Oil refining

An oil refinery takes crude oil - "unprocessed" oil, the stuff that comes out of the ground – and turns it into a number of products that have commercial and industrial uses. Gasoline is one product we know, but there are many others, including petroleum gases such as methane and butane, kerosene (also known as jet fuel, i.e. the stuff that we burn in airplanes), diesel fuel, lubricating oils (like the liquid oil you put in your car, or the precursors to greases), and various other less valuable by-products. Heavy residual oil after the other products have been separated out is known as fuel oil and is burnt in oil-fired turbines or furnaces. The final sludgy stuff at the end of the refining process is asphalt, tar, and wax, and uses are found for all of it.

Oil refining is essentially separation of these different products from crude oil, which is a mix of many different compounds. In the early days of the fossil fuel era, refineries separated out the products with highest economic value and simply dumped the remainder. Nowadays obviously dumping is illegal, and refineries must make something saleable out of every last bit of crude.

Crude oils are largely composed hydrocarbons – as the name suggests, molecules composed of carbon (C) and hydrogen (H). Like other fossil fuels, they are the remnants of undecayed plant matter, generally millions of years old, that has been chemically modified by heat and pressure within the Earth. During that modification most (but not all) of the oxygen has been driven off the original carbohydrates (e.g. C₆H₁₂O₆), leaving only the Cs and Hs behind. Although that sounds like a fairly simple substance, crude oils are mixtures of a vast an bewildering array of molecules of different lengths and structures, from the simplest hydrocarbon, methane (CH₄), with a single carbon atom, that wants to be a gas at room temperature and pressure, to chains of carbons (with hydrogens hanging off them) that are liquids or, for very long chains (up to 80 carbons), even solids. The carbon atoms can be arranged in straight chains, branched chains, rings, or even linked rings. Since the hydrocarbons are broadly sorted in characteristics by the number of carbons, they are often described by that number. Any chemical you’ve heard of that ends in “ane” (butane, hexane) or “ene” (ethylene, benzene, acetylene) is a hydrocarbon and a component of crude oil.

Each crude oil is different, and the same well can produce crude of different composition at different times. Crudes can be black or nearly clear, as “runny” as water or as viscous as tar. (The lighter varieties are sometimes called “sweet” crude). Most crude flows well enough to be transported in pipelines, but crude from the tar sands in Alberta is too viscous to flow until it is pre-processed at the mining site. The vast diversity of crudes means that oil refining is chemical engineering as an art form, because refineries have to adjust their processes with each new batch of crude to accommodate its character. The diversity of crude also means that refineries will get out different products with each new batch of crude. The BP
Whiting refinery is especially versatile in what it can handle, having just spent > $3B to build a new unit capable of processing heavy crude from tar sands.

Oil refining typically involves many distinct manipulations of the crude, including

- Distillation
- Catalytic cracking
- Reformulation

Each process takes place in a separate specialized facility or “unit” at the refinery, and the crude, or separated out parts of it, are moved through the refinery from unit to unit, in each of which it receives a different chemical manipulation. Other units that the crude will pass through include a separation unit that removes sulfur impurities that would otherwise result in sulfur dioxide pollution when the resulting fuels are burnt. As you are driven through the refinery, you’ll have the different units pointed out in succession.

The heart of oil refining is the distillation of the crude into separate components, and this is typically the first manipulation the crude experiences. “Distillation” means just what it sounds like. The crude oil is heated until it vaporizes and the vapor is passed into a tall tube called the “fractional distillation column”, where it rises and cools, so that the column is much hotter at the bottom than it is at its top.

![Distillation column, figure from BBC](image)
As the vapor cools, different components will begin to condense out at different temperatures, and so at different heights in the column. (That is, they have different boiling points). These different components are collected on trays and separated into perhaps 8 or so distinct “fractions” of the original mixture. As you might expect, the longer-chain components (e.g. fuel oil and waxes) condense out first, the lighter liquids (e.g. gasoline) later, and the smallest molecules, the gases, don’t condense at all but are collected off the top of the column.

Distillation separates out some immediately saleable parts of the crude oil, but generally the distilled components receive further treatment to make the desired output product. Other units can break hydrocarbons into smaller pieces (“cracking”), or combine (“reform”) or otherwise alter molecules. Heavy fuel oil is often passed through a cracker to reduce its chain length and viscosity or “stickiness”. Gasoline often has specially processed high octane molecules added to it to prevent knocking (premature firing) in engines. The very sludgiest residue from distillation is “coked” in the coking unit, i.e. heated to drive off all volatiles and leave behind a solid mass of carbon, which can itself be then burned as a solid fuel.

It’s important to recognize that even after all this processing and chemical tweaking, final products are not generally a uniform substance but are still mixtures of many different molecules. Gasoline is still a complex mixture, and the different grades of gasoline (“regular” or “premium”) have different mixes of components.

At BP Whiting, you should look for many different units or stages in the processing of oil, including

- pipelines carrying crude to the refinery
- tank farms where the crude is stored
- distillation columns
- catalytic crackers
- reformers
- sulfur removal units
- power generation (BP Whiting has its own combined-cycle cogeneration power plant to generate the electricity that the refinery runs on)
- cokers
- steam reforming unit that produces hydrogen
- boiler plants for heating
- control room

Starting in 2006, BP Whiting has been building a new unit for treatment of tar sand crude; that may or may not be in operation this year. If you notice this or other particular units that are of interest, note them down and we’ll put them on the list to watch for next year.
For those concerned about environmental impacts, the BP Whiting plant appears to be in compliance with Illinois regulations. Some other states do have tighter environmental regulations, and plants there operate under more stringent standards. When we toured in 2009 the engineer bringing us around said “in California, you can eat off the ground at an oil refinery”. Similarly, the extent of sulfur removal that is done is that mandated by air quality regulations. High-sulfur fuel burns just as well, and the consumer would not notice the difference. Sulfur stripping raises the price of fuel, and refineries therefore remove as much as regulations mandate.

The BP Whiting refinery itself was first put into operation in 1890, before the automobile era. It processed 17,000 barrels of oil a day (in those days actually shipped in barrels), primarily for kerosene (which was used in lamps and in cooking); the gasoline was discarded. It is currently the 5th largest refiner in the U.S. and can process over 400,000 barrels of oil a day, turning it into over 15 million barrels of refined products per day; its byproduct asphalt makes up 8% of all asphalt production in the U.S. When you drive in the Chicago area, the gasoline you’re burning has almost certainly come through the BP Whiting refinery. Love it or not, unless you’re a non-driver, you are BP Whiting’s customer.

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