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1. Crude Oil Overview
2. Refining Basics
3. Refinery Optimization and Economics
Crude Oil Characteristics

- 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 and require greater investment to process significant volumes

Light, sweet, low TAN crudes are easier to process and trade at premiums relative to heavier, sour, high TAN crudes
Majority of global crude oil reserves are sour
Most quoted benchmarks are light sweet crude oils (WTI and Brent)
What is in a Barrel of Crude Oil?

<table>
<thead>
<tr>
<th>Crude Oil Types</th>
<th>Characteristics</th>
<th>Inherent Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light Sweet</strong></td>
<td>• &gt; 34 API Gravity</td>
<td>3%</td>
</tr>
<tr>
<td>(WTI, LLS, Brent)</td>
<td>• &lt; 0.5 % Sulfur</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>• Most Expensive</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35%</td>
</tr>
<tr>
<td><strong>Medium Sour</strong></td>
<td>• 24 to 34 API Gravity</td>
<td>2%</td>
</tr>
<tr>
<td>(Mars, Arab Medium)</td>
<td>• &gt; 0.7 % Sulfur</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>• Less Expensive</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48%</td>
</tr>
<tr>
<td><strong>Heavy Sour</strong></td>
<td>• &lt; 24 API Gravity</td>
<td>1%</td>
</tr>
<tr>
<td>(Maya, WCS)</td>
<td>• &gt; 0.7 % Sulfur</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>• Least Expensive</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>63%</td>
</tr>
</tbody>
</table>

2019 U.S. Refinery Production

- **7%** Fuel Gas
- **45%** Gasoline
- **38%** Distillate
- **10%** VGO


Refineries upgrade crude oil into higher value gasoline and distillate products.
Basic Refining Concept

Crude Distillation Unit (Atmospheric)

Intermediates:
- Light Ends Recovery & Treatment
- Isomerization / Blending
- Reformer / Blending
- Hydrotreater
- Hydrotreater / Hydrocracker
- FCC / Hydrocracker
- Coker / Resid Hydrocracker

Final Products:
- Fuel Gas
- Propane
- NGLs
- Gasoline
- Gasoline Petrochemicals
- Kerosene
- Jet fuel
- Diesel
- Gasoline
- Diesel
- Gasoline Coke

Crude Oil
\[\text{Vacuum Distillation Unit}\]
\[\text{Furnace}\]
\[\text{Distillation Tower}\]
\[\text{Basic Refining Concept}\]
\[\text{FCC} / \text{Hydrocracker}\]
\[\text{Coker} / \text{Resid Hydrocracker}\]
\[\text{Heavy Gas Oil}\]
\[\text{Heavy Naphtha}\]
\[\text{Light Naphtha}\]
\[\text{Natural Gas Propane Butane}\]
\[\text{C1 - C4}\]
\[\text{C5 - C8}\]
\[\text{C8 - C12}\]
\[\text{C12 - C30}\]
\[\text{C30 - C50+}\]
\[\text{Residual Fuel Oil / Asphalt}\]
\[\text{Gasoline}\]
\[\text{Diesel}\]
\[\text{Furnace}\]
\[\text{Crude Oil}\]
Low Complexity: Hydroskimming (Topping)

Light, Sweet Crude

Distillation Tower

- LPG
- Naphtha
- Kerosene
- Diesel

Vacuum Distillation Unit

- Vacuum Gasoil
- Resid

Reformer

- Gasoline
- Hydrogen

Distillate Hydrotreater

- ULSK / Jet Fuel
- ULSD

Vacuum Distillation Unit

- VGO
- Fuel Oil
- Asphalt & Other

Gasoline
- RBOB
- CBOB
- Conventional
- CARB Premium

Distillate
- ULSK
- Jet Fuel
- ULSD
- Heating Oil

Fuel Gas
- Propane
- Butane

Low complexity refineries run sweet crude
Medium Complexity: Catalytic Cracking

Moderate complexity refineries tend to run more sour crudes, yield more high value products and achieve higher volume gain.
Fluid Catalytic Cracker (FCC)

Fluid Catalytic Cracker Yields

- Reactor
- Regenerator
- Fractionator
- Gasoil
- Spent Catalyst
- Regenerated Catalyst
- Air
- Refinery Gases
- Butylene
- Gasoline
- Light Cycle Oil
- Slurry

Québec FCC unit.

Total FCC liquid volume yield is approximately 110% of throughput.

Converts low value gasoils into higher value light products.
High complexity refineries can run heavier, more sour crudes while achieving the highest light product yields and volume gain.

Diagram showing the flow of hydrocarbons through various units such as Hydrogen Plant, Reformer, Distillate Hydrotreater, Hydrocracker (HCU), Fluid Catalytic Cracker (FCC), Delayed Coker, and Vacuum Distillation Unit.
Hydrocracker (HCU)

- Upgrades high sulfur gasoil into low sulfur gasoline, jet and diesel
- Increases volumetric yield of products through hydrogen saturation

Total Hydrocracker liquid volume yield is approximately 110% to 115% of throughput.
Delayed Coker

Coker Yields

Fuel Oil (Resid)

Furnace

Coke Drum

Coke Drum

Fractionator

Total Coker unit liquid volume yield is approximately 80% of throughput.

Upgrades low value residual fuel into higher value light products
Greg Bram
VP Supply Chain Optimization
Maximizing Refinery Profit

Feedstocks (100+)

- Prices
- Qualities
- Availability (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 slate, products, unit operating rates, and operating parameters that delivers highest profit
Linear Program (LP) Example: What’s for Breakfast?

<table>
<thead>
<tr>
<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>
</tr>
<tr>
<td>Oatmeal</td>
<td>1 cup</td>
<td>$2.50</td>
<td>4</td>
</tr>
<tr>
<td>Eggs</td>
<td>2 large eggs</td>
<td>$3.50</td>
<td>6</td>
</tr>
<tr>
<td>Bacon</td>
<td>3 slices</td>
<td>$4.00</td>
<td>8</td>
</tr>
<tr>
<td>Orange juice</td>
<td>1 cup</td>
<td>$2.50</td>
<td>2</td>
</tr>
</tbody>
</table>

Nutritional Information

Your goal is to consume at least 18 grams of protein, but not more than 10 grams of total fat for the lowest price.
### Solve for number of servings of each item:

#### Consume at least 18 grams of protein

- Bagel Servings × 3 g
- Oatmeal Servings × 4 g
- Eggs Servings × 6 g
- Bacon Servings × 8 g
- Juice Servings × 2 g

\[ \geq 18 \text{ grams protein} \]

#### Consume no more than 10 grams of total fat

- Bagel Servings × 1 g
- Oatmeal Servings × 1 g
- Eggs Servings × 5 g
- Bacon Servings × 8 g
- Juice Servings × 0 g

\[ \leq 10 \text{ grams total fat} \]

#### Minimize the cost of breakfast

- Bagel Servings × $2.00
- Oatmeal Servings × $2.50
- Eggs Servings × $3.50
- Bacon Servings × $4.00
- Juice Servings × $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></th>
<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>
<td></td>
</tr>
<tr>
<td>Oatmeal</td>
<td>2.7</td>
<td>X $2.50 = $6.75</td>
<td>X 4 = 10.8</td>
<td>X 1 = 2.7</td>
</tr>
<tr>
<td>Eggs</td>
<td>0</td>
<td></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>
<td>X 8 = 7.2</td>
</tr>
<tr>
<td>Orange juice</td>
<td>0</td>
<td></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>
<td><strong>10</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 ($/barrel) are needed for medium and heavy sour crudes to break even with light sweets.

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>Products</th>
<th>Light Sweet(^{(1)})</th>
<th>Medium Sour(^{(2)})</th>
<th>Heavy Sour(^{(2)})</th>
<th>Light Sweet @ $99/bbl Prices</th>
<th>Light Sweet @ $51/bbl Prices</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(^{(3)})</td>
<td>32%</td>
<td>24%</td>
<td>15%</td>
<td>$108</td>
<td>$60</td>
</tr>
<tr>
<td>Distillate(^{(4)})</td>
<td>30%</td>
<td>26%</td>
<td>21%</td>
<td>$117</td>
<td>$69</td>
</tr>
<tr>
<td>Heavy fuel oil(^{(5)})</td>
<td>35%</td>
<td>48%</td>
<td>63%</td>
<td>$79</td>
<td>$41</td>
</tr>
</tbody>
</table>

\(^{(1)}\) Reference crude  
\(^{(2)}\) Alternate crudes  
\(^{(3)}\) Gasoline crack: $9/bbl  
\(^{(4)}\) Distillate crack: $18/bbl  
\(^{(5)}\) 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>Crude</th>
<th>Light Sweet @ $99/bbl BEV</th>
<th>Light Sweet @ $51/bbl BEV</th>
<th>BEV @ $99/bbl % of Light Sweet</th>
<th>BEV @ $51/bbl % of Light Sweet</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; 2019 prices through November 2019. All prices are spot values. ASCI represents Argus Sour Crude Index.
Questions and Answers
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</tbody>
</table>
Hundreds of Crude Types Around the World

- Al Shaheen
- Alaska North Slope (ANS)
- Alba
- Algerian Condensate
- Amna
- Anasuria
- Arab Extra Light
- Arab Heavy
- Arab Light
- Arab Medium
- Arab Super Light
- Ardjuna
- Arun Condensate
- Asgard
- Attaka
- Azeri Light
- Bach Ho
- Bachesuero
- Bakken
- Cold Lake
- Cossack
- Cusiana
- Daqing
- Dino
- Doba Blend
- Draugen
- Dubai
- Dulang
- Eagle Ford
- Ekofisk
- Es Sider
- Escalante
- Escravos
- Flotta
- Foinaven
- Forcados
- Foroosan Blend
- Forties
- Fulmar
- Basrah Light
- BCF 17
- Belayim Blend
- Belida
- Beryl
- Bintulu Condensate
- Bonny Light
- Boscan
- Bow River
- Brass River
- Brega
- Brent Blend
- Brunei Light
- Cabinda
- Canadon Seco
- Cano Limon
- Captain
- Ceiba
- Cerro Negro
- Champion
- Cinta
- Furrial
- Gippsland
- Girassol
- Glitne
- Gryphon
- Gulflaks
- Handil Mix
- Hangze
- Harding
- Heavy Louisiana Sweet (HLS)
- Heidrun
- Hibernia
- Iran Heavy
- Iran Light
- Isthmus
- Jasmine
- Jotun
- Khafji
- Kirkuk
- Kittiwake
- Kole
- Kuito
- Kutubu Blend
- Kuwait
- Labuan
- Laminaria
- Lavan Blend
- Light Louisiana Sweet (LLS)
- Liverpool Bay
- Mandji
- Maureen
- Marib Light
- Marlim
- Mars Blend
- Masila
- Maya
- Medanito
- Minas
- Miri
- Mixed Blend Sweet
- Murban
- Rabi
- Rincon
- Saharan Blend
- Sarir
- Schiehallion
- Senipah
- Seria Light Export
- Shengzli
- Siberian Light
- Siri
- Sirri
- Sirtica
- Slepner Condensate
- Snorre
- Sokol
- Souedieh
- Statfjord
- Suez Blend
- Syncrude Sweet Blend
- Syrian Light
- N'kossa
- Nanhai Light
- Napo
- Nemba
- NFC II
- Nile Blend
- Njord
- Norne
- NW Shelf Condensate
- Olmeca
- Oman
- Oriente
- Oseberg
- Oso Condensate
- Palanca Blend
- Panyu
- Pennington
- Pierce
- Qatar Marine
- Qua Iboe
- Tapis
- Tengiz
- Terra Nova
- Tia Juana Light
- Triton
- Troll
- Turkmen Blend
- Umm Shaif
- Upper Zakum
- Urals
- Varg
- Vasaconia
- Wafra
- West Texas Intermediate (WTI)
- West Texas Sour (WTS)
- Widuri
- Xikomba
- Yoho
- Zafiro
- Zakum
- Zarzaitine
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**
  – 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.
Major Refining Processes – Combination

• **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 and hydroprocessing** – 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.
## Refining Acronyms

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

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