unit
- EPA – Environmental Protection Agency
- ESP – Electrostatic Precipitator
- FCC – Fluid Catalytic Cracker
- GDU – Gasoline Desulfurization Unit
- GHT – Gasoline Hydrotreater
- GOHT – Gas Oil Hydrotreater
- GPM – Gallon Per Minute
- HAGO – Heavy Atmospheric Gas Oil
- HCU – Hydrocracker Unit
- HDS – Hydrodesulfurization
- HDT – Hydrotreating
- HGO – Heavy Gas Oil
- HOC – Heavy Oil Cracker (FCC)
- H2 – Hydrogen
- H2S – Hydrogen Sulfide
- HF – Hydroflouric (acid)
- HVGO – Heavy Vacuum Gas Oil
- kV – Kilovolt
- kVA – Kilovolt Amp
- LCO – Light Cycle Oil
- LGO – Light Gas Oil
- LPG – Liquefied Petroleum Gas
- LSD – Low Sulfur Diesel
- LSR – Light Straight Run (Gasoline)
- MON – Motor Octane Number
- MTBE – Methyl Tertiary–Butyl Ether
- MW – Megawatt
- NGL – Natural Gas Liquids
- NOX – Nitrogen Oxides
- P–P – Propane–Propylene
- PSI – Pounds per Square Inch
- RBOB – Reformulated Blendstock for Oxygenate Blending
- RDS – Resid Desulfurization
- RFG – Reformulated Gasoline
- RON – Research Octane Number
- RVP – Reid Vapor Pressure
- SMR – Steam Methane Reformer (Hydrogen Plant)
- SOX – Sulfur Oxides
- SRU – Sulfur Recovery Unit
- TAME – Tertiary Amyl Methyl Ether
- TAN – Total Acid Number
- ULSD – Ultra–low Sulfur Diesel
- VGO – Vacuum Gas Oil
- VOC – Volatile Organic Compound
- VPP – Voluntary Protection Program
- VTB – Vacuum Tower Bottoms
- WTI – West Texas Intermediate
- WWTP – Waste Water Treatment Plant
For more information, please contact:

John Locke  
Executive Director, Investor Relations  
210-345-3077  
john.locke@valero.com

Karen Ngo  
Manager, Investor Relations  
210-345-4574  
karen.ngo@valero.com