Basics of Refining & Renewable Diesel

CAPITAL DISCIPLINE, INNOVATION AND UNMATCHED EXECUTION

Valero®

Agenda

Randy Hawkins

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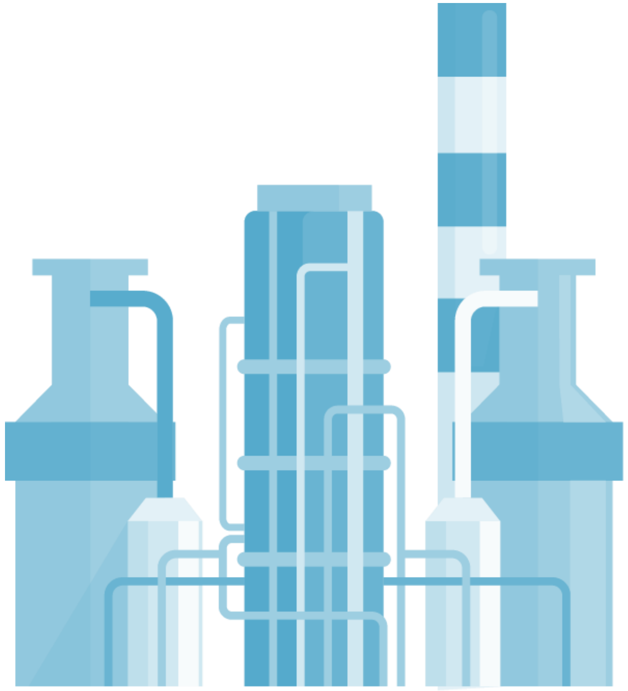
Crude & Feedstocks Supply & Trading

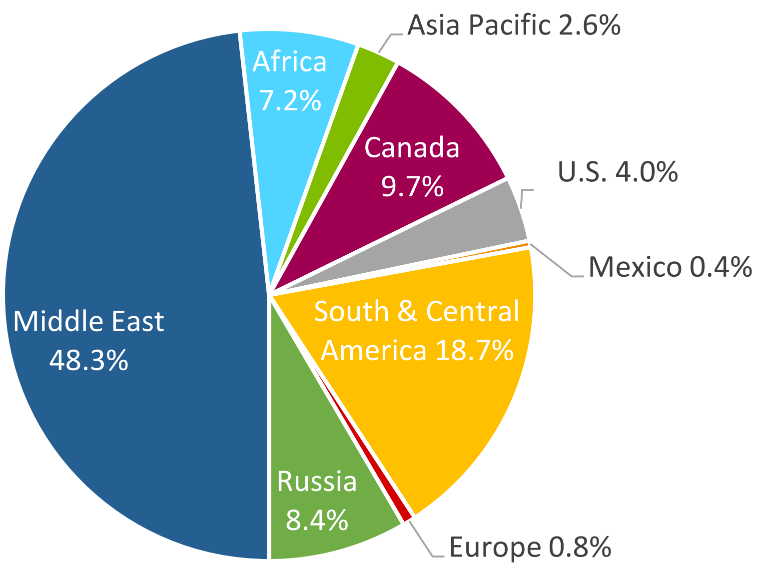
Crude oil characteristics

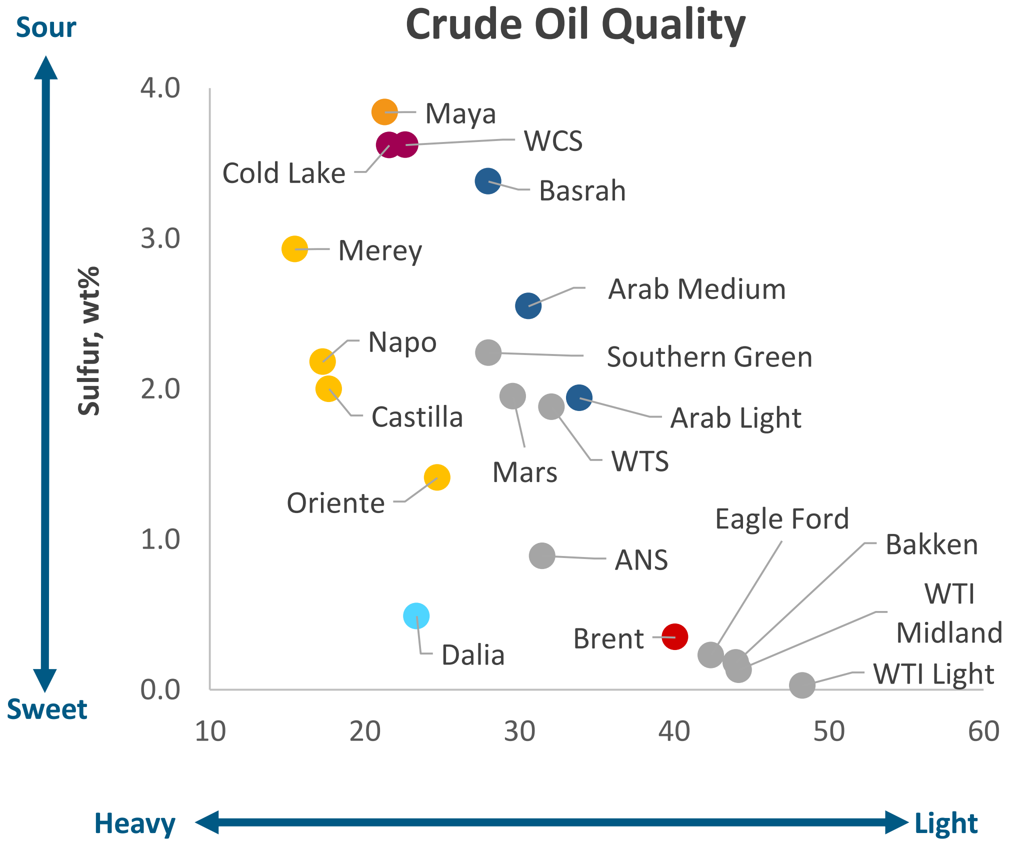
- Crude oils are blends of hydrocarbon molecules
  - Classified and priced by density, sulfur content and acidity
- **Density** is commonly measured in API gravity (relative density of crude oil to water)
  - API > 10: lighter, floats on water
  - API < 10: heavier, sinks in water
- **Sulfur** content 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



Heavy, sour, high acid crude oils are more difficult to process, but **trade at a discount** relative to light, sweet, low acid crudes oils

Crude oil reserves and quality





Majority of global reserves are **sour crude oils**

WTI and **Brent** are the primary light sweet crude oil **pricing benchmarks**

Source: Valero and industry reports.

What is in a barrel of crude oil?

Crude Oil Types	Characteristics	Inherent Yields
Light Sweet (WTI, Bakken, Brent)	• > 34 API Gravity • < 0.7 % Sulfur • Most Expensive	3% 32% 30% 35%
Medium Sour (Mars, Arab Medium)	• 24 to 34 API Gravity • > 0.7 % Sulfur • Less Expensive	2% 24% 26% 48%
Heavy Sour (Maya, WCS)	• < 24 API Gravity • > 0.7 % Sulfur • Least Expensive	1% 15% 21% 63%

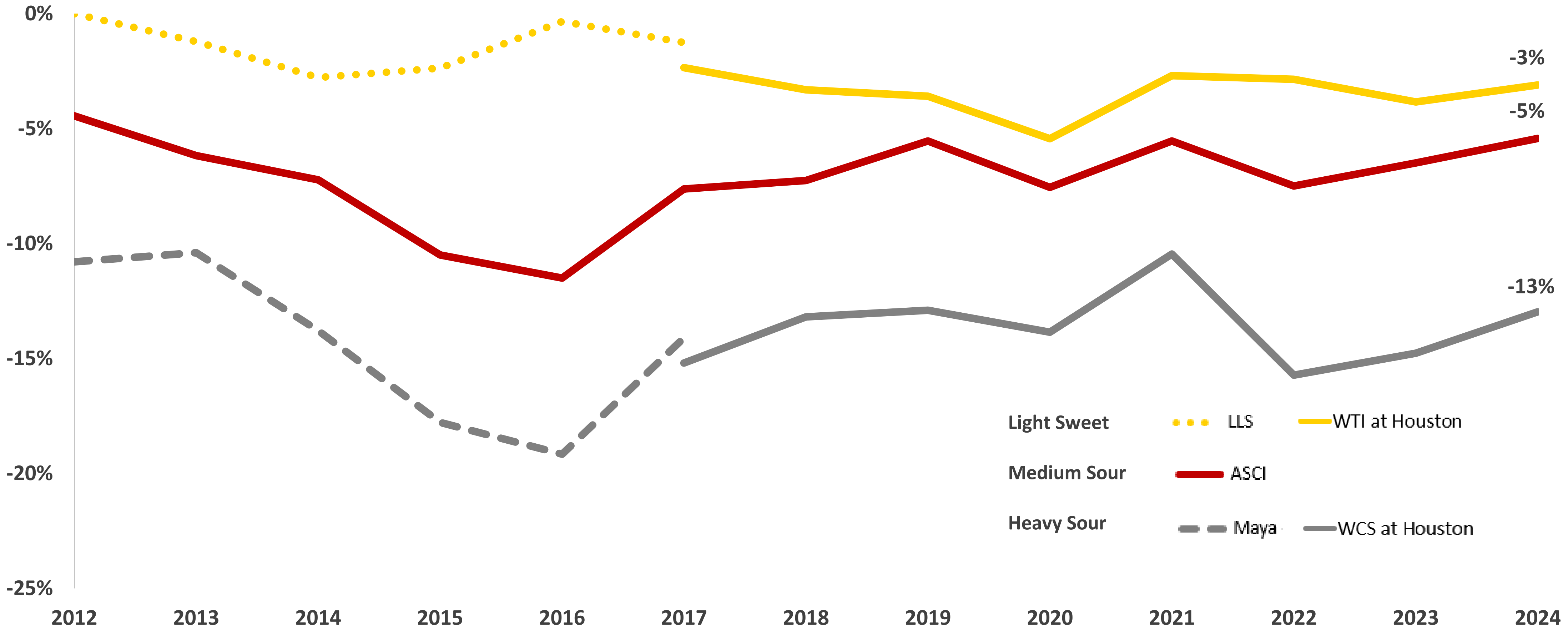
2024 U.S. Refinery Production

10%	**Refinery Gases**
43%	**Gasoline** RBOB CBOB Conventional CARB Premium
38%	**Distillate** Jet Fuel Diesel Heating Oil
9%	Fuel Oil & Other

Refineries **upgrade** crude oil into **higher value gasoline and distillates**

Source: EIA data through October 2024.

Crude oil discounts relative to ICE Brent

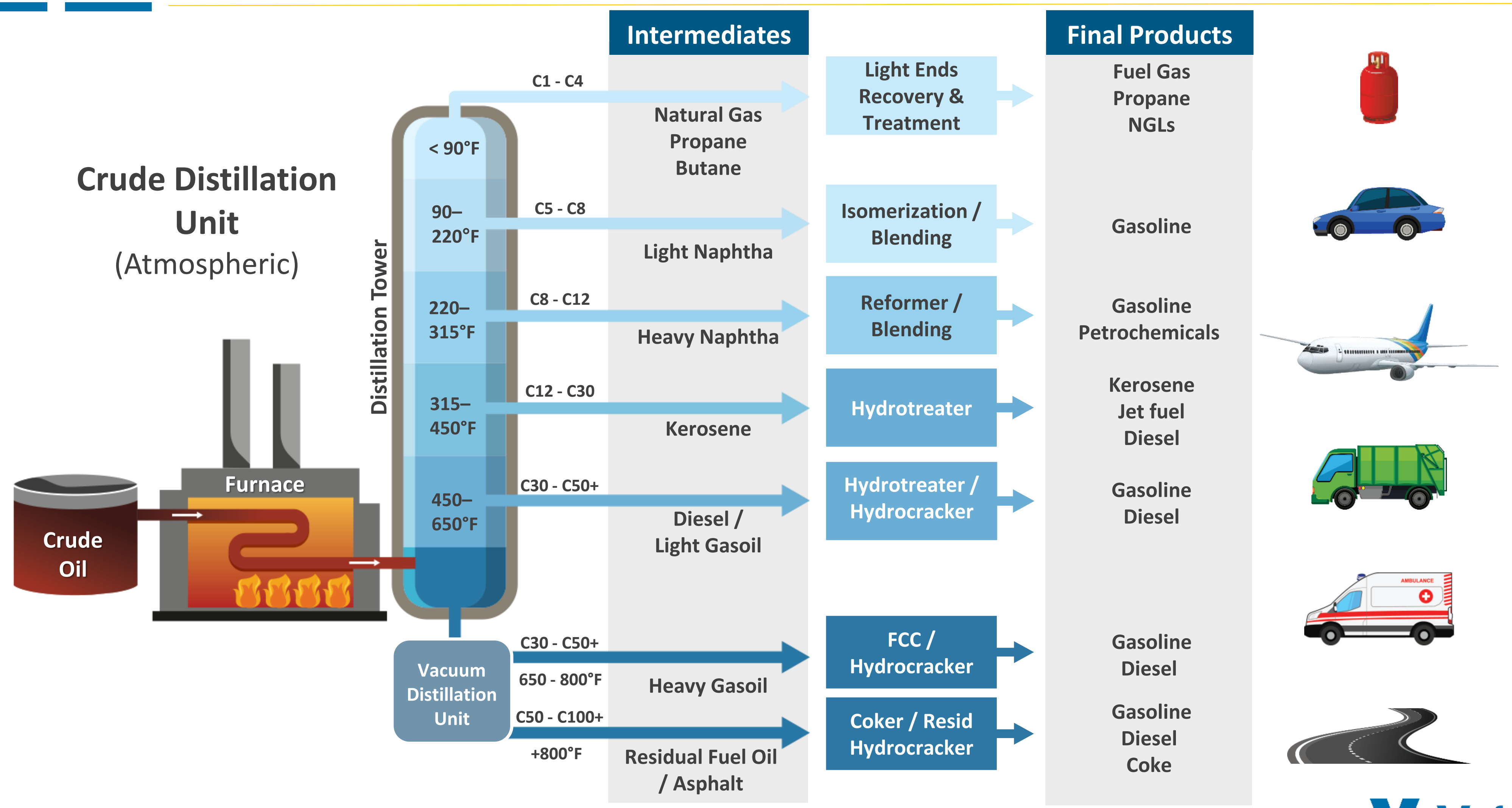


Source: Argus. ASCI represents Argus Sour Crude Index.

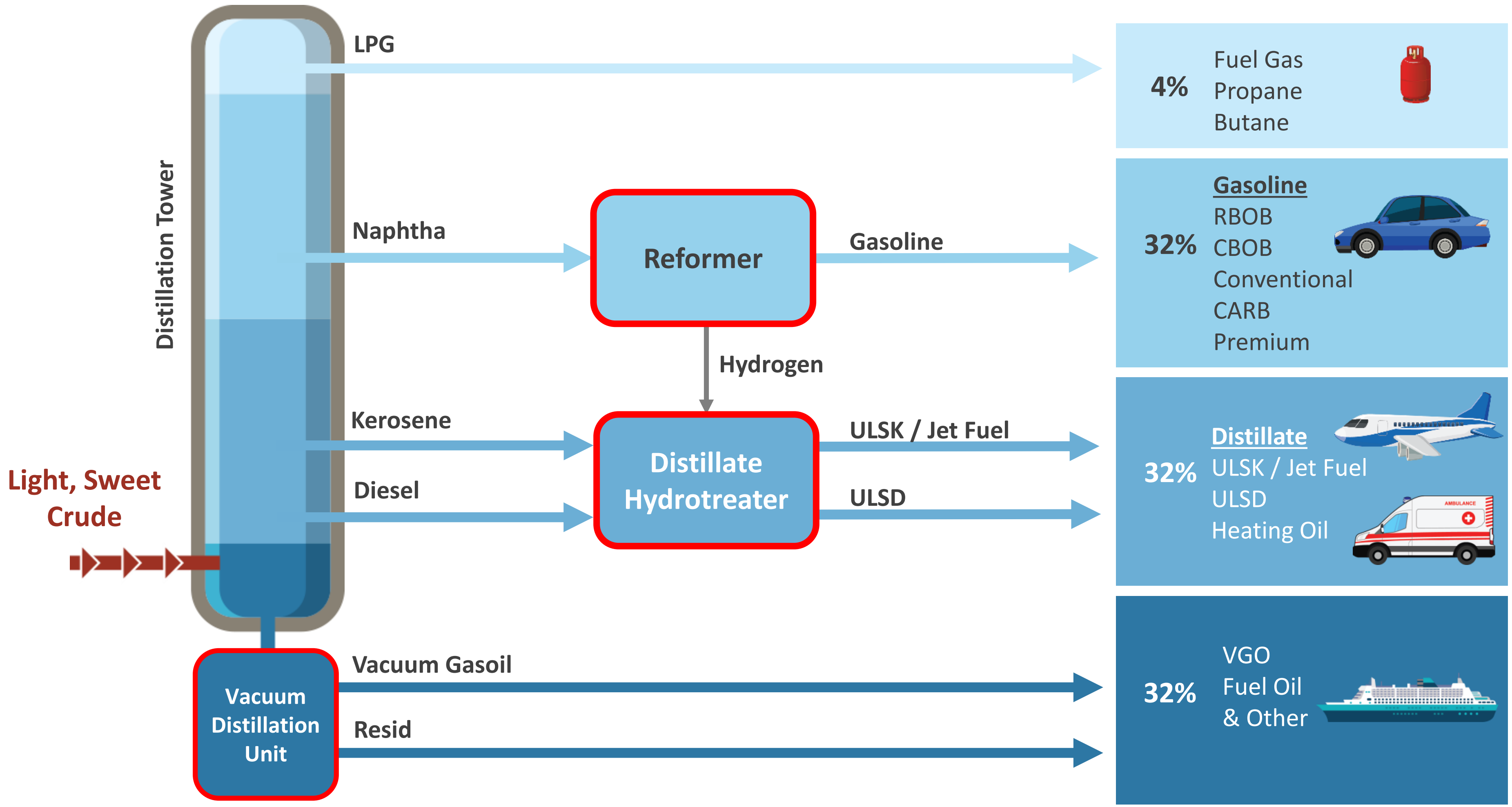
Greg Bram

Vice President
Refining Services

Basic refining concept

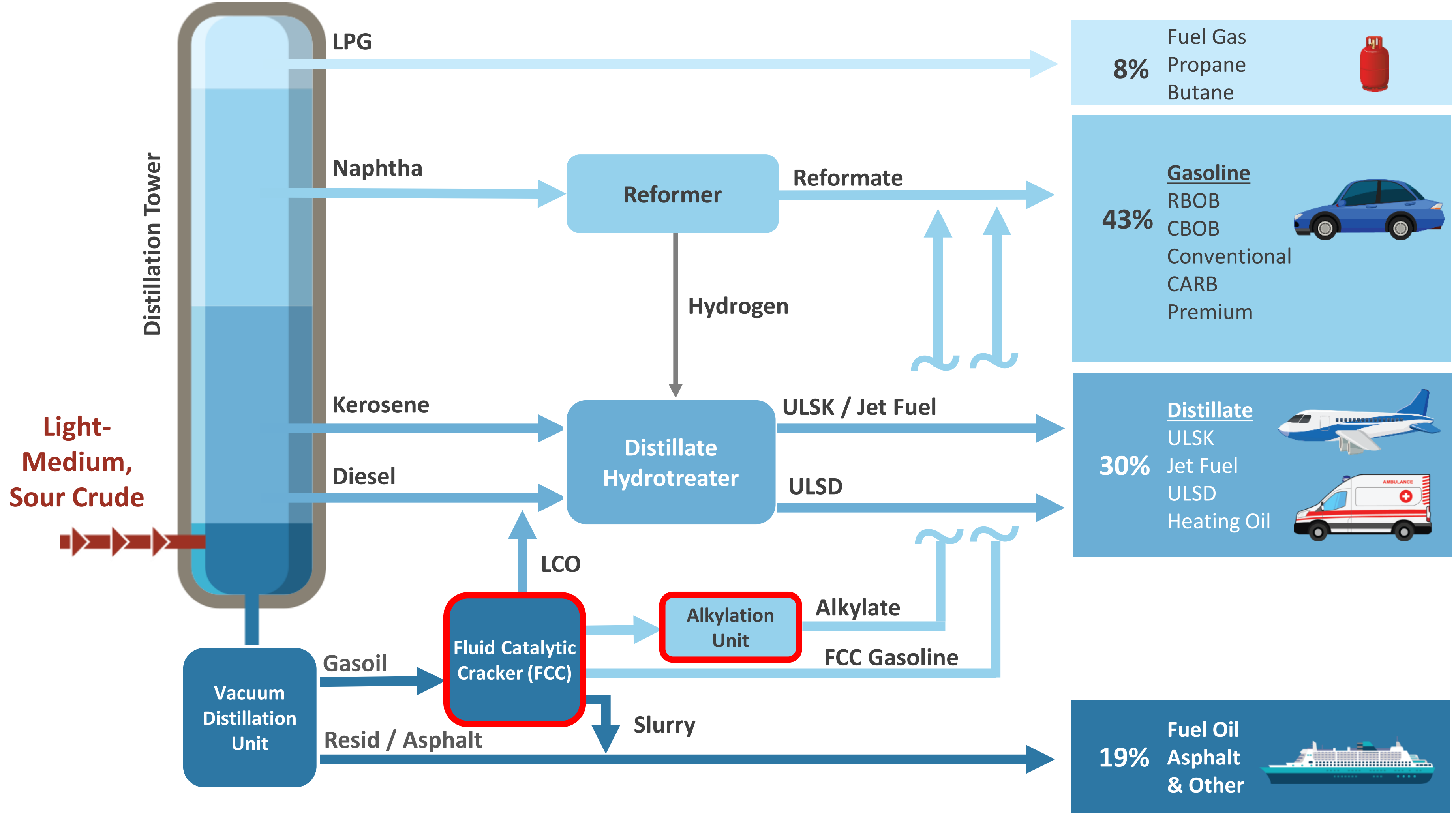


Low conversion: Hydroskimming (Topping)



Low complexity refineries process **sweet crude oils**

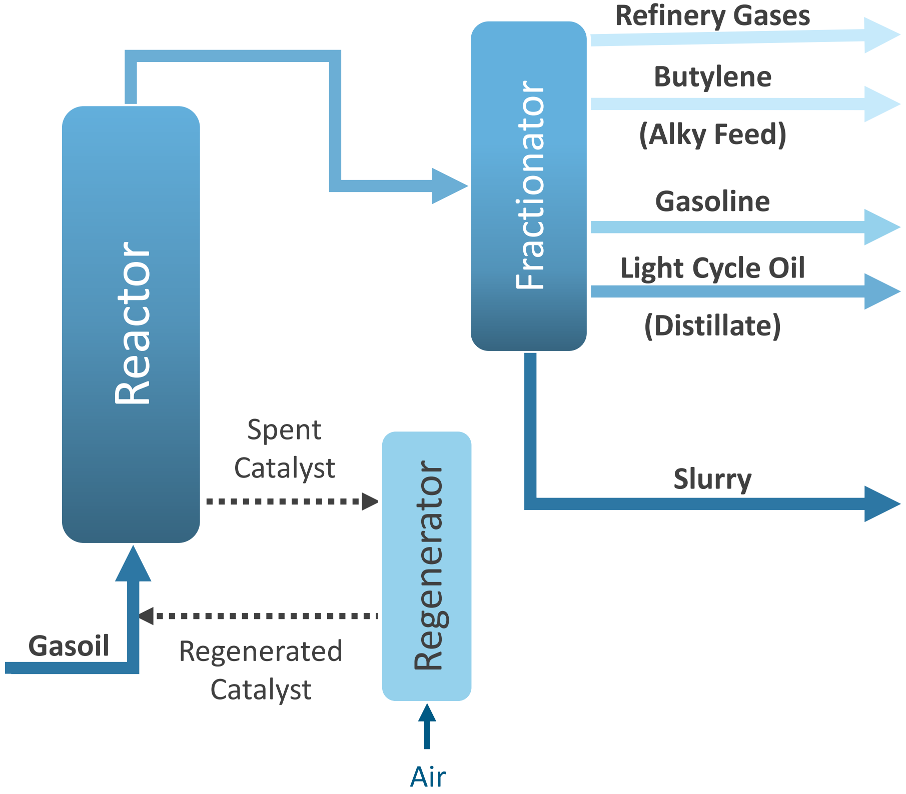
Medium conversion: Catalytic Cracking



Moderate complexity refineries tend to run more **sour crudes**, yield more **high value products** and achieve **higher volume gain**

Fluid Catalytic Cracker (FCC)

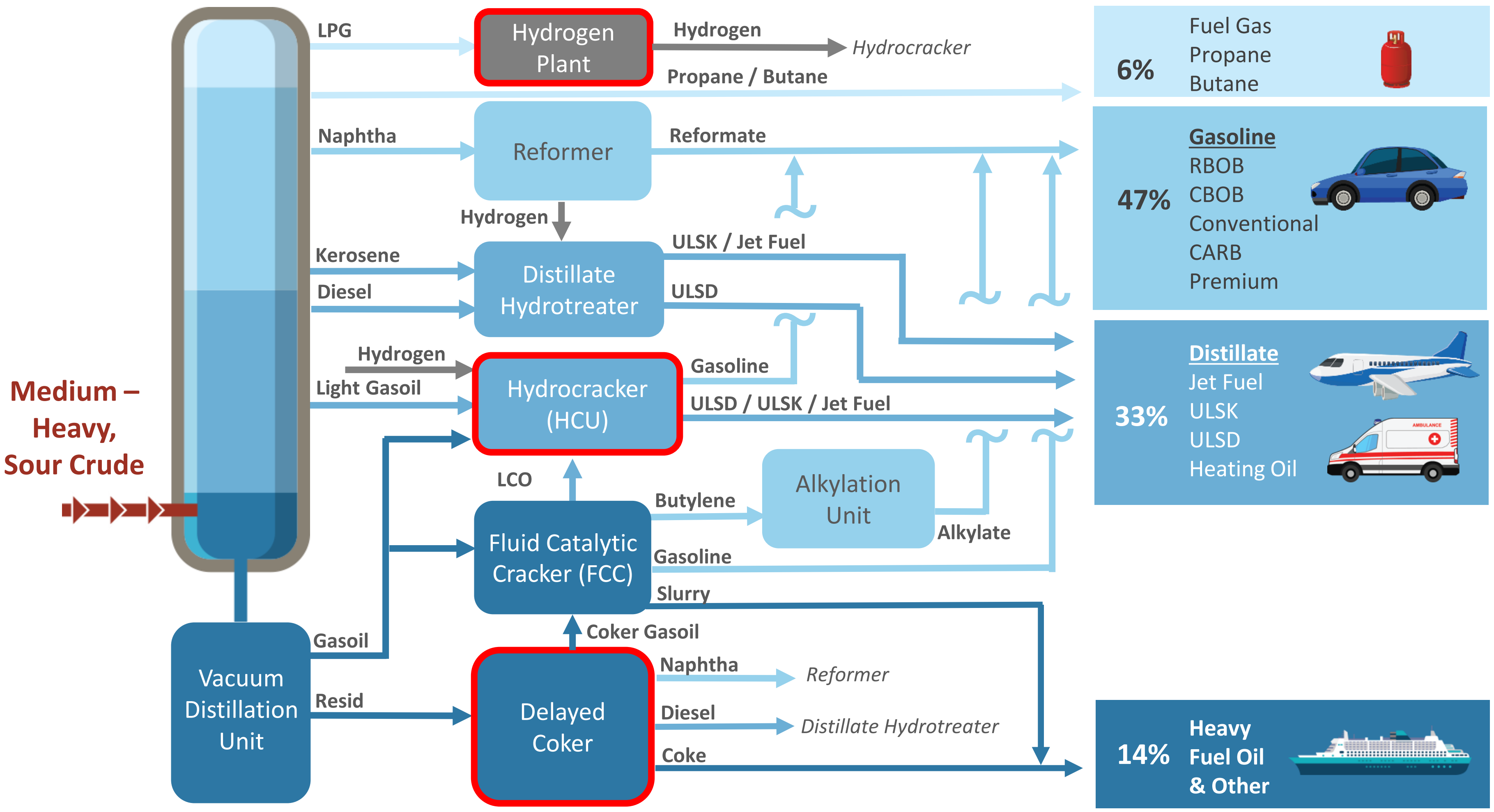
Québec FCC unit.



Total FCC liquid volume yield is approximately 110% of throughput

FCC converts **low-value gasoils** into **higher value light products**

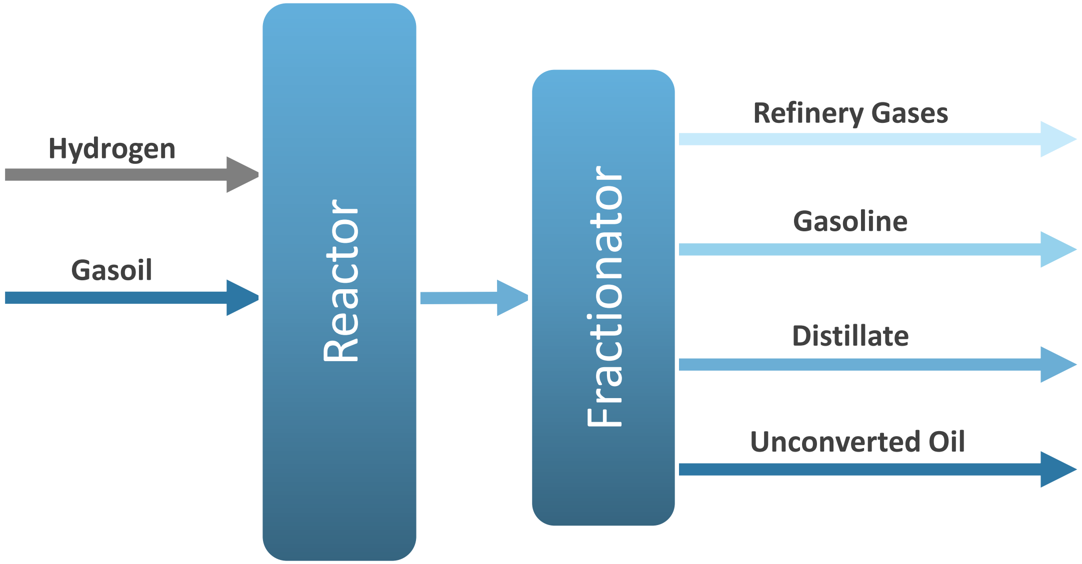
High complexity: Coking / Resid Destruction



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

Port Arthur Hydrocracker Unit.

Hydrocracker Unit (HCU)

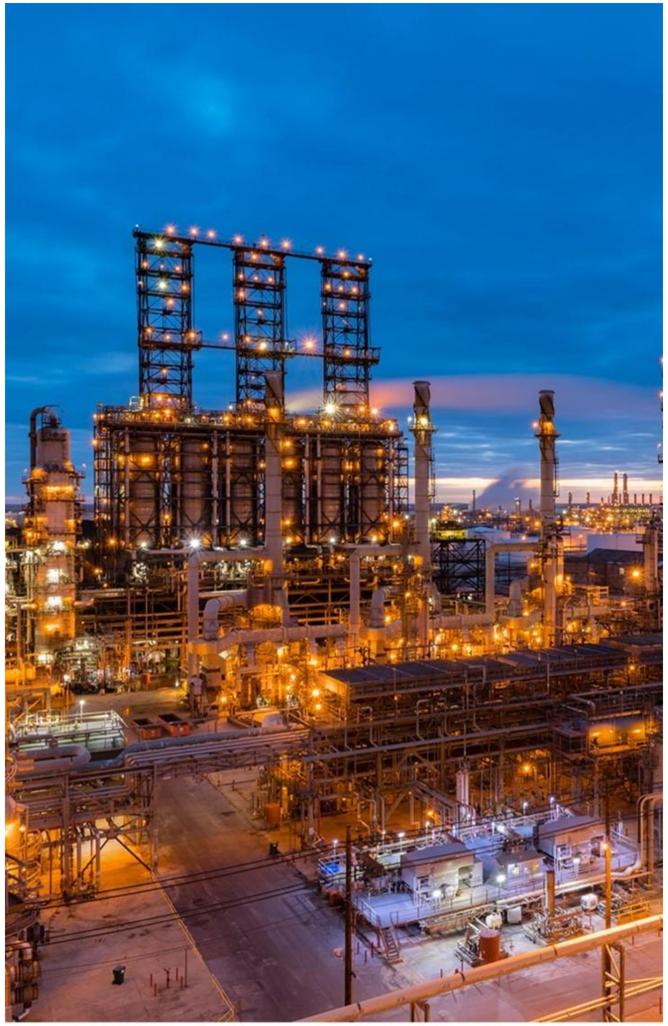


Total Hydrocracker liquid volume yield is approximately 110% to 115% of throughput

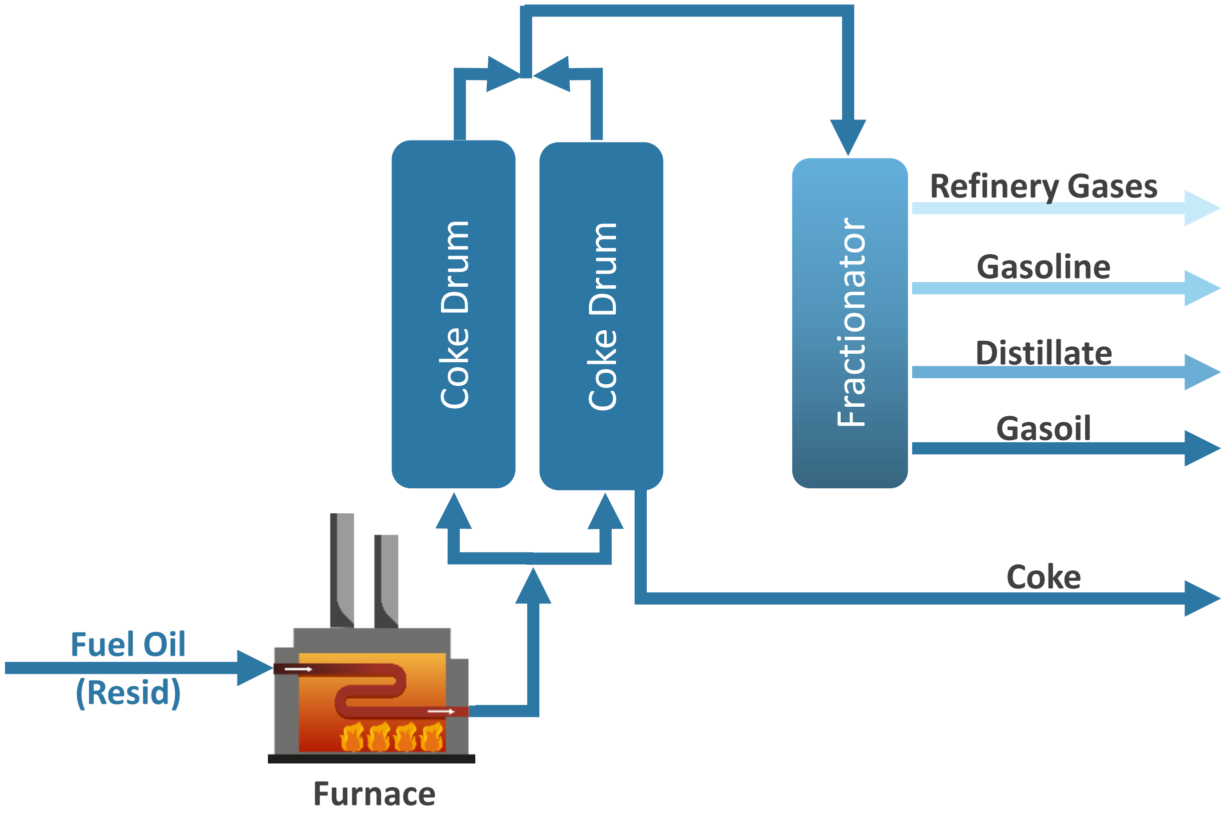
Upgrades high sulfur gasoil into **low sulfur gasoline, jet and diesel**

Increases volumetric yield of products through hydrogen saturation

Delayed Coker



Port Arthur Delayed Coker Unit



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

Upgrades **low value residual fuel oil** into **higher value light products**

Maximizing refinery profit – Linear Programming (LP) Model

Feedstocks (100+)

- Prices
- Qualities
- Availability (purchase volumes)

Refinery

Products (30+)

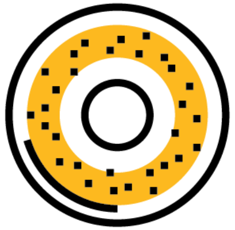
- Prices
- Specifications
- Market demand (sales volumes)

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

Relationship between variables are modeled in a series of **linear equations**

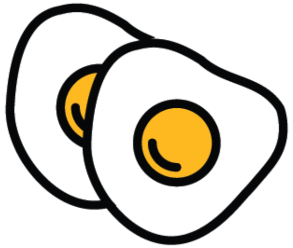
Linear program is used to find combination of feed slate, products, unit operating rates, and operating parameters **that delivers highest profit**

Linear Program (LP) example: What's for breakfast?



1 LARGE BAGEL
$2.00
3 g protein
1 g fat

1 CUP OATMEAL
$2.50
4 g protein
1 g fat



2 LARGE EGGS
$3.50
6 g protein
5 g fat

1 CUP ORANGE JUICE
$2.50
2 g protein
0 g fat

3 BACON SLICES
$4.00
8 g protein
8 g fat

Your **goal** is to consume at **least 18 grams of protein**, but **not more than 10 grams of total fat** for the **lowest price**

Optimizing breakfast from an engineer's point of view

Solve for number of servings of each item:

Consume at least 18 grams of protein

[✖ 3 g] ✚ [✖ 4 g] ✚ [✖ 6 g] ✚ [✖ 8 g] ✚ [✖ 2 g] ≥ **18 grams protein**

Consume no more than 10 grams of total fat

[✖ 1 g] ✚ [✖ 1 g] ✚ [✖ 5 g] ✚ [✖ 8 g] ✚ [✖ 0 g] ≤ **10 grams total fat**

Minimize the cost of breakfast

[✖ $2.00] ✚ [✖ $2.50] ✚ [✖ $3.50] ✚ [✖ $4.00] ✚ [✖ $2.50] = **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 is not efficient

What's the optimal breakfast?

	Servings	Unit Cost	Protein (g)	Total Fat (g)
	0			
	2.7	× $2.50 = $6.75	× 4 = 10.8	× 1 = 2.7
	0			
	0.9	× $4.00 = $3.60	× 8 = 7.2	× 8 = 7.2
	0			

Meal

$10.35	18 g	10 g
GOAL = Lowest	Min protein	Max fat

Linear programming is a branch of applied mathematics concerned with **problems of constrained optimization**

Price and "quality" of each variable drives the **optimum solution**

Eric Honeyman

Senior Vice President
Renewables Operations & Low Carbon Fuels

Global low-carbon fuel policies are driving demand growth for renewable diesel

	2030 GHG Emissions Reduction Target	Net-zero GHG Emissions Target	Primary Transportation Fuel Policy Mechanism	2030 Transportation Fuels Goal
California	40%	Net-zero by 2045	Low Carbon Fuel Standard (LCFS)	Reduce the carbon intensity of transportation fuels by at least 30%
Canada	40 to 45%	Net-zero by 2050	Clean Fuel Regulations (CFR)	Reduce the carbon intensity of transportation fuels by 15%
EU	55%	Net-zero by 2050	Renewable Energy Directive III (RED III)	Replace 29% of transport fuels with renewable energy, or reduce sector GHG intensity by 14.5%
UK	68%	Net-zero by 2050	Renewable Transport Fuel Obligation (RTFO)	Replace 19% of transport fuels with renewable fuels
Oregon	Clean Fuels Program requires a 20% carbon intensity reduction by 2030 and a 37% reduction by 2035			
New Mexico	Clean Transportation Fuel Standard, targeting a 20% carbon intensity reduction by 2030			
Washington State	Clean Fuel Standard requires a 20% carbon intensity reduction by 2034			
British Columbia	Low Carbon Fuel Standard requires a 30% carbon intensity reduction by 2030			
Norway	Biodiesel blending mandate of 33% by 2030			
Potential Policies	Hawaii, Illinois, Massachusetts, Michigan, Minnesota, New Jersey, New York, Nevada and Vermont are considering low-carbon fuel programs			

Up to 80% reduction in life cycle GHG emissions

Cost-effective fuel that can be used with existing vehicles

Drop-in fuel that does not require infrastructure investments

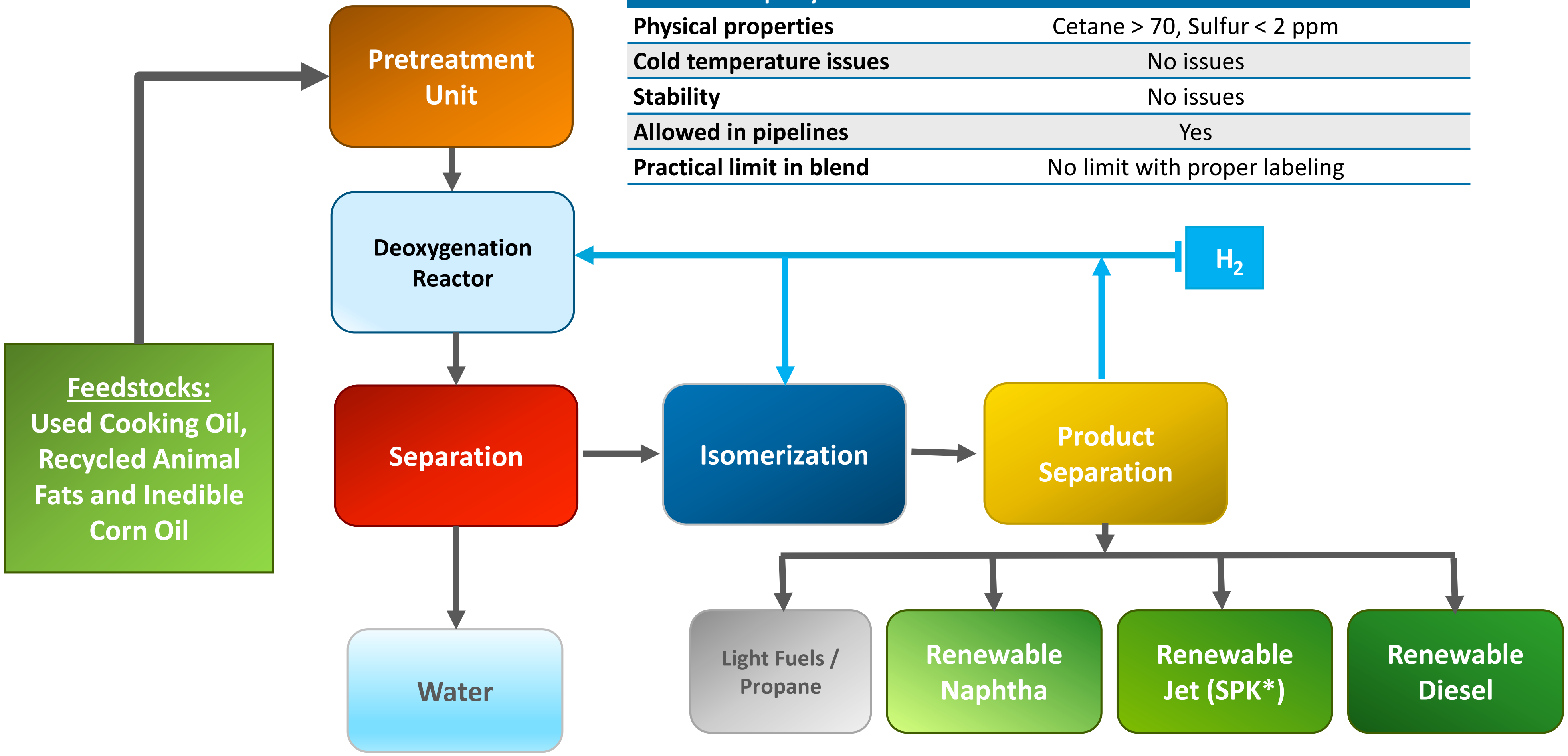
SAF mandates are expanding globally

	SAF Mandates
CORSIA	Program aims to offset growth in CO2 emission from international aviation above 85% of 2019 emissions. Participation is voluntary over 2021-2026 and becomes mandatory for participating nations starting in 2027
EU[1]	2% in 2025, 6% in 2030, 20% in 2035, 34% in 2040, 42% in 2045, and 70% in 2050.
Brazil	GHG emission reduction of 1% in 2027, progressively increasing to 10% by 2037, through the use of SAF
France[2]	1.5% in 2024, 2% in 2025 and 5% in 2030
Germany[2]	Power-to-liquid (PtL) SAF sub-mandate of 0.5% in 2026, 1% in 2028 and 2% in 2030
Indonesia	1% in 2027 on international flights, rising to 2.5% in 2030
Malaysia	1% in 2026, expected to increase to 47% in 2050
Norway	0.5% in 2020, expected to increase to 30% in 2030
Singapore	1% in 2026, possibly increasing to 3%-5% in 2030
Sweden[2]	1% in 2021 and increasing to 30% in 2030
UK	2% in 2025, increasing linearly to 10% in 2030 and then to 22% in 2040
British Columbia	1% in 2028, 2% in 2029 and 3% in 2030
Potential Policies	Denmark[1], Japan, India, Finland[1], Netherlands[1] and South Korea

[1]European Union's ReFuelEU Aviation regulation
[2]Members of the EU and will be covered by REFuelEU Aviation

Renewable diesel process and properties

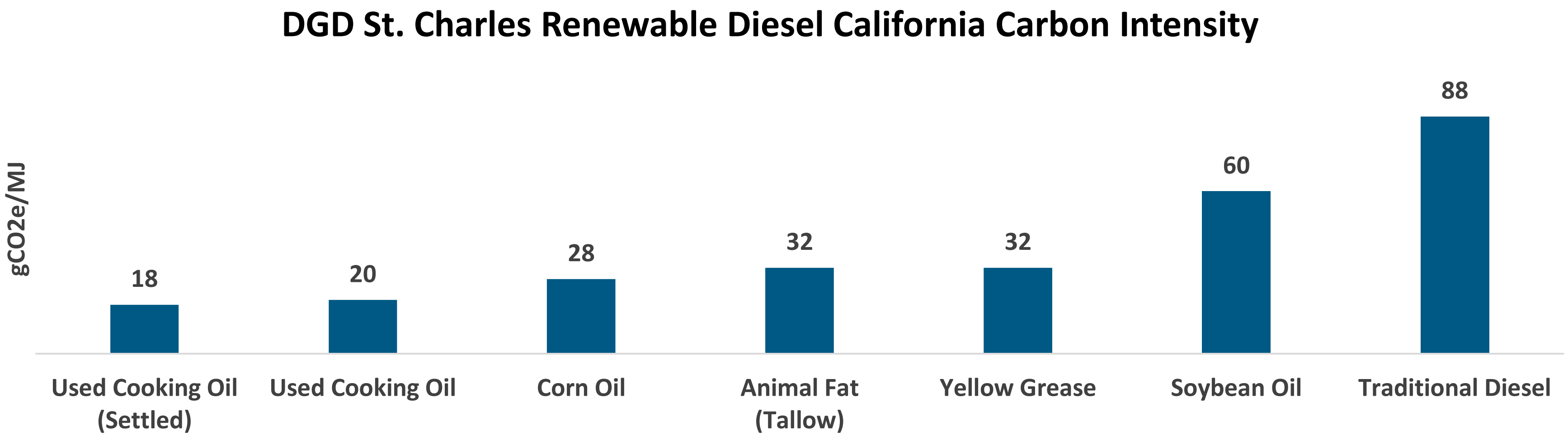
Property	Renewable Diesel
Physical properties	Cetane > 70, Sulfur < 2 ppm
Cold temperature issues	No issues
Stability	No issues
Allowed in pipelines	Yes
Practical limit in blend	No limit with proper labeling



Pretreatment Unit allows the plant to process **advantaged, low carbon intensity feedstocks**

* Synthetic paraffinic kerosene = SPK

DGD utilizes a variety of renewable feedstocks



Renewable diesel derived from **UCO has a $0.88 per gallon** LCFS credit value, compared to **soybean oil at $0.36 per gallon***

*Assuming $100 per metric ton carbon price, UCO CI of 20 and soybean oil CI of 60

Questions and Answers

Appendix Contents

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, whereby 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 number. Octane number is a measure 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 and renewable diesel acronyms

- **AGO** – Atmospheric Gasoil
- **API** – American Petroleum Institute
- **ATB** – Atmospheric Tower Bottoms
- **B–B** – Butane-Butylene Fraction
- **BBLS** – Barrels
- **BPD** – Barrels Per Day
- **BTC** – Blenders Tax Credit
- **BTX** – Benzene, Toluene, Xylene
- **CARB** – California Air Resource Board
- **CCR** – Continuous Catalytic Regenerator
- **CI** – Carbon Intensity
- **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** – Gasoil Hydrotreater
- **GPM** – Gallon Per Minute
- **HAGO** – Heavy Atmospheric Gasoil
- **HCU** – Hydrocracker Unit
- **HDS** – Hydrodesulfurization
- **HDT** – Hydrotreating
- **HGO** – Heavy Gasoil
- **HOC** – Heavy Oil Cracker
- **H2** – Hydrogen
- **H2S** – Hydrogen Sulfide
- **HF** – Hydroflouric (acid)
- **HVGO** – Heavy Vacuum Gasoil
- **kV** – Kilovolt
- **kVA** – Kilovolt Amp
- **LCFS** – Low Carbon Fuel Standard
- **LCO** – Light Cycle Oil
- **LGO** – Light Gasoil
- **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
- **PTC** – Production Tax Credit
- **RBOB** – Reformulated Blendstock for Oxygenate Blending
- **RDS** – Resid Desulfurization
- **RFG** – Reformulated Gasoline
- **RFS** – Renewable Fuel Standard
- **RIN** – Renewable Identification Number
- **RON** – Research Octane Number
- **RVP** – Reid Vapor Pressure
- **SMR** – Steam Methane Reformer (Hydrogen Plant)
- **SAF** – Sustainable Aviation Fuel
- **SOX** – Sulfur Oxides
- **SPK** – Synthetic Paraffinic Kerosene
- **SRU** – Sulfur Recovery Unit
- **TAME** – Tertiary Amyl Methyl Ether
- **TAN** – Total Acid Number
- **UCO** – Used Cooking Oil
- **ULSD** – Ultra Low Sulfur Diesel
- **ULSK** – Ultra Low Sulfur Kerosene
- **VGO** – Vacuum Gasoil
- **VOC** – Volatile Organic Compound
- **VPP** – Voluntary Protection Program
- **VTB** – Vacuum Tower Bottoms
- **WTI** – West Texas Intermediate
- **WWTP** – Waste Water Treatment Plant

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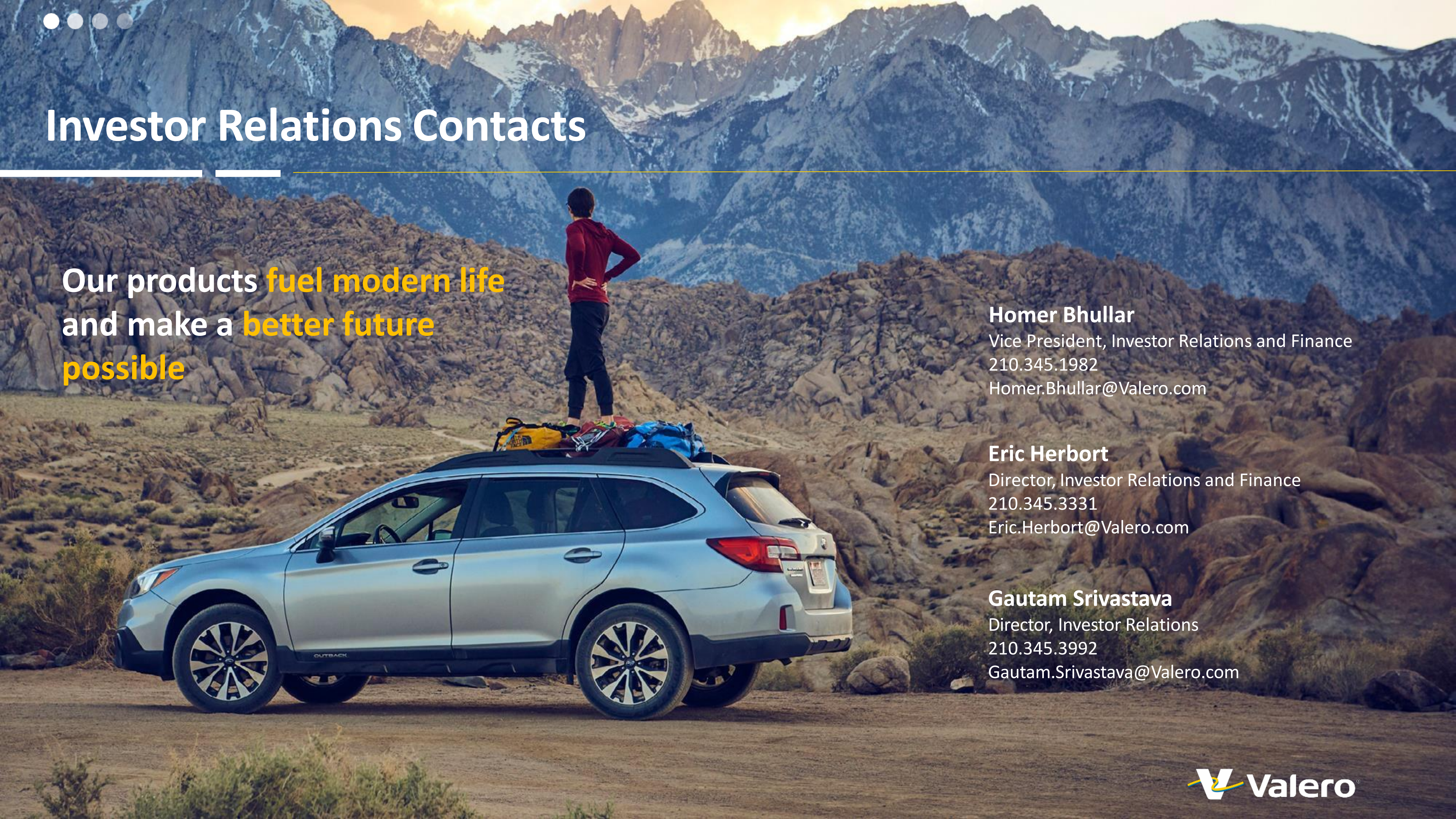

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