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Basics of Refining and Renewable Diesel

Valero®

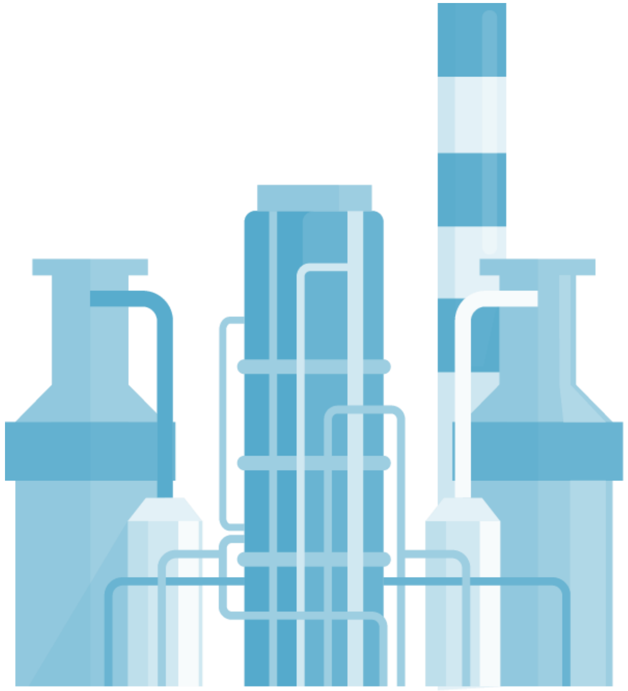
Gary Simmons

Executive Vice President
Chief Commercial Officer

Agenda

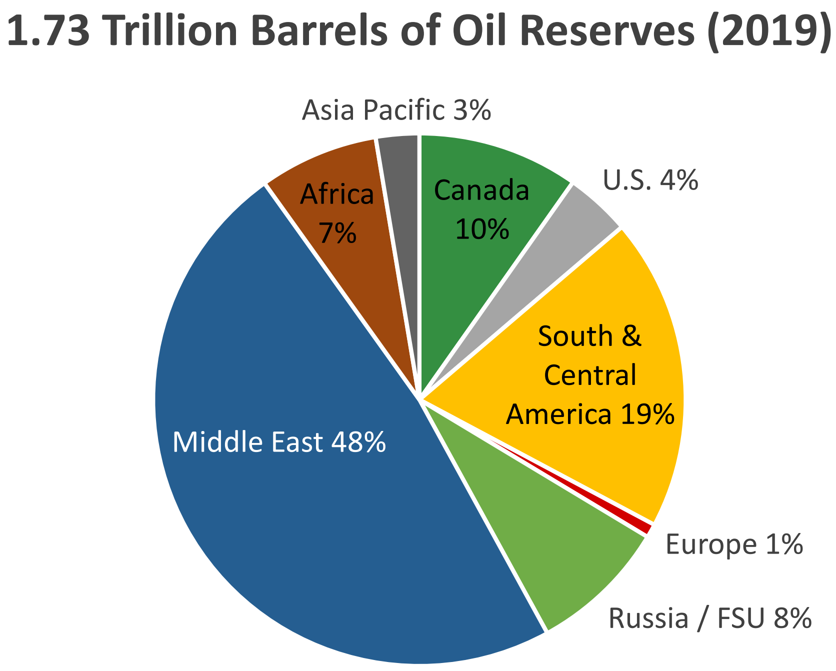
Crude Oil Characteristics

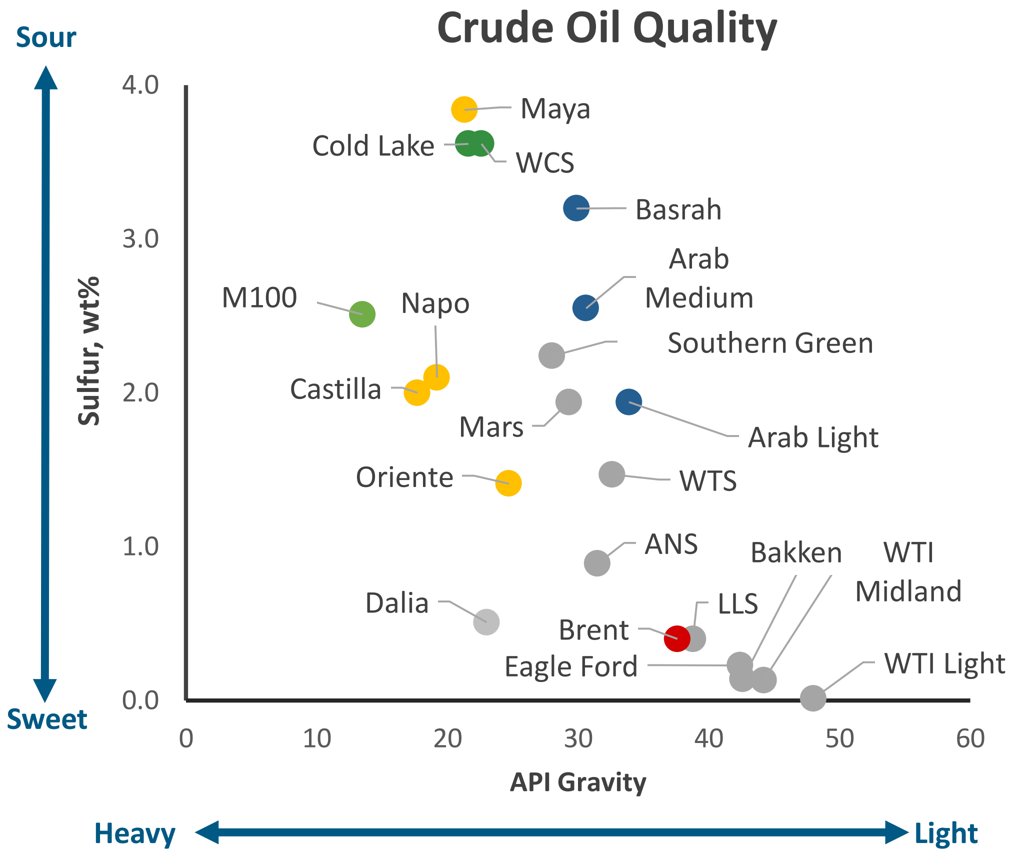
- Crude oils are blends of hydrocarbon molecules
  - Classified and priced by density, sulfur content and acidity
- **Density** is commonly measured in API gravity (relative density of crude oil to water)
  - API > 10: lighter, floats on water
  - API < 10: heavier, sinks in water
- **Sulfur** content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



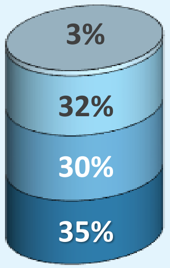
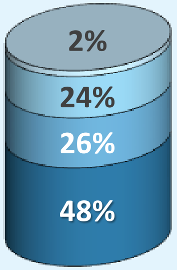
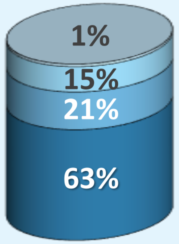


Majority of global reserves are **sour crude oils**

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, LLS, Brent)	• > 34 API Gravity • < 0.7 % Sulfur • Most Expensive	
Medium Sour (Mars, Arab Medium)	• 24 to 34 API Gravity • > 0.7 % Sulfur • Less Expensive	
Heavy Sour (Maya, WCS)	• < 24 API Gravity • > 0.7 % Sulfur • Least Expensive	

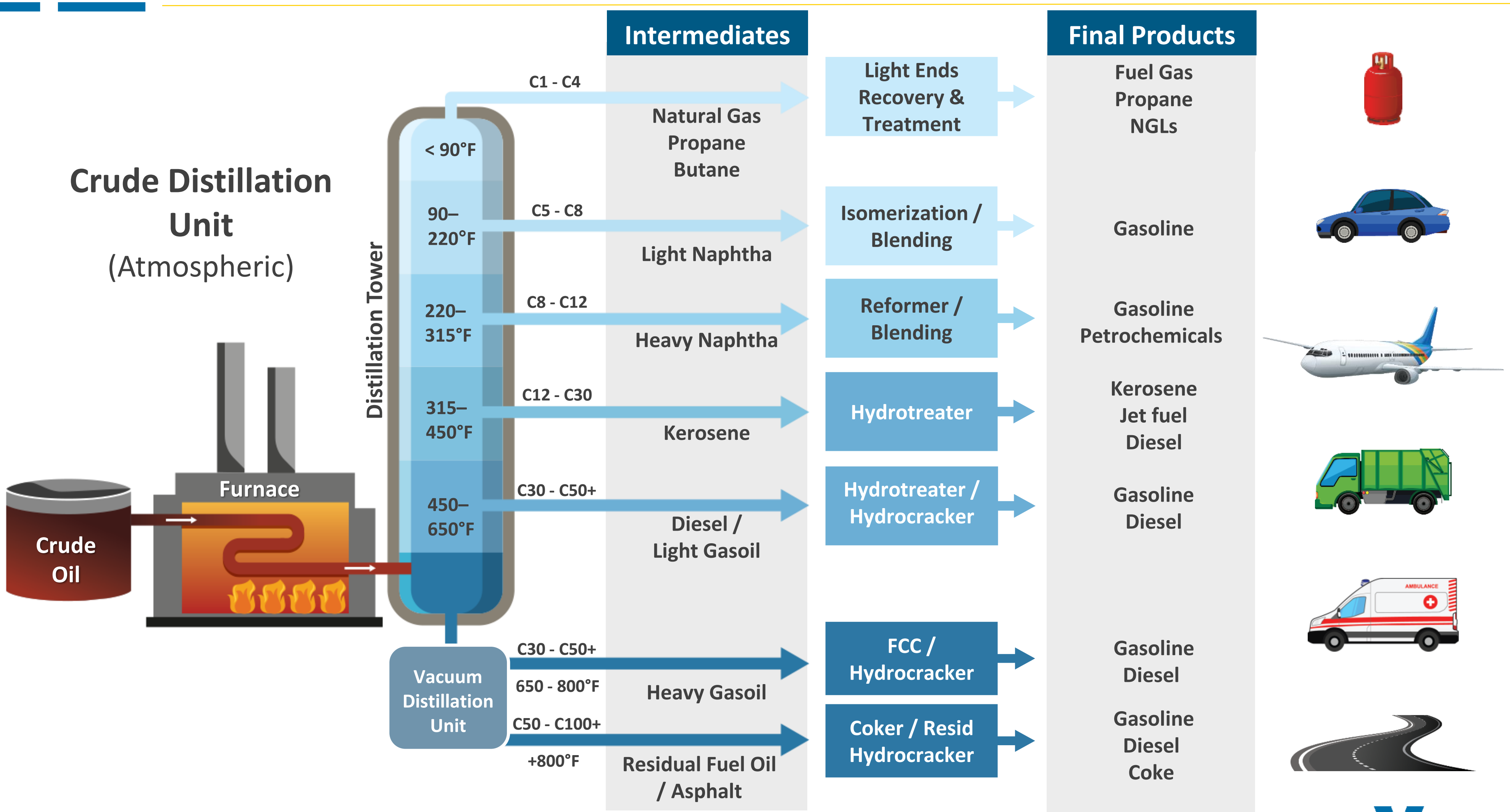
2019 U.S. Refinery Production

7%	**Refinery Gases**
45%	**Gasoline** RBOB CBOB Conventional CARB Premium
38%	**Distillate** Jet Fuel Diesel Heating Oil
10%	Fuel Oil & Other

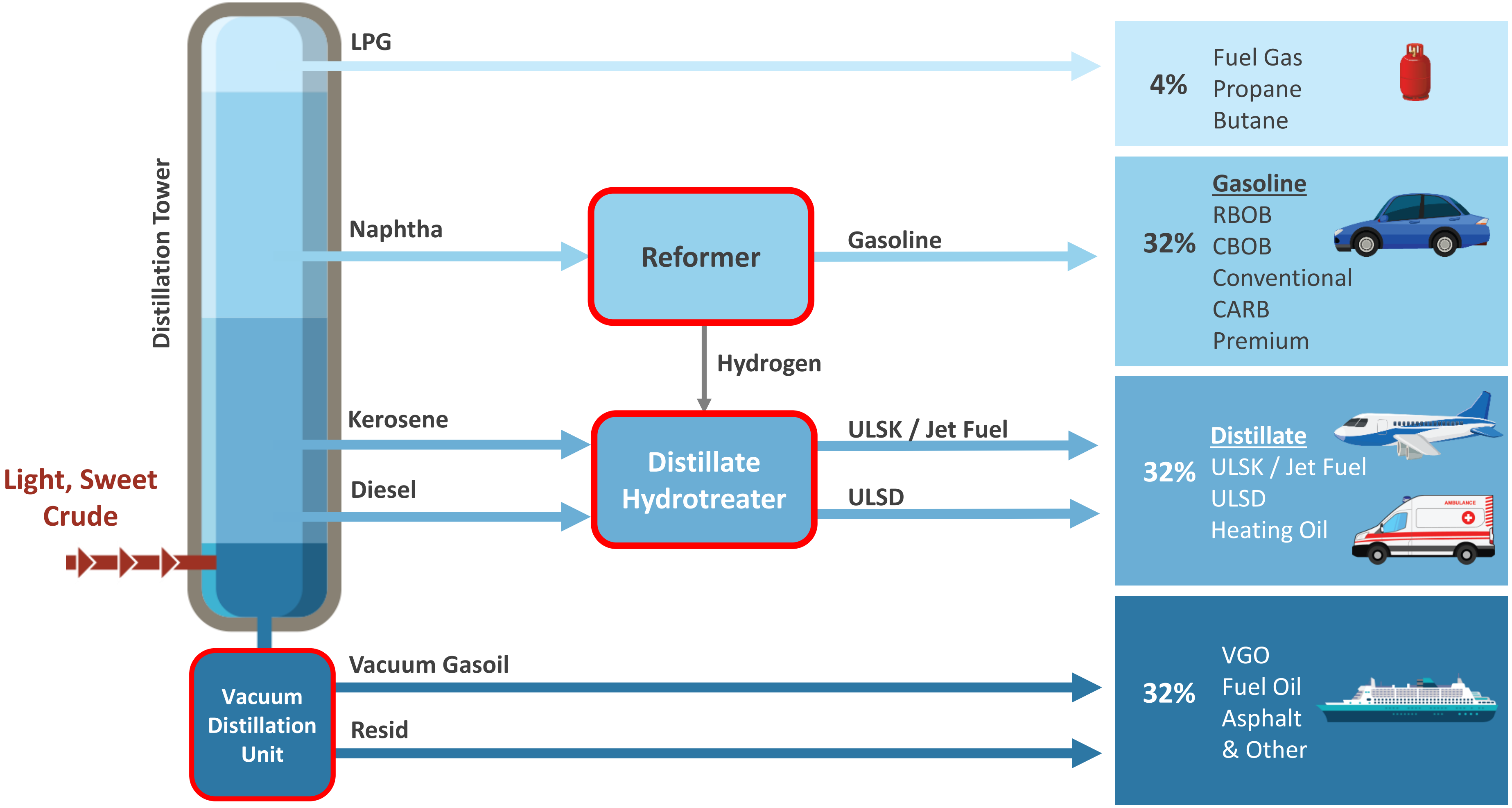
Refineries **upgrade** crude oil into **higher value gasoline** and **distillates**

Source: Energy Information Administration.

Basic Refining Concept

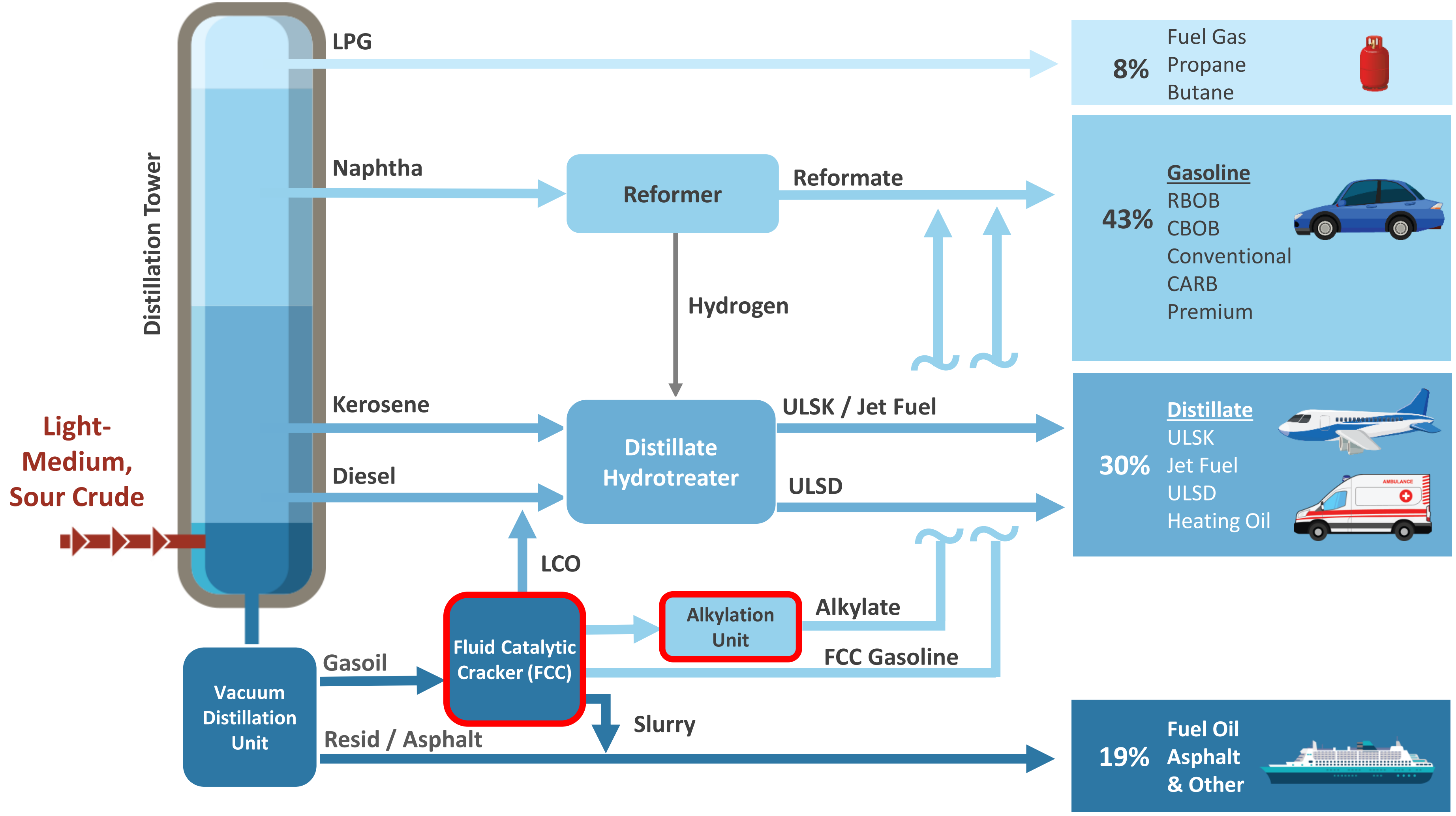


Low Conversion: Hydroskimming (Topping)



Low complexity refineries process **sweet crude oils**

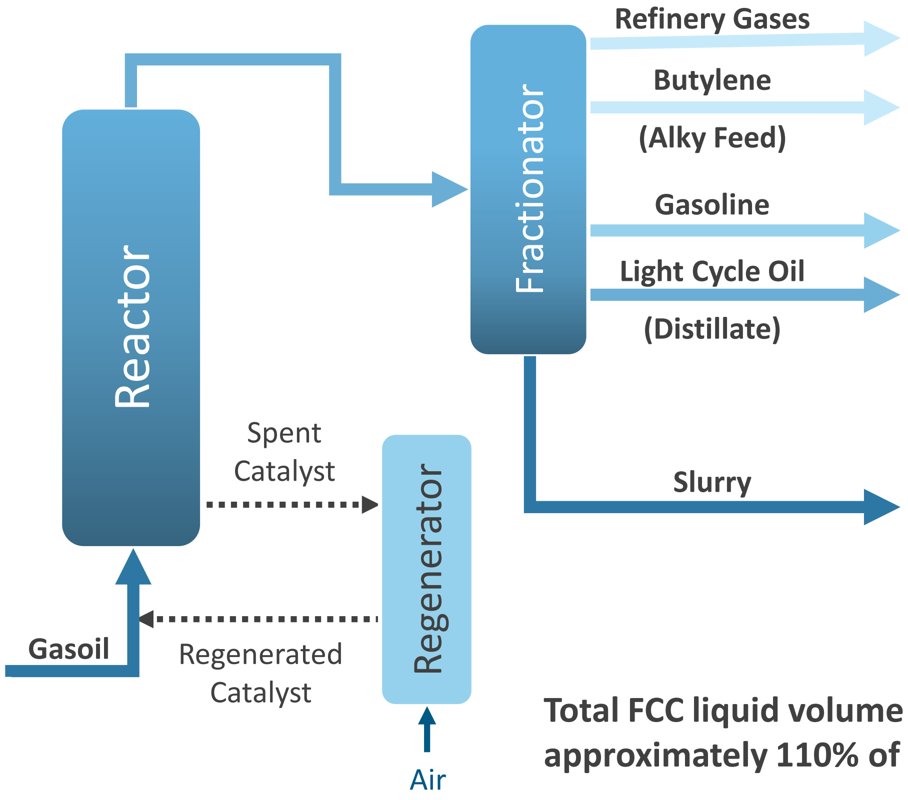
Medium Conversion: Catalytic Cracking



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

Fluid Catalytic Cracker (FCC)

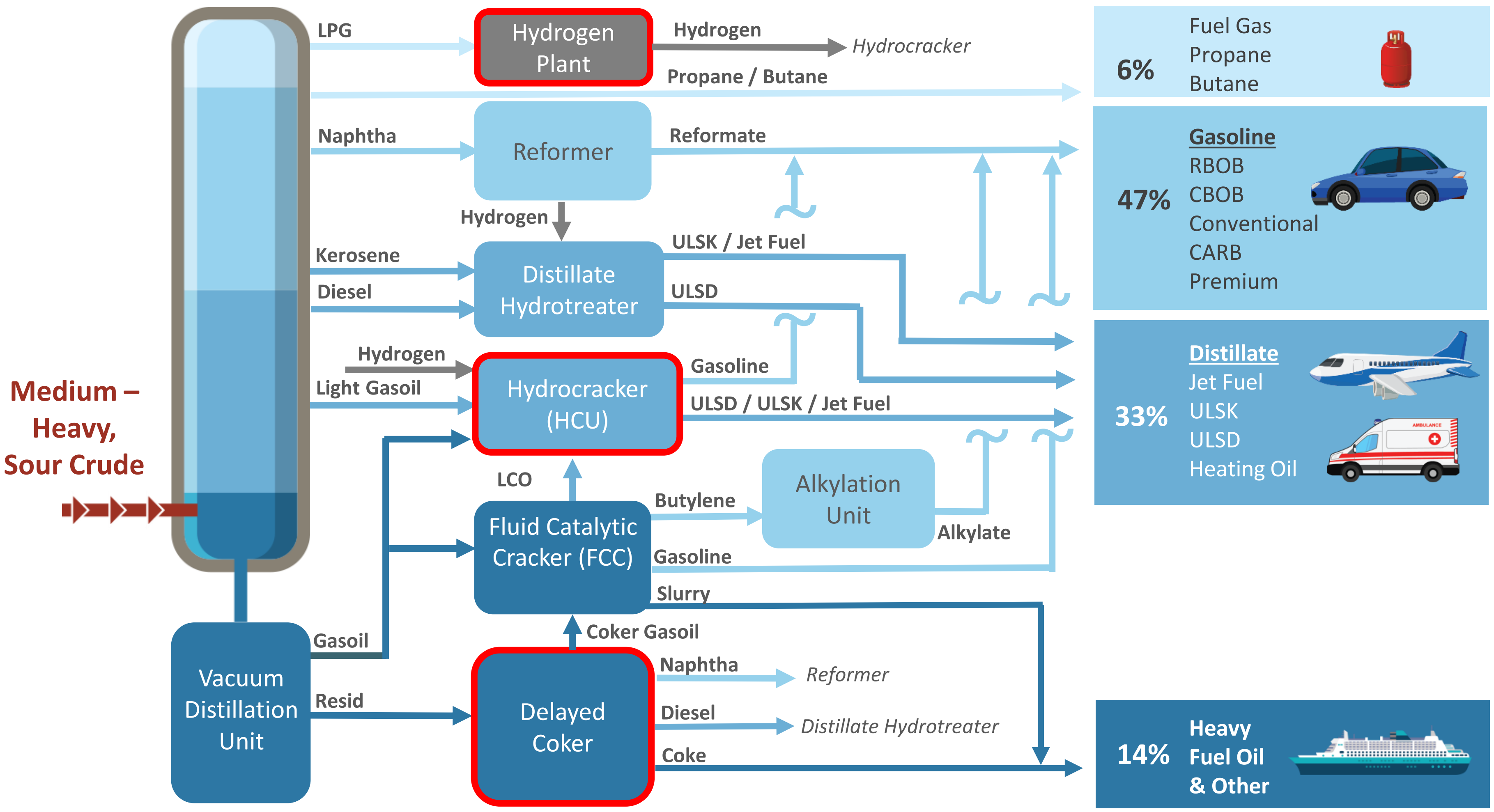
Fluid Catalytic Cracker Yields



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

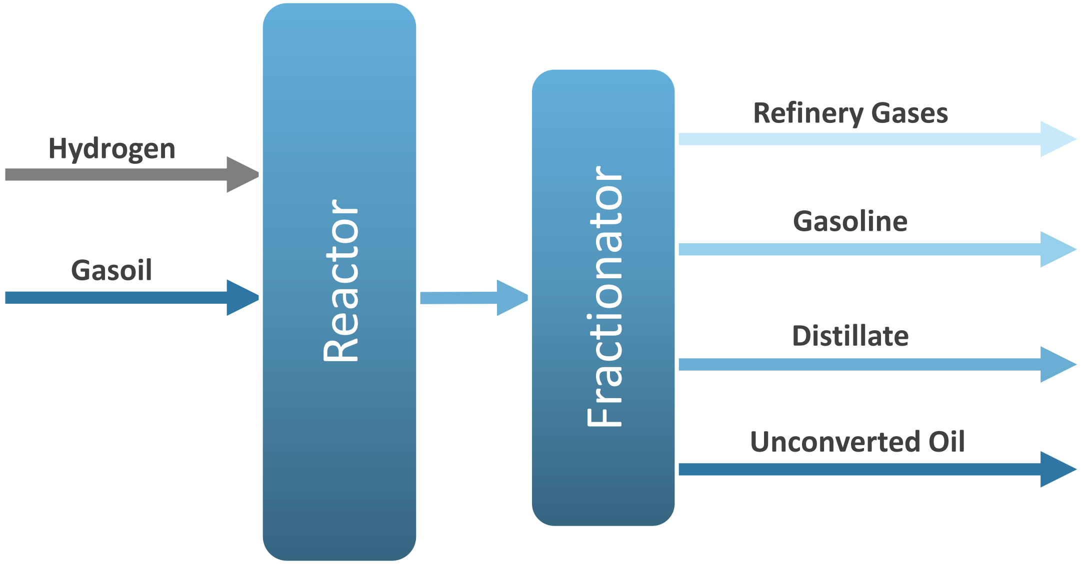


High complexity refineries can run **heavier**, more **sour** crudes oils while achieving the **highest light product yields** and **volume gain**

Hydrocracker Unit (HCU)

Port Arthur Hydrocracker Unit.

Hydrocracker Yields

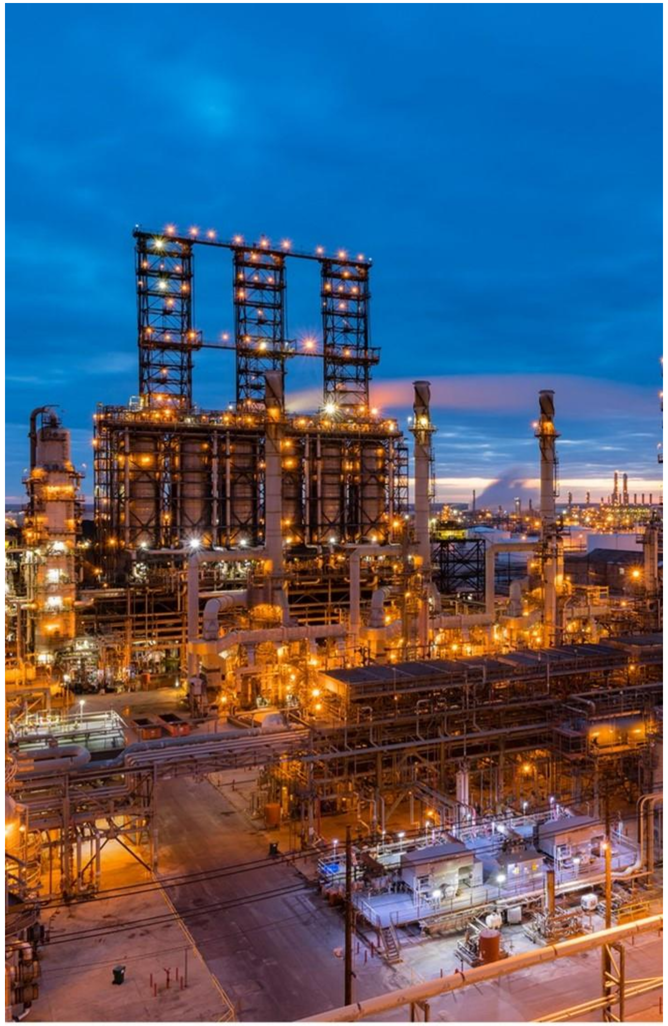


Total Hydrocracker liquid volume yield is approximately 110% to 115% of throughput

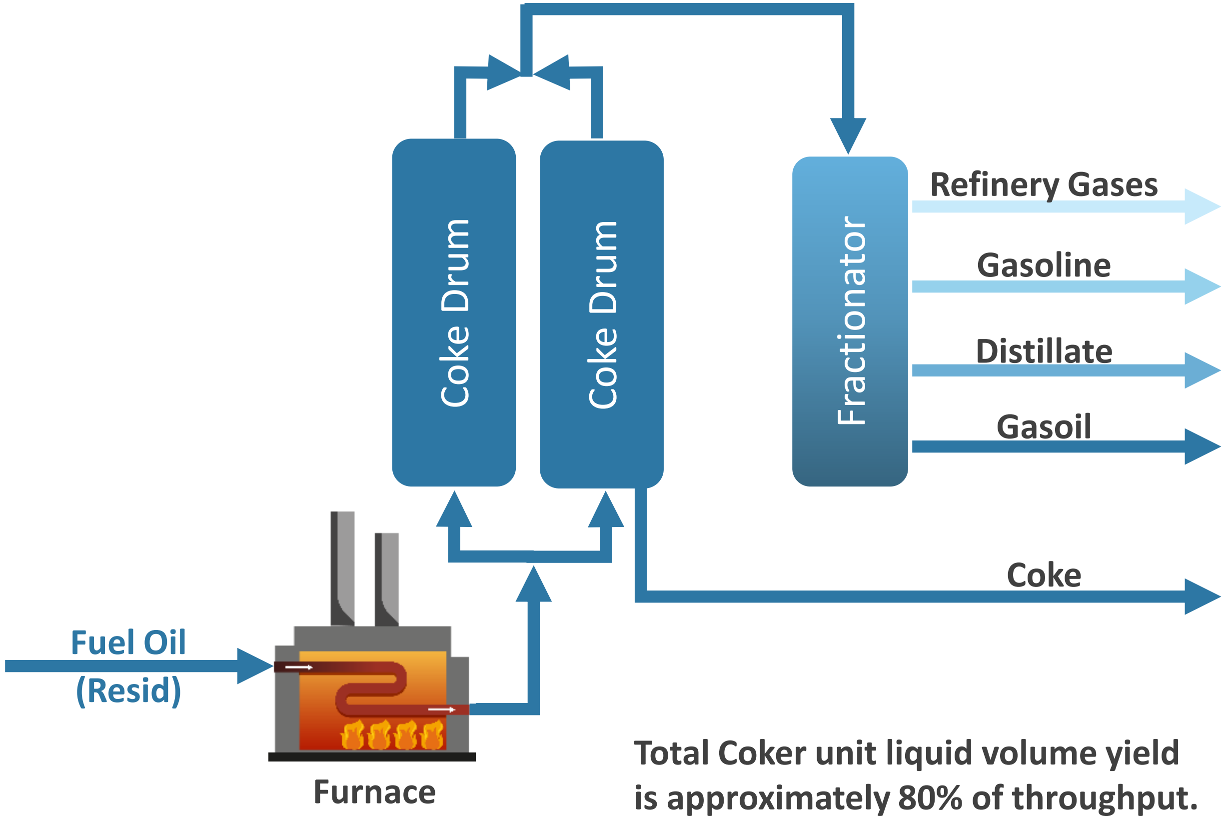
Upgrades high sulfur gasoil into **low sulfur gasoline, jet and diesel**

Increases volumetric yield of products through hydrogen saturation

Delayed Coker



Coker Yields



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

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

Greg Bram

Vice President
Supply Chain Optimization

Maximizing Refinery Profit
Linear Programming (LP) Model

Feedstocks (100+)

- Prices
- Qualities
- Availability (purchase volumes)

Refinery

Products (30+)

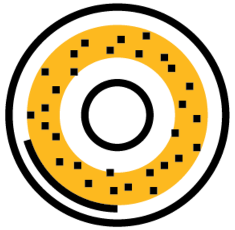
- Prices
- Specifications
- Market demand (sales volumes)

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

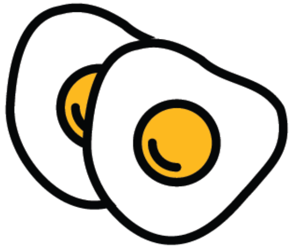
Relationship between variables are modeled in a series of **linear equations**

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



2 LARGE EGGS
$3.50
6 g protein
5 g fat

3 BACON SLICES
$4.00
8 g protein
8 g fat

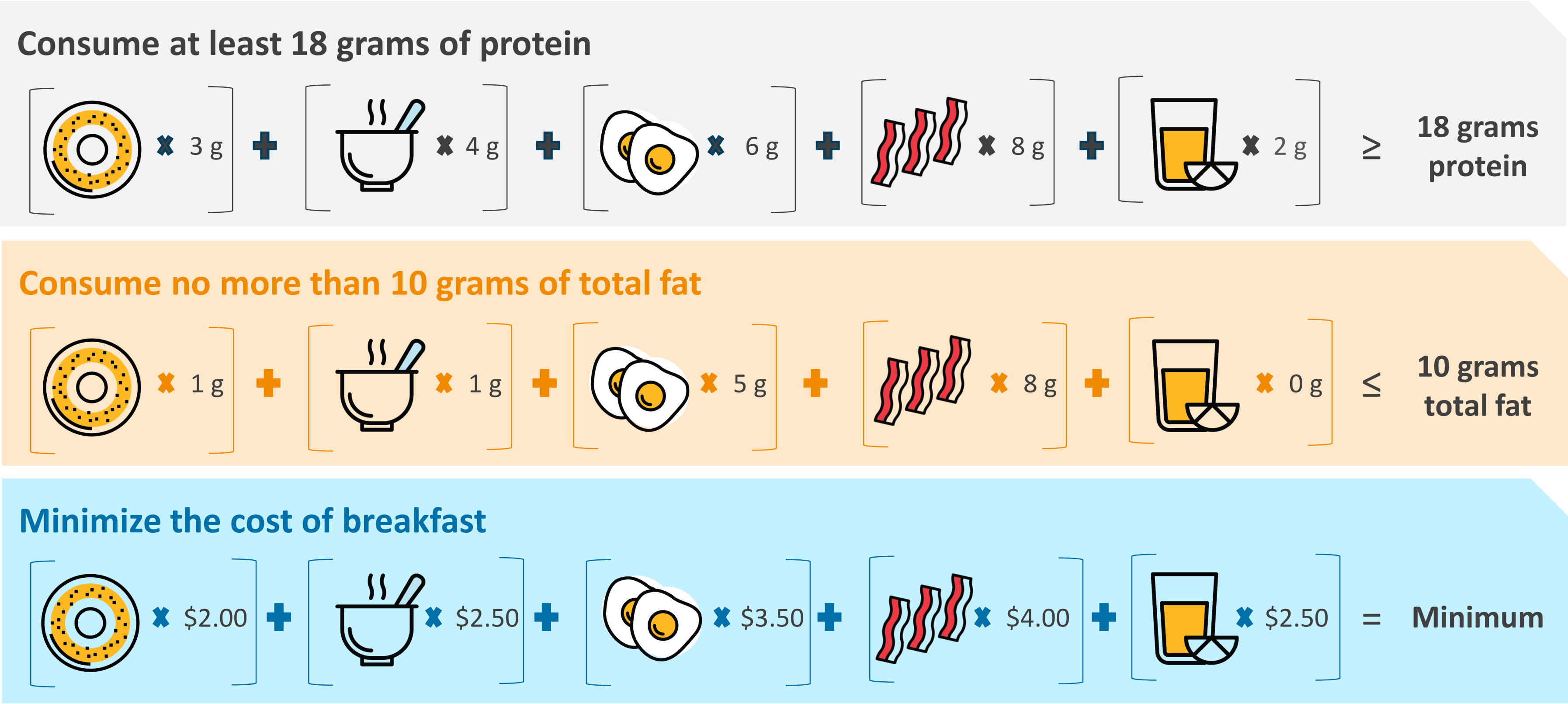
1 CUP OATMEAL
$2.50
4 g protein
1 g fat

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

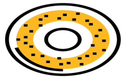
Optimizing Breakfast from an Engineer's Point of View

Solve for number of servings of each item:



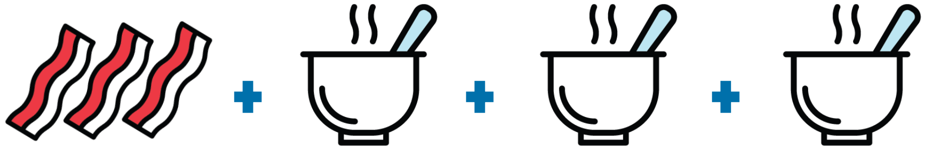
Even with only five food choices, there are so **many possible combinations** that using trial and error to find the one with the lowest cost is not efficient

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**

Crude Oil Break Even Values

Crude Product Yields and Prices (High and Low Crude Prices)

Products	Light Sweet[1] Yields	Medium Sour[2] Yields	Heavy Sour[2] Yields	Light Sweet @ $99/bbl Prices	Light Sweet @ $51/bbl Prices
Refinery gases	3%	2%	1%	$49	$31
Gasoline[3]	32%	24%	15%	$108	$60
Distillate[4]	30%	26%	21%	$117	$69
Heavy fuel oil[5]	35%	48%	63%	$79	$41

(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.

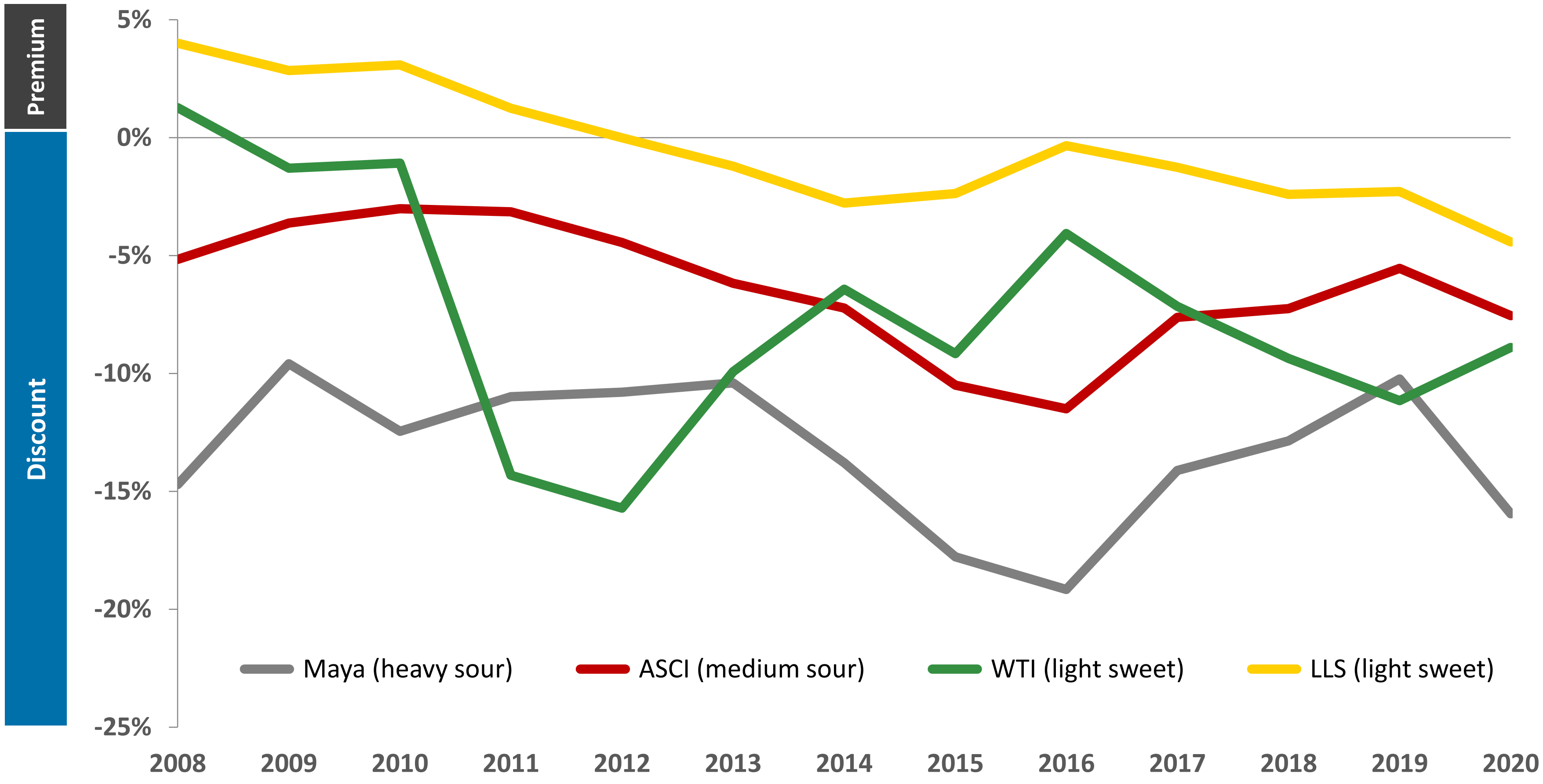
Crude Break Even Values (High and Low Crude Prices)

Crude	Light Sweet @ $99/bbl BEV	Light Sweet @ $51/bbl BEV	BEV @ $99/bbl % of Light Sweet	BEV @ $51/bbl % of Light Sweet
Medium sour	-$3.55	-$2.58	96%	95%
Heavy sour	-$7.76	-$5.65	92%	89%

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

BEV for alternate crude as a percentage of reference crude value **is relatively insensitive to flat price environment**

Crude Oil Differentials Versus ICE Brent

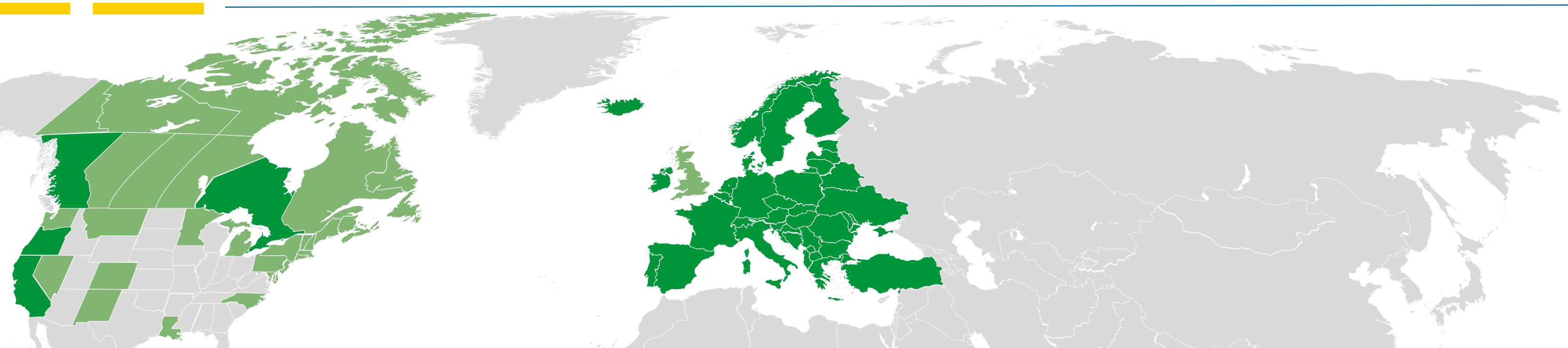


Source: Argus. ASCI represents Argus Sour Crude Index.

Martin Parrish

Senior Vice President
Alternative Energy and Project Development

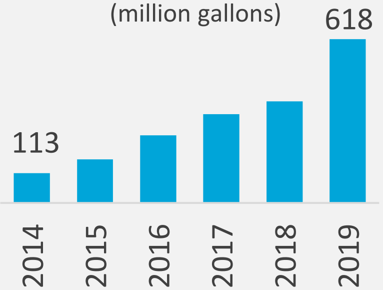
Global Low-carbon Fuel Policies Driving Demand Growth for Renewable Diesel



	2030 GHG Emissions Reduction Target	Net-Zero GHG Emissions Target	Primary Transportation Fuel Policy Mechanism	2030 Liquid Fuels Goal
California	40%	Net-zero by 2045	Low Carbon Fuel Standard (LCFS)	Reduce the carbon intensity of transportation fuels by at least 20%
Canada	30%	Net-zero by 2050	Clean Fuel Standard (CFS) – enforcement expected 2022	Reduce the carbon intensity of transportation fuels by 10-12%
EU	40%	Net-zero by 2050	Renewable Energy Directive II (RED II)	Replace 14% of transport fuels with biofuels
Other Policies in Place	• Oregon is matching California's GHG reduction target and has an LCFS policy in place • British Columbia and Ontario have existing low-carbon fuels policies • Sweden is implementing a 21% GHG reduction mandate for diesel by 2020 and aims for 50% of transport fuels to be biofuels by 2030 • Finland aims for 30% of transport fuels to be biofuels by 2030			
Potential Policies	• State of Washington continues to debate an LCFS with a 20% GHG reduction target by 2035 • New York introduced legislation that would require net-zero emissions by 2050 with the possibility of LCFS legislation • Certain Midwest states and Colorado are exploring similar renewables mandates			

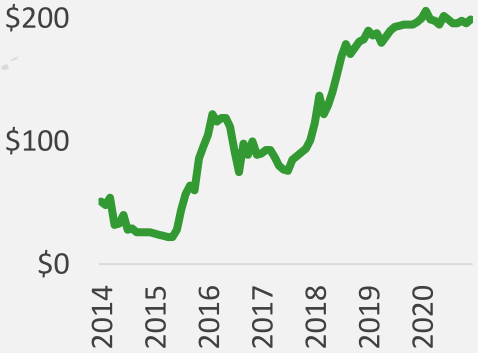
California Renewable Diesel Consumption

(million gallons)



LCFS Credit Price

(monthly average, $ per metric ton)

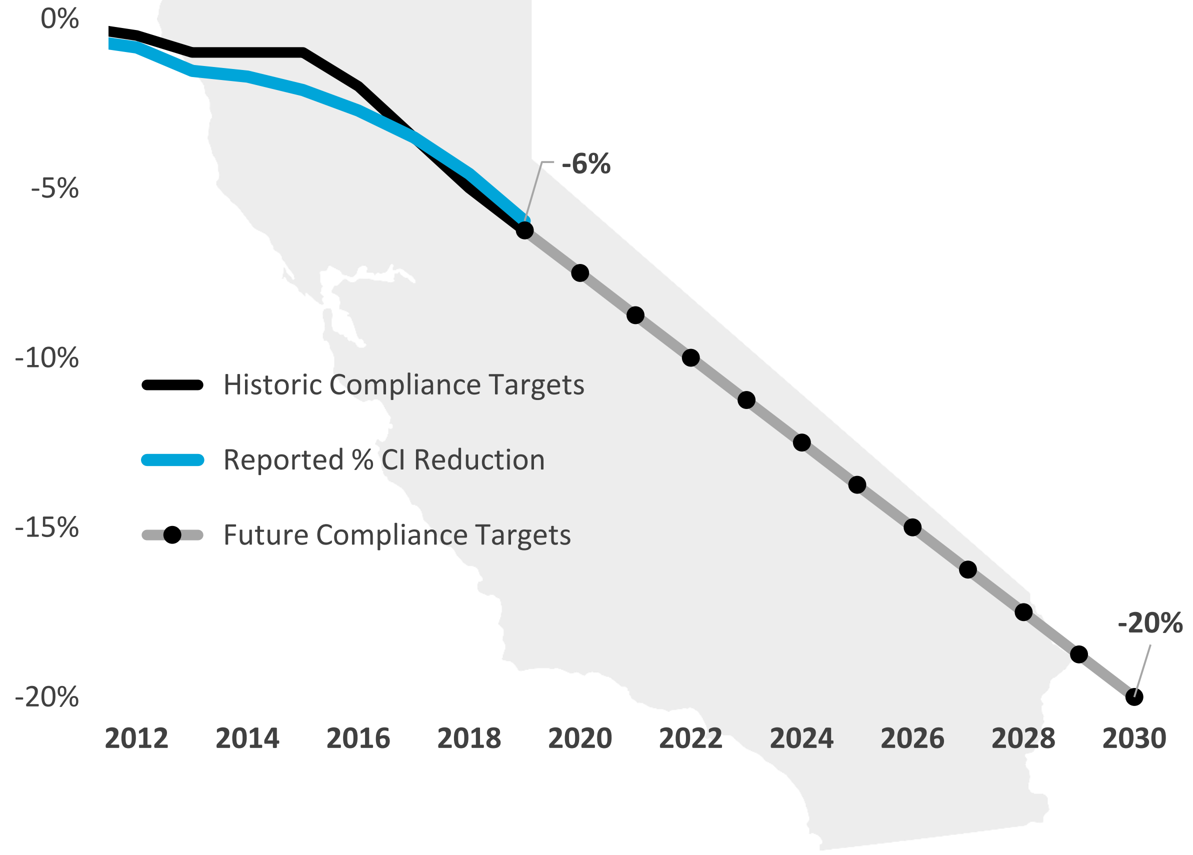


Source: California Air Resources Board. LCFS credit price through December 2020.

Renewable Diesel Driving Low Carbon Results in California

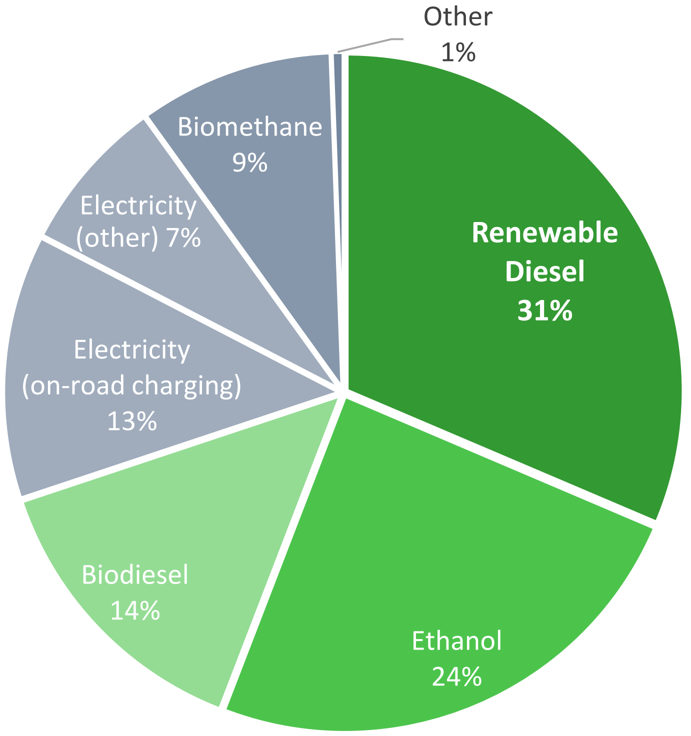
California LCFS Performance

(% reduction in carbon intensity)



LCFS Credit by Fuel Type

(2020 YTD)



Source: California Air Resources Board. 2020 through June 30.

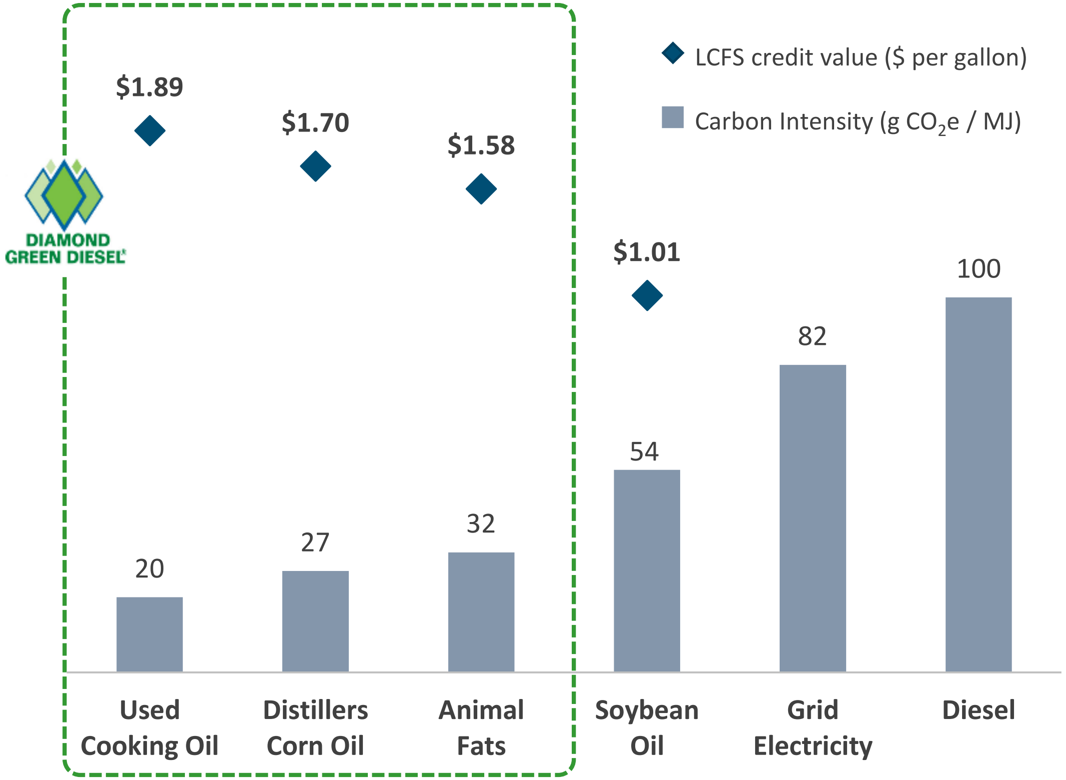
Cost-effective fuel that can be used with existing vehicles

Does not require infrastructure investments

Over 2 billion gallons consumed since 2011

Diamond Green Diesel (DGD) Feedstock and Margin Indicator

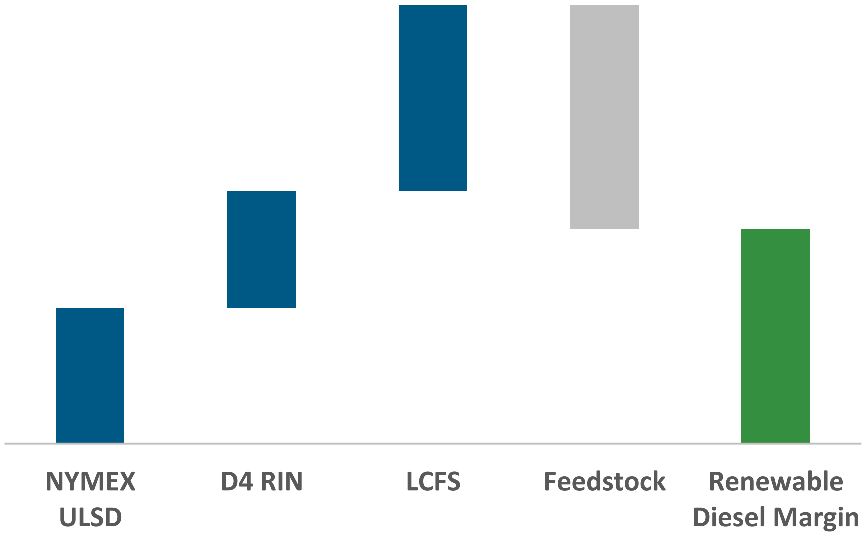
DGD Feedstock Carbon Intensity and Product Value



DGD Margin Indicator

$ per gallon

New York Ultra Low Sulfur Diesel (ULSD) price ($ per gallon)
+ 1.7 * Renewable Identification Number (D4 RIN, $ per RIN)
+ 0.007 * Low Carbon Fuel Standard (LCFS) credit ($ per metric ton)
- 8.5 * Chicago Soybean Oil price ($ per pound)

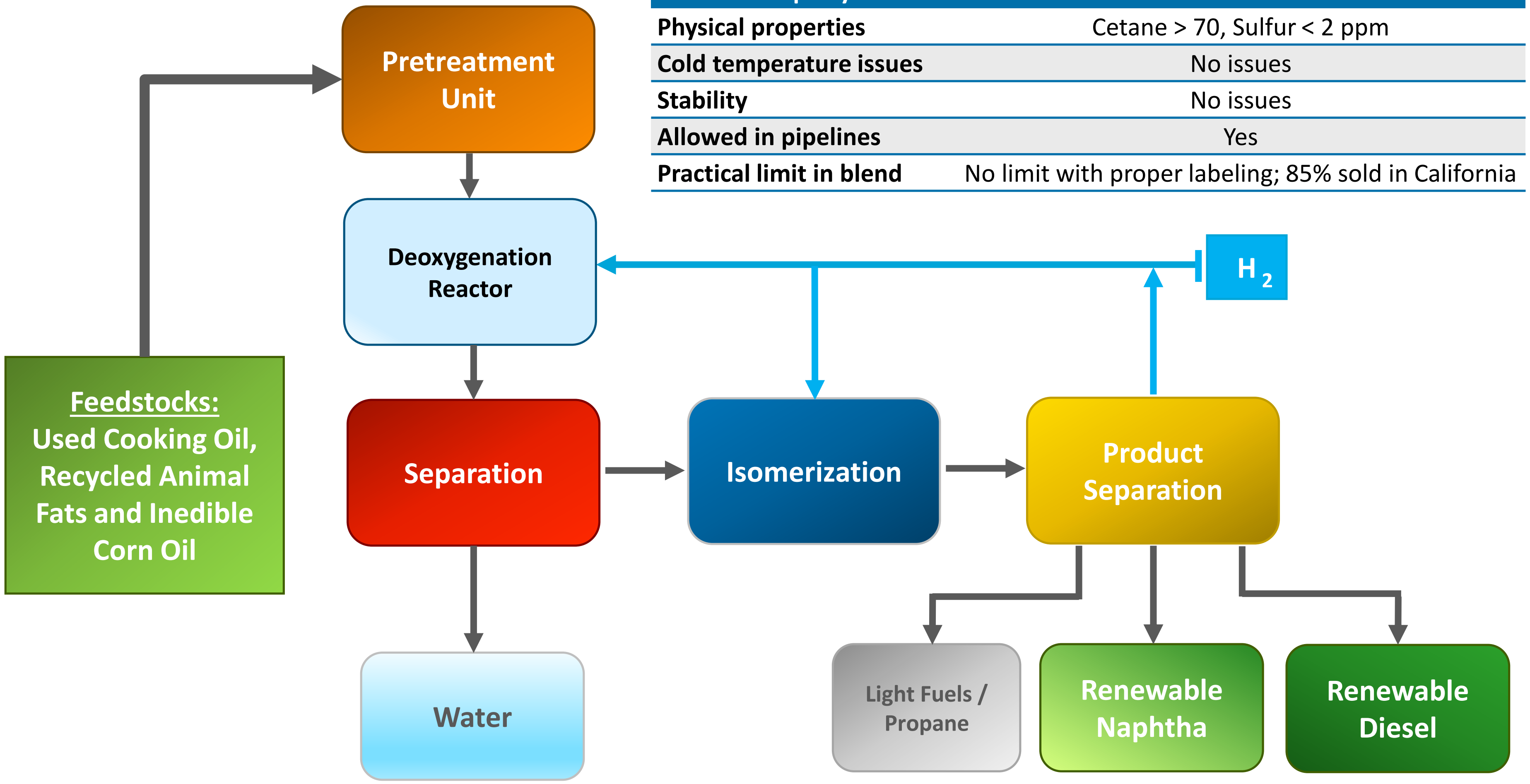


Source: California Low Carbon Fuel Standard (LCFS) 2020 values, assuming $200 per metric ton carbon price.

DGD is designed to process low carbon feedstocks for higher product value

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; 85% sold in California



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

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 (FCC)
- **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
- **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)
- **SOX** – Sulfur Oxides
- **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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