Fundamentals of the Petroleum Refining Industry

Presented by
Michelle Dunbar
Sr. Planning Engineer

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Agenda

Part 1
• Petroleum Industry Segments
• Refinery Feedstocks
• Refinery Products

Part 2
• Refining Processes
• Refineries

Part 3
• Refinery Profitability
• People
• Hydrocarbon production maps

If we are successful…you will:
• Gain insight into the basics of the refining process
• Understand how a refinery makes desired products out of crude oil
• Understand the factors that impact refinery profitability
• Get ANY question that you have answered
Petroleum Industry Segments

Could include marine activity as well
What a Refinery Does

- “Left Side” Barrel does not provide market what it needs
- A refinery maximizes the conversion of crude oil into desirable products (transportation fuels)
World Wide Refining

Largest Worldwide Refineries

<table>
<thead>
<tr>
<th>Name of Refinery</th>
<th>Location</th>
<th>Barrels per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jamnagar Refinery (Reliance Industries Limited)</td>
<td>Jamnagar, Gujarat, India</td>
<td>1,240,000[2]</td>
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<tr>
<td>Paraguana Refinery Complex (PDVSA)</td>
<td>Paraguana, Falcon, Venezuela</td>
<td>940,000</td>
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<tr>
<td>SK Energy Co., Ltd. Ulsan Refinery (SK Energy)</td>
<td>Ulsan, South Korea</td>
<td>850,000</td>
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<tr>
<td>GS Caltex Yeosu Refinery (GS Caltex)</td>
<td>Yeosu, South Korea</td>
<td>730,000</td>
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<tr>
<td>ExxonMobil</td>
<td>Singapore</td>
<td>605,000</td>
</tr>
<tr>
<td>Port Arthur Refinery (Motiva Enterprises)</td>
<td>Port Arthur, Texas, USA</td>
<td>600,000</td>
</tr>
<tr>
<td>Baytown Refinery (ExxonMobil)</td>
<td>Baytown, TX, USA</td>
<td>572,500</td>
</tr>
<tr>
<td>Ras Tanura Refinery (Saudi Aramco)</td>
<td>Saudi Arabia</td>
<td>550,000</td>
</tr>
<tr>
<td>S-Oil Ulsan Refinery (S-Oil)</td>
<td>Ulsan, South Korea</td>
<td>503,000</td>
</tr>
<tr>
<td>Marathon Petroleum Refinery (Marathon Petroleum)</td>
<td>Garyville, LA</td>
<td>490,000</td>
</tr>
</tbody>
</table>

Source: Oil & Gas Journal

Approximately 650 Refineries in the world.

HollyFrontier Refineries

<table>
<thead>
<tr>
<th>HFC Refinery</th>
<th>MBPD Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Dorado, KS</td>
<td>135</td>
</tr>
<tr>
<td>Tulsa, OK</td>
<td>125</td>
</tr>
<tr>
<td>Navajo (NM)</td>
<td>100</td>
</tr>
<tr>
<td>Cheyenne, WY</td>
<td>52</td>
</tr>
<tr>
<td>Woods Cross, UT</td>
<td>31</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>443</strong></td>
</tr>
</tbody>
</table>

Source: Oil & Gas Journal
US Refining Overview

- Number of U.S. Refineries has decreased, but throughput per refinery is higher
Crude Oil Origin and Properties

• Formed when dead sea organisms (plankton and algae) are buried under sedimentary rock and are exposed to intense heat and pressure

• Key Properties
  – API Gravity - Heavy or Light (% of large HC molecules vs. small)
  – Sulfur Content - Sour or Sweet (contains high sulfur or low)

• Other Properties
  – Pour Point deg F ( % straight chain / waxy vs. ring compounds)
  – Distillation Range - % fractions boiled off at specified temperatures
  – Carbon Residue – solids after distillation, asphalt content
  – TAN or Total Acid Number (corrosive acids present)
  – Contamination levels (sodium, metals, chlorides)
Crude Oil Cost

- High sulfur, heavy crude is lowest cost. Requires extremely complex refinery to convert into high value products.
- Low sulfur, light crude is highest cost. Simple refining yields high value products.
- Also a function of location of crude supply versus refining centers. Refiners close to crude production enjoy advantage over refineries distant from supply.
Refinery Crude Snapshot
Dec 2012 – Delivered to Tulsa Refinery

- **WTI** – West Texas Intermediate
  - API 40.8
  - 0.30% Sulfur
  - $88.25 / BBL

- **WTS** – West Texas Sour
  - API 32.1
  - 1.9 % Sulfur
  - $81.41 / BBL

- **WCS** – Western Canadian Select
  - API 20.3
  - 3.4 % Sulfur
  - $57.87 / BBL

These margins have a large impact on Refinery Crude Selection and can change drastically from month to month.
Hydrocarbon Chemistry

- The chemistry of crude oil is hydrocarbon chemistry

- Understanding the molecule types and their properties is key to understanding the refining process

- Although it can be very complex, we will focus on the essential basics!
What are Hydrocarbons?

- **Molecules** made of Hydrogen (H) and Carbon (C) atoms
  - Carbon atoms have four valence electrons that can participate in the formation of chemical bonds
  - Hydrogen has one electron that can participate
  - Think of each atom as having “hands” that attach to each other (Carbon has 4, Hydrogen has 1)

- Properties vary by the *number of C and H atoms* and *the way they hold hands!*

- As number of carbon atoms increases, the hydrocarbon molecule…
  - Gets bigger and “heavier”
  - Is more viscous
  - Has a higher boiling point
  - Becomes less volatile / less flammable

- HC molecules can contain other elements, such as Sulfur, Nitrogen, metals

![Boiling Temperature vs. # of Carbon Atoms](#)
Hydrocarbon Names

- Hydrocarbon prefix names are assigned by longest chain of Carbon atoms

<table>
<thead>
<tr>
<th>Carbons</th>
<th>Prefix</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Meth</td>
<td>Methane</td>
</tr>
<tr>
<td>2</td>
<td>Eth</td>
<td>Ethane, Ethylene</td>
</tr>
<tr>
<td>3</td>
<td>Prop</td>
<td>Propane, Propylene</td>
</tr>
<tr>
<td>4</td>
<td>But</td>
<td>Butane, isobutane</td>
</tr>
<tr>
<td>5</td>
<td>Pent</td>
<td>Pentane, cyclopentane</td>
</tr>
<tr>
<td>6</td>
<td>Hex</td>
<td>Hexane, cyclohexane</td>
</tr>
<tr>
<td>7</td>
<td>Hept</td>
<td>Normal hepatne</td>
</tr>
<tr>
<td>8</td>
<td>Oct</td>
<td>Octane, iso-octane</td>
</tr>
<tr>
<td>9</td>
<td>Non</td>
<td>Nonane</td>
</tr>
<tr>
<td>10</td>
<td>Dec</td>
<td>Decane</td>
</tr>
<tr>
<td>11</td>
<td>Undec</td>
<td>Undecane</td>
</tr>
<tr>
<td>12</td>
<td>Dodec</td>
<td>2,2,4 tri-methyl dodecane</td>
</tr>
<tr>
<td>13</td>
<td>Tridec</td>
<td>Tridecalene</td>
</tr>
<tr>
<td>14</td>
<td>Tetradec</td>
<td>Tetradecane</td>
</tr>
<tr>
<td>15</td>
<td>Pentadec</td>
<td>Pantadecane</td>
</tr>
</tbody>
</table>
Contaminants

- Non hydrocarbon atoms attached to the HC molecules (organic), in solution, or as solids
  - Sulfur
  - Nitrogen
  - Oxygen
  - Metals (iron, zinc, etc.)
  - Salts (Na, Mg, Ca)
  - Acids
  - Silt, Sediment

- These contaminants cause fouling of equipment, corrosion, catalyst poisoning, and unwanted emissions from produced fuels
- Non hydrocarbon molecules can also be contained in the HC mixture (inorganic or elemental)
- **The refinery has processes to remove these contaminants**
Refined Products

PRIMARY PRODUCTS
- Gasoline – automobile, light truck, small engine fuel
- Diesel – automobile, heavy trucks, trains, heavy equipment
- Jet Fuel – Commercial and military aircraft

SECONDARY PRODUCTS
- Kerosene – Home heating, charcoal fluid
- Liquified Petroleum Gas (LPG) – Chemical feed, heating, commercial applications
- Fuel Oil – Home Heating, Ships, boilers, furnaces (1 through 6 Oil)
- Asphalt – Roads, roofing material, sealants
- Carbon Black Oil – Carbon black manufacture, carbon composites, tires
- Lubricating Oil – Engine & machinery lubrication
- Waxes – Candles, industrial sealants
- Petroleum Coke – Coal fired boilers, metals manufacture (anodes, fuel)
- Sulfur – Chemical and fertilizer manufacture
- NaHS (sodium hydrosulfide) – paper, copper mining, leather industries (Holly emphasis)
Refinery Products
Boiling Points

- Boiling point largely determines the molecules destination
- Overlap in boiling ranges provides flexibility in production
Product Specifications

• Every refinery product has numerous specifications that must be met

• Specifications are determined by end user requirements, regulatory agencies, and pipeline / terminal operators

• Products are tested and certified by Refinery Laboratories prior to shipment

• Testing protocols are standardized for all products by ASTM (American Society for Testing and Materials)
Gasoline Specifications

- **Volutility (Vapor Pressure, Distillation)**
  - Easy start in cold weather, yet no vapor lock in warm weather, minimize evaporative emissions
  - Higher boiling fractions do not burn as completely (ex. 380 F 90% point)

- **Combustion characteristics (octane rating)**
  - Deliver adequate power without engine knocking

- **Stability and Corrosiveness (copper strip corrosion, gum formation)**
  - Does not form harmful engine deposits, cause excessive wear, or contaminate or corrode the fuel system

- **Automobile emissions reduction (Oxygenates, Sulfur, Benzene)**
  - Oxygenates reduce some emissions
  - Sulfur limited to reduce SO2 (<30 ppm)
  - Benzene is known carcinogen, limit to 0.63% by volume
What is Octane Rating?

- A number that indicates the tendency for a gasoline to pre-ignite and cause engine “knocking”

- All engines have an optimum octane rating for efficient and safe operation (ideal firing, no engine damage)

- Octane rating requirement is mainly a function of compression ratio in the cylinders (10:1 typical for commuter cars, higher for high performance sports cars)

- Higher altitude allows lower octane gasoline (lower atmospheric pressure results in less absolute cylinder pressure upon compression)

- Determined on a test engine in the lab at the refineries
  - Research Octane (typical mild driving, low engine load)
  - Motor Octane (severe, sustained high speed, high load driving)
  - Use reference fuels (normal heptane = 0, iso-octane = 100)

- The Octane number is equal to the percent of iso-octane (100) in the iso-octane / normal heptane (0) blend that “knocks” at the same compression ratio as the gasoline or component being measured

- Research and Motor Octane averaged to give Anti-Knock Index seen on gas pumps
  \[
  \frac{R+M}{2} = \text{Road Octane or AKI}
  \]
Diesel Specifications

• Volatility (Distillation, Flash Point) control smoke and combustion deposits, safe handling
  – Start in cold weather, no vapor lock in warm weather
  – Higher boiling fractions do not burn as completely (ex. 640 F 90% point)
• Combustion characteristics (API Gravity, Cetane Rating, Viscosity)
  – Deliver adequate power, fuel atomizes at injector
  – Smooth starting, operation, and little exhaust smoke
• Contaminants (copper strip corrosion, ash, carbon residue)
  – Fuel injector performance, corrosion, fouling
• Lubricity
  – Fuel injection equipment lubricated by fuel
• Cold temperature operation (cloud point)
  – Wax formation, filter plugging at low temperatures
• Emissions reduction (Sulfur)
  – Sulfur limited to reduce SO2 (15 ppm by weight max)
What is Cetane Rating?

- An indicator of the time period between the start of injection and start of combustion. The higher the cetane, the quicker the fuel burns. n-cetane (C\textsubscript{16}H\textsubscript{34}) molecule ignites quickly, assigned cetane number of 100. Alpha-methyl naphthalene is the 0 cetane reference fuel.

- Cetane Number can be determined on a test engine with reference fuels similar to knock engine for gasoline with reference fuels, but is not normally done. Increase compression ratio until time between injection and ignition = 2.4 ms.

- Calculated Cetane Index (CI) is a substitute for Cetane Number, and is based on density and distillation properties of the fuel
  \[
  \text{C.I.} = -420.34 + 0.016 (\text{API Gravity})^2 + 0.192 (\text{API Gravity})(\log \text{ of 50\% point in degrees}) + 65.01 (\log \text{ of 50\% point in degrees})^2 - 0.0001809 (\log \text{ of 50\% point in degrees})^2
  \]

- Typical rating 42-45 in the U.S.

- Low cetane fuel leads to poor combustion, power loss and high emissions

- Higher cetane fuel provides easier starting, lower temperature starting and smoother operation

- Cetane Improver (combustion promoter) can be used, but cetane number improvement must be proven on engine
Jet Fuel Specifications

• Combustion Characteristics: Energy content, smoke / particulate formation, aromatic and naphthalene content, distillation properties

• Stability: storage stability (oxidation), thermal stability (gum) JFTOT (jet fuel thermal oxidation test)

• Lubricity: Jet Fuel provides lubrication for some injection system moving parts

• Fluidity: Ability to pump through system, freeze point, viscosity

• Volatility: Tendency to vaporize for ignition (flash point), tendency to vaporize in fuel system / vapor lock

• Corrosivity – organic acids (total acidity) and mercaptan sulfur (sulfur containing hydrocarbons) content

• Water Separability – Ability for water to drop out of fuel (WISM test)

• Electrical Conductivity – to avoid static discharge ignition

Jet Fuel has to burn in the engine completely, flow at low temperatures, and create no harm to the engine components.
Asphalt Properties

- Made from Asphaltenic Crude Vacuum Bottoms or PDA Pitch
- Two main Properties
  - **Softening Point**: lowest temperature at which standardized weight and shape will sink into asphalt (80 – 340 F)
  - **Hardness**: Depth to which a test needle penetrated into asphalt over time at specified temperature (0 Pen, 30-40 mm Pen, 250-3000mm Pen)
- Asphalt Products
  - **Straight Run**: straight off vacuum unit or PDA, used for paving
  - **Cut Back**: Use diluents to lower the flow temperature, diluent evaporates after paving
    - RC – Rapid Cure – naphtha diluent
    - MC – Medium Cure – Kerosene Diluent
    - SC – Slow Cure – Gas Oil Diluent
  - **Emulsion Asphalt**: Alternative to cutback, 30-50% water plus emulsifying chemical (like a soap)
  - **Industrial or Blown Asphalt**: Roofing, waterproofing material, harder than other asphalts. Made by blowing air through hot asphalt, causing asphaltenes to combine.
Refinery Processes

- **Distillation / Fractionation** – Heating liquid to mostly vapor, then condensing the vapor into different fractions to produce desired boiling range mixture (fraction or cut)

- **Conversion (Cracking and Reforming)** – Using catalysts and / or heat, convert molecules into different sizes and configurations to achieve desired properties

- **Treating (Hydrotreating, Chemical Treating)** – Using catalysts and chemicals, remove impurities from the hydrocarbons

- **Combining** – Using catalysts and chemicals, combine molecules to form others

- **Blending** – Blend various fractions together to obtain desired finished product properties
Fractional Distillation Column

Replaced batch distillation
~1920s
Atmospheric Crude Distillation Unit

**Purpose**
- Distills crude oil into fractions for further processing
- First step in the refining process

- Molecules separated by boiling ranges, but not chemically altered
- Salts in crude either occur as salts dissolved in water or solids suspended in oil

Crude Oil contacted with 3-10% water at 230-260°F to remove salts and sediment (fine sand, clay, soil) to minimize corrosion and fouling

Desalted crude heated to ~650 - 680 deg F in feed furnace, limited by thermal cracking of light material ~700°F

Low pressure (~25 psig)
Vacuum Distillation Unit

Purpose

• Recover gas oil streams from atmospheric residuals
• Vacuum conditions lower the boiling point of gas oils so that they vaporize at lower temperatures

• Mild vacuum 1-2 psia
• Vacuum is used so separation occurs at lower temperature
• Vacuum tower metallurgy important – sulfur and naphthenic acid corrosion
• Limited to <750, thermal cracking of heavy ends at ~800F
Crude & Vacuum Distillation
Fluid Catalytic Cracker (FCC)

Purpose
- Convert gas oils into lighter products – primarily gasoline
- Largest gasoline producer in refinery

- Circulating catalyst like fine powder
- 4:1 to 6:1 wt. % ratio of catalyst circulation to feed is typical
- Cracking of heavy hydrocarbons forms coke on catalyst, burned off in regenerator
- 975-1050 F, low pressure reaction, most of the heat required produced from coke burn on catalyst
- Significant volume gain feed vs. liquid products ~5%
- Riser Residence Time is ~1-2 seconds, to keep catalyst / oil contact time low
- Catalyst degrades over time due to metals, sulfur. Fresh catalyst added to maintain activity
FCC Unit

FCC Catalyst

FCC Regenerator cyclones

FCC Reactor / Regenerator Structure
Hydrotreater

Purpose

- Remove sulfur (and nitrogen if required) from molecules in process unit feed with minimal cracking of hydrocarbons
- Sulfur, nitrogen are catalyst poison for reforming, isomerization, hydrocracking

- Uses fixed bed cobalt / nickel / molybdenum oxide catalyst
- High temperature (600-750 deg F), medium pressure (300-600 psig) process
- Hydrogen combines with sulfur and nitrogen removed from Hydrocarbon to form H2S and NH3
- Many applications: Reformer feed, kerosene, diesel, FCC Feed, FCC Gasoline, 1st stage hydrocracker
- Also saturates aromatic (benzene ring containing) compounds. Good for diesel fuel cetane number and jet, bad for gasoline (reduces octane number)
Hydrotreating Reactions

- Cobalt / Molybdenum oxide catalyst (Co-Mo) removes Sulfur and form H2S
- Nickel (Ni) added to the catalyst to remove Nitrogen and form NH3
- H2 at high pressure minimizes coke formation. Ties up free carbon bond when S or N removed, or if cracking of C-C bond occurs
Hydrotreater Unit

Artesia Gas Oil Hydrotreater

Reactor

Catalyst
Hydrocracker

**Purpose**
- Catalytic Cracking in the presence of hydrogen
- Convert heavy material into lighter product
- Can crack molecules that FCC cannot
- Makes iso-butane for alkylation process

- Uses fixed bed nickel / molybdenum catalyst, hydrogen prevents coke formation with cracking reaction

- 1st stage reactor primarily hydrotreating, 2nd stage reactor hydrocracking

- High temperature (600-800 degF), high pressure (1,500 – 3,000 psig) process

- Unlike FCC, no olefins produced (H2 rich cracking environment)

- 10% gain in volume typical
Hydrocracking Reactions

- Catalytic Cracking & Hydrogenation Superimposed
- Cracking provides olefins for hydrogenation, hydrogenation provides heat for cracking
- Sum of reactions exothermic, can “runaway” if not controlled (H2 quench in Reactor)

Partial Saturation

4H₂

Ethylbenzene

H₁₃C₆ —— H₂ —— H₁₃C₆

H₂C

Ethylcyclohexane

H₂C

Isohexane

H ——— C ——— C₃H₇

CH₃

CH₃

Side Chain Hydrocracking and Isomerization

Ring Separation and Opening
Hydrocracker

- Fractionator
- Charge Furnace
- Reactors
- Heat Exchangers
- Catalyst
Delayed Coker

Purpose
- Convert heavy residuum into gas oil feed for FCC / Hydrocracker and light products
- Allows refiners to economically process heavy crude

- Thermal cracking process (no catalyst) at 950 deg F, low pressure (time and temperature)
- Cracks heavy feeds not suitable for FCC or Hydrocracker
- Coke Drums are batch operation where feed switches between drums every 18-24 hours
- Drum fills with coke and is drilled out with high pressure water
Coke Drum Operation

Types of Coke
- Green (used for fuel). Has residual HC, perhaps high metals, Sulfur
- Anode (used for aluminum manufacture), “calcined” at 2500 F to remove HC
- Needle (crystalline) used as anodes in electric arc furnaces
 Delayed Coker

- Most US Coke is exported
  - Fuel for Power Generation
  - Smelting industry (Aluminum and Steel)
  - Fuel for Cement Making
Solvent De-asphaltalting

Purpose
- Maximize recovery of Gas Oil from Residual streams after atmospheric or vacuum distillation (up to 2/3 of feed to gas oil)
- Extract paraffinic / naphthenic DAO from asphaltenic pitch
- A method to separate molecules of different configurations that are in the same boiling range

- Light paraffinic solvent (butane or propane) extracts paraffinic rich gas oil DAO
- DAO and pitch separated form solvent by heating
Solvent Deasphalter Chemistry

- Paraffinic solvent has “affinity” for heavy paraffinic molecules (Gas Oil) and effectively “attach” to them
- Paraffinic molecules effectively become lighter and rise in the solution (DAO)
- Asphaltenic molecules drop in the solution solution (Pitch)
Solvent Deasphalter

ROSE (Residuum Oil Supercritical Extraction)
Naphtha Reforming – Fixed Bed

**Purpose**
- Convert low octane (55-65) naphtha into high octane (90 -100+) gasoline component
- Straight chain C7-C8 and unsaturated rings converted to aromatic compounds and isomers
- Increased popularity in 1970s to produce unleaded gasoline with tetraethyl lead phase out
- Creates Benzene, mainly from any cyclohexane and normal hexane in feeds (precursors)

- Multiple reactors due to endothermic reaction (temperature drop)
- Precious metal catalyst (platinum / rhenium) on inert base
- 100 psig, 975 F in H2 rich atmosphere
- Produces H2 for refinery hydrotreaters
- Volume loss and cracking
- Must shutdown unit and regenerate catalyst every 6-18 months (heat and burn)
- Recycle hydrogen minimizes carbon on catalyst with cracking reactions
Continuous Catalytic Reforming - CCR

**Purpose**
- Convert low octane / value naphtha into high octane gasoline component (C7-C8) range
- Same reactions as Semi Regen Unit
- Introduced in 1980s, advantages over semi regeneration unit
- Creates Benzene, mainly from any cyclohexane and normal hexane in feeds (precursors)

- Precious metal catalyst (platinum / rhenium) on inert base
- 50 psig in H2 rich atmosphere
- Continuously regenerate catalyst and add fresh on line
- Advantages over semi – regen
  - Higher reformate yield and octane
  - Higher H2 yield
  - Lower operating costs
  - Increased run length

Volume loss significant at higher octane
- Catalyst flows by gravity through reactors and is regenerated, sent back to top reactor with N2 and H2
Types of Reforming Reactions

- **Methylcyclohexane**
  - Octane = 83
  - **Dehydrogenation**
  - **Toluene (111)** + **Hydrogen**

- **N-Heptane**
  - Octane = 0
  - **Aromatization**
  - **Toluene (111)** + **Hydrogen**

- **N-Octane**
  - Octane = -10
  - **Isomerization**
  - **2,5 Dimethylhexane (95)**

- **N-Heptane**
  - Octane = 0
  - + **Hydrogen**
  - **Cracking**
  - **Isopentane (93)** + **methane**
Naphtha Reformer (CCR)

Catalyst – Spherical shape to facilitate flow in CCR unit

Reactor & Catalyst
Regen Structure

Furnace
**HF Acid Alkylation Unit**

**Purpose**
- Combines FCC olefinic material with isobutane to form high octane (up to 95) blending component
- Uses HF acid catalyst, ~ 0.3 lbs / BBL of Alkylate produced
- Operating Temperature ~70 F
- Best when processing combined C3/C4 olefin feed (vs. Sulfuric)
Sulfuric Acid Alkylation Unit

Purpose
- Combines FCC olefin material with iso-butane to form high octane blending component
- Operating Temperature ~40-50 F and 10 psig, maintained by LPG auto-refrigeration
- Two designs, auto-refrigeration (Kellog, shown) and effluent refrigeration (Stratco)
- Best with C4 olefin only feed
About 11% of the gasoline pool in the US is Alkylate. 60% of that Alkylate is produced in HF Units. During the last decade 9 of the 10 new alkylation units commissioned were Sulfuric Acid units – due to safety choices.
Gasoline is a blend of many components
- Lower RVP in summer to minimize evaporative emissions
- Reformate is octane “knob”, can be adjusted easily
- Additives at terminal make branded gasolines “different”
- Ethanol blended at terminal, not in refinery or pipeline – affinity for water
Gasoline Blending

- Gasoline Blend “recipes” are developed using computer optimization model
- Balances all factors to meet product demand and specifications in the most cost effective way

**Component Considerations**
- Inventory
- Future Shipments
- Component Properties
- Refinery Production

**Blend Recipe**
- RVP
- Octane
- Sulfur
- Benzene
- Volume
- Distillation

**Shipment Considerations**
Gasoline Blending

Product Terminal / Blender

Truck Loading Rack
Auxiliary Processes & Utilities

- Steam Methane Reformer (hydrogen production)
- Light Ends Recovery Units
- Lube Oil Units
- Amine Treater
- Caustic and Merox Treaters
- Sulfur Recovery, Tail Gas Treating, NaHS Units
- Sour Water Strippers
- Water Treating (de-ionization)
- Steam Production
- Waste Water Processing
- Relief Systems and Flares
- Plant and Instrument Air
- Flare Gas Recovery Units
- MSAT Benzene Reduction Units (similar to ISOM unit)
- Nitrogen Systems
- Electrical Systems
Sulfur Recovery

Purpose
- Converts H2S gas into elemental sulfur, “Claus” Unit

1/3 of H2S burned in Reaction Furnace to produce SO2 (sulfur dioxide)  \( \frac{1}{3} \text{H}_2\text{S} + \text{O}_2 \rightarrow \text{SO}_2 + \text{H}_2\text{O} \)
- Zinc Oxide catalyst beds convert SO2 and H2S into elemental sulfur and water  \( \text{SO}_2 + 2\text{H}_2\text{S} \rightarrow 3\text{S} + 2\text{H}_2\text{O} \)
- Sulfur is collected in pit or tank and trucked / railed. Used in chemical manufacture.
- Process is about 96% efficient, so Tail Gas Treating (SCOT Unit or other) required to purify off gas
Sulfur Recovery

Sulfur Recovery Reaction Furnace

Empty Sulfur Pit with heating coils

Truck

Rail

MOLLEN SULFUR

DOT 111A100W1
RUPTURE DISC 165 PSI
TANK 100 PSI
TESTED 2000 UTCI DUE 2010
LC-34H
APPLIED 7-00
BY UTCI
Steam Production

Purpose
• Provide steam for process heating, steam stripping in distillation, and steam turbine drivers

- Multiple Boilers at various steam pressure levels
- Certain Process Units are net producers of steam from waste heat
Steam Production

Fired Steam Boiler

Boiler Tubes

Mud Drum

Steam Drum
Waste Water Treatment

Purpose

• Remove Oil, Grease and other contaminants from Refinery Waste Water to meet discharge permit requirements

Many processes combined to meet specific refinery waste characteristics and discharge requirements

• Oil removal and biological treatment are 1st steps
• Can be re-used, injected underground or sent to waterway

A refinery typically uses more water than crude oil!
Waste Water Treatment

API Separator

Direct Air Flotation Unit

Activated Sludge Treatment

1. Trash trap (inclined rods)
2. Oil retention baffles
3. Flow distributors (vertical rods)
4. Oil layer
5. Slotted pipe skimmer
6. Adjustable overflow weir
7. Sludge sump
8. Chain and flight scraper
Waste Water Treatment

Aeration Basin (Sludge Treatment)

API Separator

Carbon Filters

DAF Unit
Tulsa Refinery

- 125,000 BPD capacity
- West Refinery primarily lubes, sweet crude
- East Refinery fuels, light and limited heavy crude
- Interconnecting Pipelines Integrate Operations East and West Refineries

Crude
- 3 Sunoco Pipelines 85KBPD
  - Barnsdall OK
  - Little Farm OK
  - Bad Creek OK
- Magellan Cimmaron 40KBPD
  (Cushing OK)

Products
- St. Louis / Chicago
- Kansas City, Northern US
- El Dorado, KS
- Local Rack
Refinery Profit Drivers

Refinery Profitability

Raw Material & Input Costs
- Crude Oil Balance
- Intermediate Feed availability
- Natural Gas / Electricity costs

Refinery Configuration
- Complexity
- Crude flexibility
- Highest value products
- Liquid Volume Gain and Yield
- Unit limitations

Reliability & Efficiency
- Size
- Uptime & Capacity Utilization
- Turnaround frequency and duration
- Operating Expenses
- Capital Investment

Product Value
- Product Balance
- Location
- Competition
- Inventory Value / Risk
- Seasonal factors

Refinery profitability is an extremely complex, multi-variable problem
Gross and Net Profit Margins

Net Profit Margin = Product Value – Feedstock Cost – Operating Expenses

More complex refineries can process lower cost, heavier crude oil into higher value products, but operating costs are higher.
“Crack Spread”

• Shorthand method to estimate refinery gross margin (product value minus crude oil cost in proportion to product production vs. crude)
• Stated in $$ / BBL
• Common Refinery Crack Spreads ($$ / BBL)
  ➢ 3-2-1…. (2 x Gasoline + 1 x Diesel - 3 x Crude) / 3
    • 3 BBLs of Crude makes 2 BBLs gasoline, 1 BBL Diesel
  ➢ 5-3-2…. (3 x Gasoline + 2 x Diesel – 5 x Crude) / 3
    • 5 BBLs of Crude makes 3 BBLS gasoline, 2 BBLs Diesel
Maximizing Profitability

• Linear Program (LP) - Computer simulation tool that helps to optimize refinery operation
• Inputs include:
  – Crude oil properties, prices
  – Product prices and logistical limits
  – Unit conversion capabilities and limitations
  – Shutdown periods and abnormal operations
  – Variable operating costs (costs that vary with charge rate)
• Defines what each incremental barrel of crude charge and unit charge is worth
• Various cases are simulated to determine highest profitability operating mode
  – Crude charge rates and types
  – Unit rates, reaction severities, product specification targets
  – Production targets (i.e. maximum diesel over gasoline, etc.)
# The Refinery Organization

## Operations
- Monitor unit operation against targets and adjust
- Initiate maintenance activity on equipment
- Ready equipment and provide safe work permitting for maintenance activity
- Respond to abnormal situations, emergency response

## Maintenance
- Inspect, troubleshoot and repair broken equipment
- Preventive maintenance and upkeep of equipment
- Improve the reliability of equipment, implement plant changes / upgrades
- Manage major maintenance turnarounds

## Technical
- Monitor all aspects of facility performance
- Provide technical oversight for all operations and maintenance activity
- Establish unit operating plans
- Assure legal compliance
- Design new facilities and changes
- Safety, Health and Environmental Assurance

## Administrative
- Manage all aspects of the business
- Procure parts, materials, chemicals / catalysts, supplies
- Warehouse Management
- Cost accounting
- Clerical, compliance reporting and record keeping
People in the Refinery

Operations
- Control Board Operators
- Outside Operators
- Operating Specialists (Day Support)
- Contractors (coke cutting, 3rd party facility operators)
- Trainers

Maintenance
- Pipefitters / Boilermakers
- Instrumentation & Electrical
- Rotating Equipment
- Equipment Operators
- Scaffold, Insulators, Carpenters
- Contract Services
- Turnaround contractors
- Maintenance Planners

Technical
- Chemical, Mechanical, Electrical, Control Engineers
- Safety, Health, Environmental Engineers / Specialists
- Equipment Inspectors
- Laboratory Technicians, Chemists
- Project Engineers, Designers
- Technical Trainers
- Outside consultants, technical experts

Administrative
- Management
- Purchasing agents
- Warehouse workers
- Accountants
- Office assistants
US Field Crude Production vs. Oklahoma Production (thousand barrels per day)

- U.S. Field Production of Crude Oil (Thousand Barrels per Day)
- Oklahoma Field Production of Crude Oil (Thousand Barrels per Day)
Regular Gasoline (July 2012)
Retail Price: $3.44/gallon

- Taxes: 12%
- Distribution & Marketing: 8%
- Refining: 15%
- Crude Oil: 65%

Diesel (July 2012)
Retail Price: $3.72/gallon

- Taxes: 13%
- Distribution & Marketing: 12%
- Refining: 15%
- Crude Oil: 60%