Kansas Department of Health and Environment

Bureau of Environmental Remediation/Remedial Section

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Petroleum Refining: A 125 Year Kansas Legacy

Kansans have been trying to gather and market petroleum since before Kansas was made a state in 1861. As early as 1855 petroleum was being found in springs and seeps near Osawatomie and Paola. The oil would be skimmed off and bottled to be sold as medicine, since industry had not realized the massive potential of petroleum.

However, a number of things had to happen before petroleum could become anything resembling an industry in Kansas. The first oil well in the pioneering oil fields in Pennsylvania wasn't drilled until 1859. The Civil War interrupted Kansas' economic development. The refining and uses of petroleum had not yet been developed. Kansans were still traveling over wagon trails; the railroads wouldn't crisscross the state until nearly the 1870's. But since then oil and gas has become a $4.3 billion industry in Kansas, employing tens of thousands and providing an essential tax base for the state. Only agriculture exceeds oil and gas in economic importance.

The Mid-American Refining Company facility after it was closed in 1981. This refinery operated in Chanute for 48 years.

Finding, drilling, and extracting petroleum is only the beginning of the story. Oil is little more than a useless potential pollutant until it can be refined and marketed, at which point it is essential to modern life. Kansas has never been the most important petroleum-producing state, but our history reflects the advancement of the American petroleum industry from its most primitive form to the high-tech system it is today.

Development of the Refining Industry

Once the Civil War ended, Kansas entrepreneurs wanted to follow the lead of the booming Pennsylvania oil business and look for oil in Kansas as well. Logically they started in places where oil had already been found, such as at Wea Creek near Paola. The process of finding oil was hit-and-miss at the time, and what oil was collected had to be placed in wooden casks and shipped out for refining. It wasn't until 1886 that an oil refinery, a primitive facility

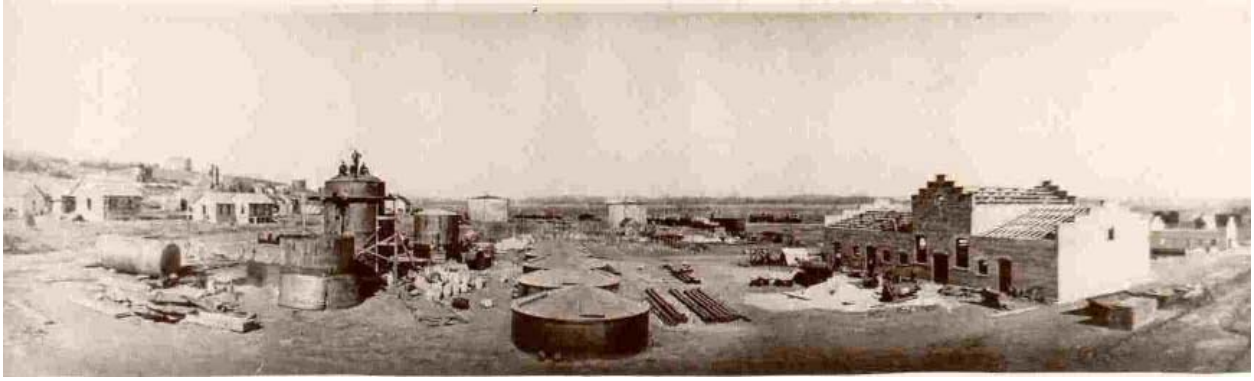
capable of processing 25 barrels of crude oil a day, was constructed in Paola. However, this refinery did not last very long, and Paola didn't get another refinery until the Paola Refining Company constructed one in 1905.

Kansas did not have any refineries to purchase crude oil from the fields, and this hindered oil field development. The nearest refinery was in Chicago, and it was not economical to ship crude oil by rail such a long distance. There were many proposals to build a refinery in Wilson County, which had become an oil-producing center in the 1890's. In 1897 Standard Oil built a state-of-the-art refinery near Neodesha.

Standard, which had been profitably pumping, refining, and marketing petroleum products in the East, was well-positioned to become Kansas' premiere refinery. The company was well-capitalized and could afford to install steel storage tanks and pipelines to gather crude oil from the fields, and negotiate favorable railroad freight rates. Standard had an experienced marketing staff and the most experienced and innovative refinery managers in the business. Kansas oil producers were enthusiastically expecting Standard to purchase all the oil they could pull out of the ground.

Furthermore, Standard had a reputation for producing high quality products, primarily lubricants and kerosene, both of which were desperately needed in a state that by 1890 was already approaching a population of 1.5 million people. Kerosene was used in lamps for lighting and also in heaters and cooking stoves. The purity of kerosene was important— too great a percentage of naphtha and the fuel became dangerously explosive.

Over the next few years, however, Standard's preeminence in the industry became worrisome for the Kansas oil men. There was a general suspicion of monopolies and trusts. Small businessmen and entrepreneurs were critical of Standard's influence in the Kansas oil industry; Standard controlled nearly half of the production, most of the pipelines, and the sole refinery in Kansas. Overproduction of oil flooded the Neodesha refinery with far more oil than it could use and crude prices fell precipitously. Oil men, expecting high profits in return for their risk and their labor, began to complain.



The Sunflower State Refining Company in Niotaze, built in 1905. This was the only refinery in the state built and managed by a woman, Miss Hermena Kaessmann. The refinery was the largest in Kansas for several years.

Politicians and businessmen began agitating for a state-run refinery to provide competition for Standard. To get past a constitutional ban on the state government

When the Mid-America Refining Company was closed, there was still oil in the tanks and pipelines. Years later, the oil began to leak onto the ground.

engaging in commerce, it was proposed that prison inmates be employed as refinery workers. The state refinery was never built, but many private refineries were. There were 16 refineries built between 1904 and 1910, in Atchison, Caney, Chanute, Cherryvale, Coffeyville, Erie, Humboldt, Independence, Kansas City, Longton, Niotaze, Paola, and Petrolia. One of these was the National Refining Co., which still exists as Coffeyville Resources in Coffeyville.

Some of these refineries lasted only a few years, while most managed to survive declining supplies from nearby oil fields, increased competition, and the evolution of refining technology for ten years or more.

These early refineries were very primitive, operating more like alcohol distilleries than the sophisticated petrochemical operations of today. Kansas law at the time said that the oil producer could lay claim to all the oil he could pump out of the ground, and this encouraged overproduction from a forest of closely spaced oil wells. The production companies had to store all the oil they pumped until it could be shipped to a refinery by pipeline or tank car. The best steel or wood tanks available at the time were not very airtight, and up to five or six percent of the oil volume could be lost per year due to evaporation. In addition, the evaporative vapors could be explosive. Fires caused by accident or lightning strikes were devastating.

It made sense to build simple refineries within or near the producing oil fields. A "skimming plant" could use the simplest distillation methods to extract kerosene, the most valuable product until 1915, and other light fractions such as gasoline and naphtha. The residue, approximately half the volume of the unprocessed crude oil, was too heavy to vaporize under normal conditions and could be stored in tanks until it was shipped out to be processed into lubricating oils and greases, or sold as fuel oil. There was only a very limited market for gasoline or naphtha, and their explosiveness made storage a problem, so excess amounts of these products might simply be poured into an open pit and burned just to get rid of them. The very lightest fractions of methane, butane, and propane would probably just escape into the atmosphere or be flared off.

These simple refineries could be taken out of service as production from local oil fields or the demand from local markets declined, or as the equipment wore out or was made obsolete by new refining techniques and technologies.

A refinery would sell its products to local "jobbers," who would run retail operations.

Sometimes old structures still exist at former refinery sites. This is a photograph of KDHE personnel taking soil samples at the H&H Refinery in Osawatomie. The refinery was active from 1919 until 1923.

Contamination has the potential to migrate from a site into the surrounding areas. Here, contaminated rainwater is beginning to flow into the local watershed.

Some would deliver kerosene from a tank on the back of a wagon to homes and businesses. Hardware and grocery stores stored barrels of kerosene and other petroleum products in the back of the store; a customer would bring his own container to be filled from the barrel.

The Kansas oil industry began a new boom in 1914 when the rich oil fields near El Dorado were discovered. These fields were the first to be found by analyzing the underlying geology of the area. This approach proved so powerful that it is still being used in oil exploration today. Soon tens of thousands of barrels of oil were being produced per week.

To handle the new production, new refineries were built, particularly to fill the need for fuel oil and gasoline to help the American war effort in World War I. There were 29 new refineries built in Arkansas City, Augusta, Chanute, Cherryvale, Coffeyville, El Dorado, Humboldt, Hutchinson, Kansas City, Moran, Osawatomie, and Wichita.

World War I proved the utility of gasoline engines for automobiles and trucks, and gasoline became more important as a refinery product. Ocean-going steamships converted from using coal as their primary fuel to using heavy fuel oil, which had the advantage of being pumped into the engine rather than being shoveled. In response to the changing market, refineries researched ways to increase the amount of gasoline and other valuable products extracted from every barrel of crude oil. These investigations were kept secret to prevent competitors from stealing the refiners' ideas. They also developed better materials and techniques for building refinery equipment, to make it easier to manage and more durable. The stills and condensers were being run at more precise temperatures and pressures to produce better products. Even so, it wasn't until the 1920's that industrial chemists began making serious investigations into the nature of crude oil and developing scientific methods for distilling and treating crude oil into marketable products.

Since each refinery could market their own brands of fuels and oils, a reputation for quality was important. Advertising became more sophisticated and important, and one way refineries began to market their product was through developing networks of dedicated filling stations. These stations used underground fuel storage tanks, because they were out of the way and the cool earth helped prevent gasoline from evaporating. The fuel pumps were in front of the station, rather than being hidden in the back

yard, and often had glass reservoirs on top of them so the customer could judge the quality of the fuel by its color and clarity. Filling stations also provided mechanical services and free radiator and tire filling. The refinery's marketing department insisted that the stations be kept tidy and attractively landscaped. As a result, the customer became more aware of brands of gasoline and oil, a development that helped drive the success of the major oil companies that continues today.

One challenge for refinery managers was the rapid technological development and improvement of engines for automobiles, airplanes, tractors, ships, and other motorized vehicles. The engineers designing these engines worked on improving performance, fuel economy, and ease of maintenance. They decided that for best engine performance, there needed to be a supply of consistently high-quality fuel and lubricants, and the refineries worked hard to fill this need.

As a result, each refinery built a state-of-the-art laboratory where professional chemists would constantly test the quality of each step of the refinery process. The crude oil coming into the refinery would be tested for its specific gravity, proportions of paraffin compounds to asphalt compounds, type and amount of contaminating materials, and other features. From this data, the chemists and process managers would coordinate the most effective way of refining the desired products from the crude oil. The refinery's chemists would also experiment with new equipment and processes to discover better, more efficient refining methods, and develop new high value products.

For example, refineries began to use pressurized stills and high temperatures to thermocrack gas oil into the more lucrative gasoline. These techniques required tanks, stills, furnaces, piping, and valves that could handle the stresses. Sometimes an accident was catastrophic, such as when the Dubbs cracking units at the Moore Refining Co. in Arkansas City exploded, igniting a fire that destroyed the entire refinery. Only part of the refinery was ever rebuilt, operating as the Arkansas City Refinery Co.

Thermocracking wasn't the only advanced process being developed. New methods were created to turn unprocessed crude oil into final products in a single pass without storing, reheating, and reprocessing intermediate products. Many skimming plants, located in or near the oil fields, began to go out of business in the 1920's and 1930's, replaced by refineries that could handle more complex equipment and processes.

Left, the Warren Petroleum Co. refinery in Galva in 1938. Its small size and relative simplicity, as well as its location in a well field, indicate this was a skimming plant. On the right is the Vickers Petroleum Company in 1967. This was a complete refinery, capable of turning crude oil into dozens of products.

Even with the more complex equipment and processes, 43 refineries were built, changed hands, or continued to operate during the 1920's, in Arkansas City, Augusta, Baxter Springs, Chanute, Cherryvale, Coffeyville, El Dorado, Erie, Florence, Fredonia, Humboldt, Hutchinson, Kansas City, Moran, Neodesha, Osawatomie, Potwin, Russell, and Wichita.

The economic crisis of the 1930's did affect the petroleum industry; however, demand for fuels remained relatively steady throughout the decade. This period is marked by an expansion in the national pipeline system, which made it cheaper to deliver refined products to market. For the first time more petroleum products were delivered by pipelines than by rail or barges. Independent pipeline companies encouraged product quality standards, because it was easier to schedule the delivery of a quantity of fuel of a standard quality, rather than a specific batch of fuel from a specific refinery. However, most pipelines were owned by vertically integrated production, refining, and marketing companies, who owned the oil they were transporting.

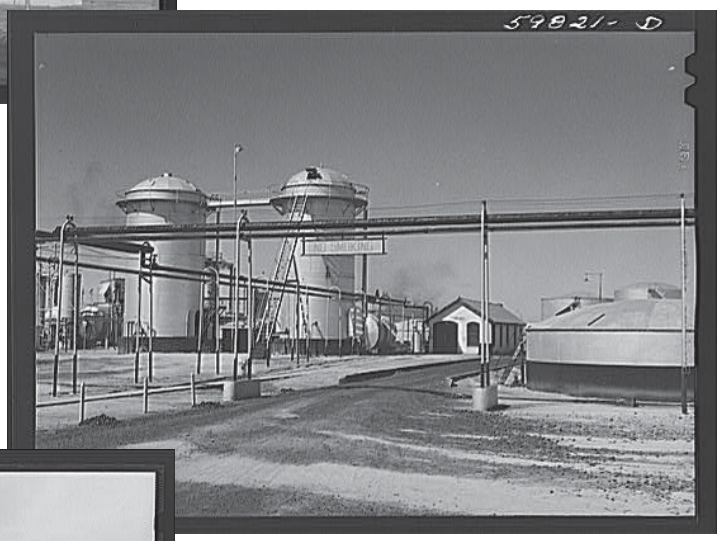
31 refineries operated in the 1930's in Arkansas City, Chanute, Chase, Coffeyville, El Dorado, Fredonia, Galva, Garnett, Great Bend, Hutchinson, Kansas City, Natoma, McPherson, Neodesha, Parsons, Phillipsburg, Potwin, Russell, Scott City, and Wichita.

Catalytic cracking was introduced in 1938 by the Houdry process. This process was more efficient than previous attempts to commercialize cracking oils; thermocracking required a great deal of heat, and experiments with previous catalysts proved too expensive or inefficient. The Houdry process enabled refineries to produce abundant gasoline relatively cheaply.

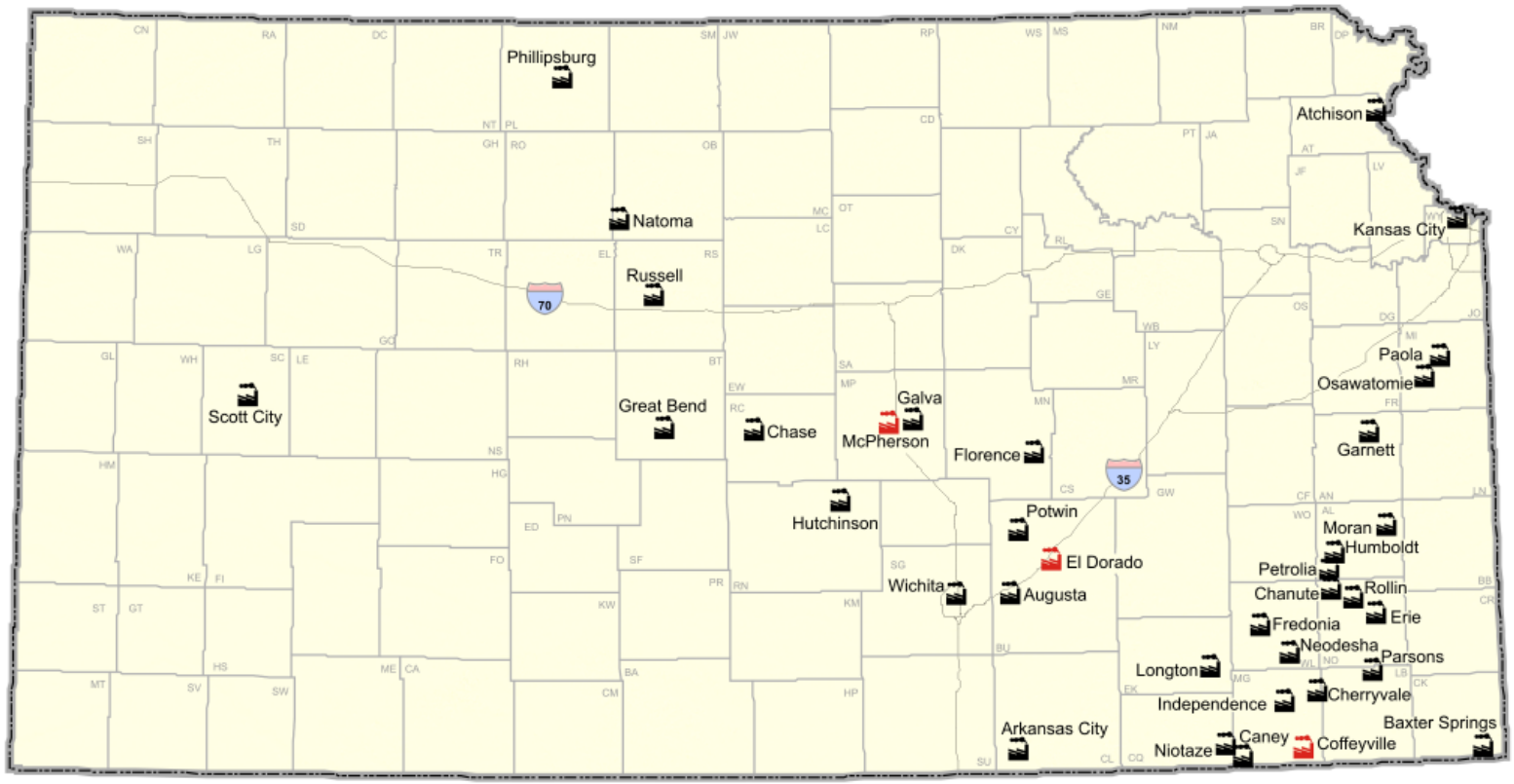
Since 1940 few new oil refineries have been built in Kansas. The refineries that have operated since then have slowly closed as the oil industry consolidated. Economic conditions, the need to upgrade equipment in response to technology changes, and government policies, including environmental regulations, encouraged small refineries to close and large refineries to get larger. Nationally, most of America's refining capability is along the East, West, and Gulf Coasts, near international shipping corridors and population centers. Today only three Kansas refineries still exist: Coffeyville Resources in Coffeyville, Frontier Refining Co. in El Dorado, and the NCRA Refinery in McPherson.

This photograph was taken of the Coastal Derby refinery in Wichita during the years the facility was being demolished. This was the Derby Oil Company from 1920 until 1955, the Colorado Interstate Gas Company from 1955 to 1973, and the Coastal Derby Refining Company from 1973 until 1993. Contamination at the site is being addressed by El Paso Merchant Energy – Petroleum Company.

Barnsdall Refinery
Wichita
1926-1951



Petroleum Refinery Towns



Interstate

Historic Refineries

Active Refineries

COUNTY

Kansas Refinery Locations and Dates

Arkansas City

Lesh Refining Corp.	1915-1924
Milliken Refining Co.	1917-1919
Kanotex Refining Co.	1917-1996
Simms Petroleum Co.	1920
Mid-Co. Petroleum Co.	1920-1922
Moore Refining Co.	1922-1925
Roxana Petroleum Co.	1923-1928
Arkansas City Refining Co.	1925-1938
Shell Petroleum Corp.	1929-1938

Atchison

Uncle Sam Oil Co.	1906-1910

Augusta

Walnut River Refining Co.	1917
Bliss Oil and Refining Co.	1917-1919
White Eagle Oil and Refining Co.	1917-1934
Universal Petroleum Corporation	1920
Crystal White Oil Co.	1921-1922
Harvey Crude Oil Co.	1921
Socony-Vacuum Oil Co./Mobil Oil	1935-1983
Augusta Oil Refining Co.	1917-1922
Lakeside Refining Co.	1917-1923
Grant Oil Co.	1923-1926
Equitable Refining Co.	1922-0923

Baxter Springs

Good Eagle Refining	1920
General American Oil Co.	1921-1923
McCree Petroleum Co.	1923

Caney

Kanotex Refining Co.	1907-1919

Chanute

Kansas Refining Co.	1905
Kansas Co.-Operative Refining Co.	1905-1917
Chanute Refining Co.	1905-1916

Chanute continued

Cudahay	1916
Kanotex	1917
Morgan Refining Co.	1917
Sinclair Refining Co.	1917-1921
Mutual Oil Co.	1919-1924
Peerless Oil and Refining Co.	1921-1931
McWhorter-Chanute Refining Co.	1923-1923
Altitude Petroleum Corp.	1931-1934
Petroleum Products Co.	1933-1942
Chanute Refining Co.	1935-1963
MARCO. (Mid-America Refining Co.)	1943-1956
Warwick Wax Co.	1943-1946
Sun Chemical Corp.	1946-1959
Western Petrochemical Corp.	1959-1979
Petrolite	1979
Mid-Region Petroleum	1989-1996

Chase

Security Petroleum Co.	1934-1935
Cusco Oil and Refining	1935-1937
Western Refining Co.	1935-1936
Chase Refining Co.	1936-1939

Cherryvale

Uncle Sam Oil Co.	1905-1921
Wright Producing and Refining Co.	1917-1919
Imperial Refining Co.	1921-1923

Coffeyville

Kansas Oil Refining Co.	1905-1926
National Refining Co.	1906-1944
Cudahy Refining Co.	1913-1916
Sinclair Refining Co.	1917-1948
Cooperative Refining Association	1944-1982
Farmland Industries	1982-2004
Coffeyville Resources Refining and Marketing LLC	2004-present

El Dorado

Trapshooters Refining Co.	1917
Midland Refining Co.	1917-1923
El Dorado Refining Co.	1917-1958
Reliance Refining Co.	1918
Railroad Men's Refining Co.	1918-1919
Fidelity Refining Co.	1919-1921
Tri-State Oil and Refining Co.	1919-1921
St. Louis Oil and Refining Co.	1919-1923
Red Ball Refining Co.	1921-1922
Associated Producers and Refining Co.	1921-1923
Bell Producing and Refining Corp.	1921-1923
Marigold Refining Co.	1922
Richardson Refining Co.	1922-1925
Industrial Refining Co.	1923-1925
Skelly Oil Co.	1923-1977
Fina Oil and Chemical Co.	1958-1977
Pester	1977-1982
Getty Oil	1977-1982
Texaco	1982-1999
Frontier Refining and Marketing	1999-present

Erie

Great Western Oil Refining Co.	1905-1923

Florence

Great Western Petroleum Corp.	1922-1923
Gordon Refining Co.	1923-1924

Fredonia

Red Bird Refining Co.	1923-1926
Fredonia Oil and Refining Co.	1937-1940

Galva

Warren Petroleum Co.	1935-1942

Garnett

Anco Refining Co.	1939-1940

Kansas Refinery Locations and Dates

Great Bend

Falcon Refining	1932-1942

Humboldt

Miller Petroleum Co.	1904-1929
Stewart Oil Refinery	1906
Minnetonka Refining Co.	1917-1920

Hutchinson

Hutchinson Refining Co.	1915-1919
Hutchinson Petroleum Co.	1920-1921
Frontier Refining Co.	1921-1925
United Oil and Refining Co.	1925-1926
Hutchinson Oil Refining Co.	1928-1929
Sunflower Refining Corp.	1933
United Oil and Refining	1933-1935
Hutchinson Oil and Refining Co.	1933-1935

Independence

Petroleum Products Co.	1916
Standard Asphalt and Rubber	1916
Empire Refining Co.	1919-1922

Kansas City

Kansas City Refining Co.	1907-1926
Uncle Sam Oil Co.	1909-1916
Rosedale Refining Co.	1916-1917
General Refining Co.	1917
Sinclair Refining Co.	1917-1948
North American Refining Co.	1919-1923
Miller Petroleum Co.	1920
Prairie Refining Co.	1922
Indiana Refining Co.	1921
Manhattan Oil Co.	1926-1929
Independent Oil and Gas Co.	1929-1931
The Fairfax Gasoline Co.	1931
Phillips Petroleum	1931-1982
Coral Refinery	1970-1978

Longton

Superior Refinery	1905-1908
Kanotex	1908-1909

McPherson

Dickey Refining Co.	1933-1937
Globe Oil and Refining Co.	1933-1943
Bay Petroleum	1937-1953
National Cooperative Refining Assoc.	1943-1999
Cooperative Refining	1999-2000
National Cooperative Refining Assoc.	2000-Present

Moran

Eastern Kansas Oil Co.	1915-1917
Commonwealth Oil and Refining Co.	1919-1926

Natoma

Kreuger Refining Co.	1934-1938

Neodesha

Standard Oil Co.	1887-1970

Niotaze

Sunflower State Refining Co.	1905-1909
Miller Refining Co.	1912
Niotaze Refining Co.	1913-1915
Schock Refining Co.	1915
O. K. Refining Co.	1916-1919

Osawatomie

H&H Refinery Co.	1919-1923

Paola

Paola Oil, Gas and Mining Co.	1886
Paola Refining Co.	1905-1909

Parsons

Roper Petroleum Co.	1938-1940

Petrolia

Petrolia Refining Co.	1906-1909
Kansas Crude Oil Co.	1914-1916

Phillipsburg

Cooperative Refining Assoc.	1938-1982

Potwin

Vickers Petroleum Co.	1920-1970

Rollin

Rollin Oil Refinery	1915-1916

Russell

West Kansas Refining Co.	1925-1926
Russell County Pipe Line Co.	1926
Derby Oil Co.	1926-1929
Russell Refining Co.	1935-1937
United Refining Co.	1937-1939

Scott City

Shallow Water Refinery	1937-1981

Wichita

Wichita Independent Oil & Refining Co.	1914-1918
Derby Oil Co.	1916-1955
Sterling Oil and Refining Co.	1916-1924
Evans-Thwing Refining Co.	1917-1919
Golden Rule Refining Co.	1917-1943
Blue Ridge Refining Co.	1921-1922
Fugatt-Giles Oil Corp.	1921-1923
Tuxedo Oil and Refining Co.	1922-1923
Kansas-Texas Oil & Refining Co.	1923-1924
Tri-State Oil & Refining Corp.	1924
Waite Phillips Co.	1924-1926
Barnsdall Refining Co.	1926-1951
Super Refined Oil Co.	1950-1970
Colorado Interstate Gas Co.	1955-1973
Coastal Derby Refining Co.	1973-1993

Sampling the contents of abandoned oil drums at the Western Petrochemical refinery site.

Petroleum Products

The first really important product made from petroleum was kerosene, which was sold to be used in lamps, space heaters, cooking stoves, and internal combustion engines. Today it is sold also as liquid paraffin for decorative lamps and is a primary component in jet fuel. The highest quality kerosene was a clear as water, contained no sulfur compounds which would cause a stink as it was used, and had a flash point of at least 110° F. As early as 1879 Kansas had laws regulating the purity and safety of lamp oils.

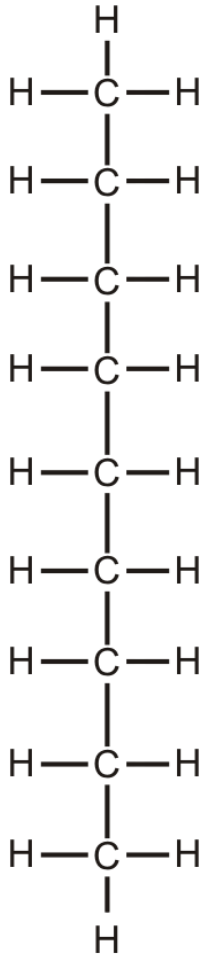
When we think of petroleum products today we usually think of gasoline that we put in our cars. Gasoline is a mixture of hydrocarbons, lighter than kerosene with a lower flash point. Before gasoline automobile engines became common, gasoline and naphtha would be used as a grease-cutting solvent. Gasoline can be extracted from crude oil by distillation (straight-run gasoline), or by thermal or catalytic cracking. It can also be condensed from the product of natural gas wells— this is called casinghead gasoline. The various types of gasoline are blended together to produce gasoline with the desired characteristics.

Automobile engines are precision machines requiring fuel with very specific features. One measure of fuel quality is the octane rating scale. This scale measures how evenly a particular blend of fuel combusts in a cylinder by comparing it to a standardized mixture of iso-octane and heptane— the number represents the percentage of iso-octane in the reference mixture. The point is to prevent knocking— a phenomenon in which the fuel in a cylinder ignites prematurely, robbing the engine of power and causing wear to the cylinder.

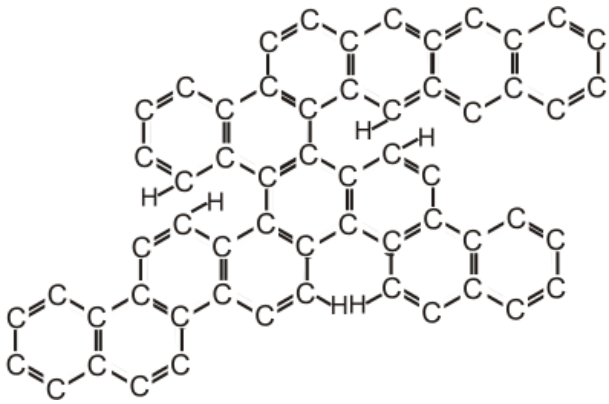
Refineries began to add tetra-ethyl lead to gasoline blends in the 1920's in order to improve their octane rating. However, the United States discontinued almost all uses of leaded gasoline in 1973, and very little is sold in the United States today. As a result, the average level of lead in the blood of Americans has been reduced. Today gasoline is often blended with methyl tert-butyl ether (MTBE) to increase the octane rating and reduce smog. While MTBE performs admirably as a fuel additive, if it is spilled or leaks into the environment, it can easily contaminate large amounts of groundwater. MTBE may be phased out soon in favor of gasoline additives such as ethanol.

Naphtha, a petroleum fraction heavier than gasoline, can be chemically converted to gasoline at the refinery, or used as an industrial solvent or as fuel for things like camp stoves.

The lightest fractions of all, hydrogen, methane, butane, and propane, might be captured and sold, used as chemical inputs for other



An example of a paraffin-type molecule. The long chains slide easily past one another, making paraffins excellent lubricants.



An asphaltic-type molecule. The high proportion of carbon results in coke formation when these are cracked into smaller molecules.

refinery processes, or used as fuel for the refinery.

Fractions of petroleum that are heavier than kerosene include light gas oil, which is used to make diesel fuel and furnace oil, or thermally or catalytically cracked to make more gasoline. The heavy oil at the bottom of the column can be used as fuel, or, depending on the nature of the crude oil used, refined into paraffin-based products or asphalt-based products.

All crude oil contains some paraffins and some asphaltenes, but the proportions of each are different for each oil field from which the crude oil comes. Paraffins are hydrocarbons that come in long, snaky chains of molecules that easily slide past one another. These make excellent lubricating oils. The large paraffin molecules, when crystallized, form paraffin wax. Another product is petroleum jelly, which is commonly used as a base for medicines and cosmetics.

Asphaltenes, however, are very complex molecules that, because of the way the carbon atoms form rings with one another, have a structure similar to that of chicken wire. Asphaltenes are thick and gummy, and used to make things like paving material and shingles.

The final residue, coke is made of almost pure carbon, and is created by thermal or cracking processes. When petroleum molecules that have a high proportion of carbon, like asphaltenes, are cracked, some of the carbon forms coke. If not properly managed, coke can clog up pipes, process units, and catalysts, shortening equipment life and decreasing efficiency. If extracted from oil residue, it can be burned as fuel, or purified for applications requiring pure carbon.

Refineries must remove sulfur from their products to improve the product characteristics and to comply with laws limiting the amount of sulfur in fuels. Powdered sulfur is one by-product of petroleum refining. Another refinery product is feedstock for petrochemical plants. A chemical company would further treat the feedstock to produce very pure products that can be used to produce anything from plastics to dyes to flavorings.

Finished liquid products, like gasoline, diesel, aviation fuel, or fuel oil, can be delivered from the refinery to terminals through a national pipeline system. From there, they are delivered to retail outlets by truck. Very large users of product, such as major airports, will commonly have dedicated pipelines delivering fuel directly to the facility.

At the Coastal Derby refinery in El Dorado, the oily material remaining in this storage tank was too thick to remove with a pump, but too thin to remove by digging. With KDHE approval, the contractor mixed this material with soil to stabilize it, at which point the mixture could be loaded onto a truck for disposal in a permitted landfill as a solid waste.

Pits found at the Mid-America Refining Company site filled with water, oil, and debris.

The Refining Process

The refining process actually begins at the oil well. The pumped oil is mixed with salt water (brine) and mud as it comes out of the well, and in the tanks, the oil, brine, and mud settle into layers. The crude oil is pumped from the top of the tank into a truck or into a pipeline for delivery to a refinery. The brine and mud is disposed of according to the well's permit; often by injecting it right back into the oil-bearing geologic formation; this repressurizes the formation makes the oil easier to pump. This injection is regulated by the Kansas Corporation Commission through a state permitting process to avoid brine pollution to the surface or groundwater.

Crude oil is not made up of only one kind of molecule; instead, it is a combination of a vast number of hydrocarbon compounds, along with a small amount of impurities and salts. The hydrocarbon compounds range from the smallest molecules such as methane, or natural gas, to large asphaltenes and paraffin chains, that can be separated from one another because they have different boiling points. The lightest molecules have the lowest boiling points, and the heaviest ones have the highest.

As the crude oil enters the refinery through a pipeline, it is tested in the refinery's laboratory to determine the kinds of hydrocarbons in it. Every oil field produces crude oil with different mixtures of hydrocarbons. A "light" crude oil has a higher proportion of lighter hydrocarbons, such as the compounds used in gasoline blends. A "heavy" crude oil has a higher proportion of heavier compounds, and may produce plenty of lubricating oil, wax, and/or asphalt. "Sweet" oil is low in sulfur, and since sulfur must be removed from oil as it is converted to fuel, it requires less processing. "Sour" oil is high in sulfur. Some crude oil has a great deal of water mixed in it as an emulsion; this water has to be removed. The choice of crude oil to be used by the refinery is dependent on price, market demand for particular products, and the refinery's processes. Crude oil is stored in large tanks until the refinery is ready to process it.

The first step is to remove excess salt from the crude oil by mixing it with water. The salt will be dissolved in the water, and as the water and oil are separated, the salt can be washed away.

The next stage of refining is atmospheric distillation. This is essentially the same process that was used by the earliest oil refineries, such as the Paola refinery built in 1886. This process is also known as "straight-run" distillation. Atmospheric distillation is based on the fact that as you heat crude oil, the lightest molecules boil first, followed by the next lightest, and so on. The vapors are removed and recondensed into "cuts" or "fractions." Each fraction can be described in terms of its specific gravity, a measure of the size and weight of the molecules within the fraction. The remainder, called residue, may be burned to fuel other refinery processes or converted into other products.

Part of the former Coastal Derby refinery in El Dorado.

At 90° F, the lightest fractions of oil vaporize; these are the gases such as methane, ethane, and butane. The gasoline fraction is vaporized between 90 and 220° F. Between 220 and 315° F, the product obtained is naphtha. Kerosene is distilled between 315 and 450° F, and gas oil between 450 and 800° F.

If the temperature of the crude oil gets above 1000° F, the heavy hydrocarbons will begin to crack— break up into smaller compounds similar to those found in kerosene. Cracking is not part of straight-run distillation, because the molecules in the oil actually change.

The earliest refineries distilled crude oil in batches in very simple stills which were basically large iron tanks built over a furnace. The still would be filled with crude oil and heated from the furnace and by introducing steam into the still, until it started to boil. The vapors would be captured in a condenser and allowed to condense back into liquid. This is almost exactly the same process used to distill liquor. After each fraction of crude oil boiled off, the still was heated further until the next fraction boils. The refinery operator would control the product coming out of the condenser by controlling the temperature of the still. Each fraction would be collected in a separate container, possibly redistilled to produce a purer fraction, treated to remove impurities such as sulfur compounds, and prepared for market. If this approach seems somewhat imprecise and unsophisticated, that's because it was; but when your most valuable products are lamp oil and axle grease, it is not necessary to be very precise when cutting your fractions.

In order to increase the volume of any particular product produced through straight-run distillation, the refinery operator can move his "cut points," the temperatures between which a fraction is being distilled. Modern refineries do this when switching from making summer gasoline to winter gasoline; winter gasoline is distilled at slightly lower temperatures and has a slightly lower gravity, increasing its volatility and making it easier to ignite in cold weather. Summer gasoline is distilled at slightly higher temperatures and has a higher gravity, which helps prevent it from evaporating as quickly and causing vapor lock. Early refinery operators wanted to maximize the production of lamp oil, but if they were careless and set the cut point too low, the final product would be too light, increasing the possibility it would explode when being used. This is why Kansas regulated the quality of lamp oil beginning in 1879; to be sold in Kansas, it had to have a flash point above 110° F.

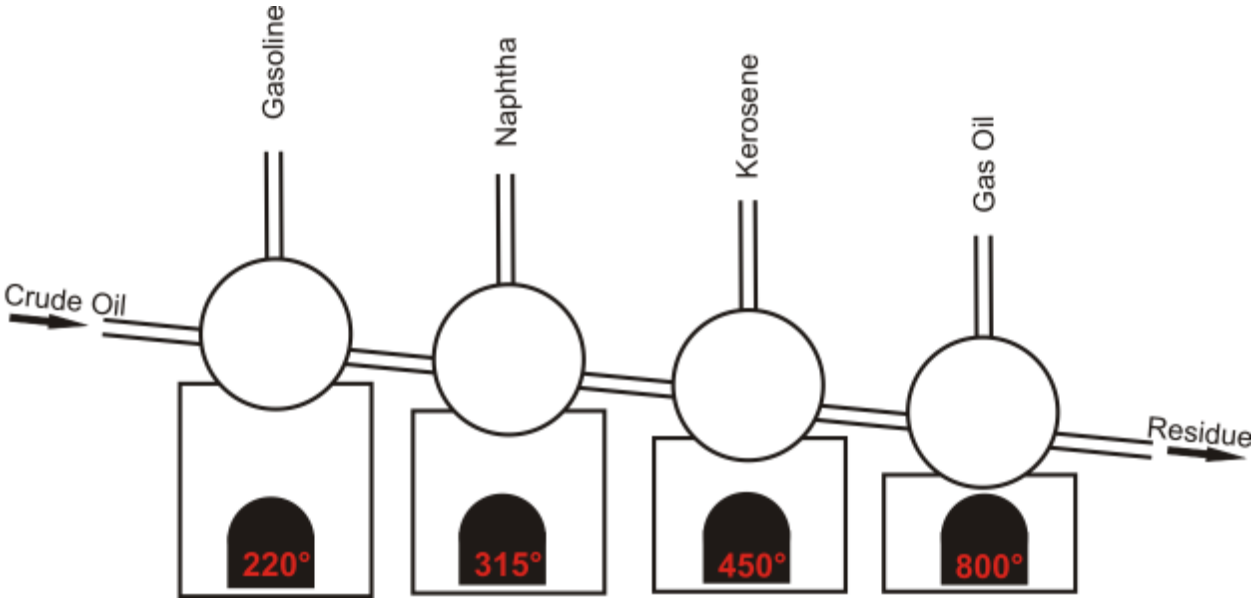
Some early refiners would "run to coke" in the still; heat the oil to above 1000° F until all the

residue cracked to kerosene. The material left in the still was solid coke, which had to be removed by hand after cooling the still down. This might damage the still; the weight of the coke could cause the hot steel to sag and distort, in which case the still would have to be replaced.

Around 1906 a continuous distillation method was developed. Instead of heating one still up to 800° F, four stills would be connected with piping. Crude oil was run into the first still, which heated it to 220° F, and the vapors were captured into a dedicated condenser. The hot residue would flow by gravity to the next still, where it was heated to 315° F, and so on. Meanwhile, fresh crude oil continuously entered the first still, while heavy oil residue would leave the last one. This process sped up production, while conserving fuel and wear and tear on the equipment due to alternately heating and cooling the stills.

After each fraction was distilled, it needed to be purified before it could be sold. Purification would remove compounds from the product that could be smelly when burned, produce soot that darkened lamp glass, and produce color in the product. Consumers knew to look for "water white" kerosene; the lack of color indicated its purity. Kerosene produced through cracking was always colored, requiring more treatment before it could be sold. Sulfur and nitrogen compounds could be removed from the product by mixing the product with sulfuric acid, then letting the mixture settle until the product and the acid separated. The sulfur and nitrogen compounds would precipitate and form a sludge which would have to be disposed of. The product would be removed and mixed with a caustic soda (lye) solution to return the pH to normal and remove more impurities; then the product could be redistilled. Other methods of purification included trickling the product through powdered charred bone or fuller's earth, a type of clay.

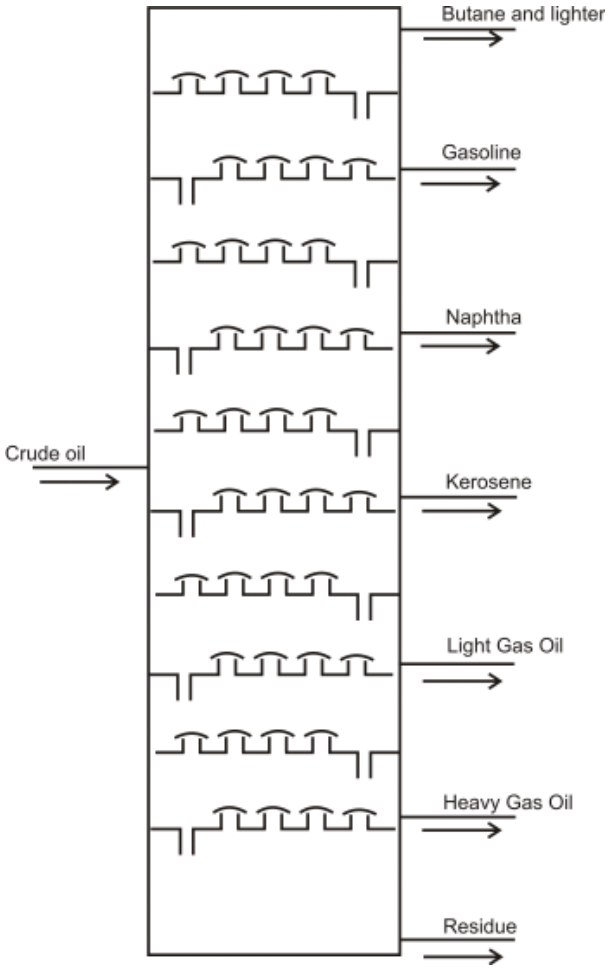
The residue from the last still could be sold as heavy fuel oil. Paraffin wax could be removed from the residue of paraffin-based crude oil by cooling it and pressing it through giant cloth filters; the remaining oil was excellent for lubrication, and the wax had many uses. Asphaltic-based crude oil residue could be used to make asphalt paving materials, paint base, or shingles.



A diagram of an early continuous distillation method. Temperatures are in degrees Fahrenheit.

Chemical engineers in the 1920's invented the modern bubble-cap distilling tower which is still used today. The tower can cut very clean fractions of product from the base crude oil because it uses a technique known as reflux. Reflux means that at various points in the distillation, parts of each fraction are reintroduced into lower parts of the distilling tower to be reheated and redistilled. This results in product fractions that overlap very little.

In the distilling tower, the crude oil is preheated before it enters the bottom of the tower. Once in the tower, the lightest fractions rise to the top, the middle fractions rise to the middle, and the heaviest residue is pumped out of the bottom. The tower is filled with trays, which provide a surface on which vapors can condense and collect. Each tray has openings covered with little caps that allow vapors to bubble up through them. As any fraction reaches the level where it will condense, it becomes a liquid and fills the trays. Some of that liquid will overflow into trays beneath, to be reheated and vaporize again (reflux). At the appropriate spot, the product is pumped out of the trays into a sidedraw. Some of the product is reintroduced back into the distilling tower at a lower level, and the rest is drawn off for further processing.



A simplified diagram of a modern bubble cap distillation tower.

The residue still needs further distillation into more cuts, but when its temperature is raised to above 800° F it will begin to crack, and cracking is a process that needs to be carefully controlled. To separate these heavy oil fractions without adding more heat, the residue is pumped into a vacuum flashing unit, which is a separate distilling tower that is kept at a vapor pressure lower than the outside atmosphere. The lowered pressure means the lighter fractions of the residue can vaporize without adding more heat. The vacuum flashing unit wasn't developed until refinery engineers learned to make equipment that could handle high temperatures and low pressures without breaking down.

The same technology that can make vacuum flashers can make high-pressure units as well, and in the mid-1920's the first commercial high-pressure thermal cracking units came online. In a high-pressure thermal cracking unit, the residue from the distilling tower is heated to around 1000° F in a still kept at high atmospheric pressure. This encourages large hydrocarbons to break into smaller, more valuable ones, while discouraging the formation of coke which would clog the pipes in the processing unit. Running an early high-pressure cracking unit could be a dicey business; there was always the danger of an explosion and devastating fire that would destroy most of the refinery. Despite the danger, cracking was the best means for increasing the amount of gasoline extracted from each barrel of crude oil.

Petroleum contamination can wash or seep into streams and other waterways, staining the soil along the banks and endangering wildlife and communities downstream. Below right: Absorbent boom has been deployed in a drainage way to capture an oil sheen near the Coastal Derby refinery in Wichita.

Catalytic cracking takes place at lower temperatures and pressures than thermal cracking. A catalyst is an agent which facilitates a chemical reaction, while not directly participating in that reaction. The catalyst remains unchanged, and can be used over and over again. In 1938 petroleum chemists developed the Houdry process, which was the first commercial catalytic cracking process. The modern process was developed by 1949. Over the years new catalysts that are cheaper and longer-lasting came into use. The refinery operator can choose catalysts depending on the needs of the refinery, such as producing higher proportions of high-octane gasoline or working at lower temperatures.

In the cat-cracker reactor, hot gas oil from either the straight-run distillation tower or from the vacuum flashing unit is mixed with steam and bubbled through a catalyst, which has been manufactured into a very fine dust. The catalyst cracks the oil into gasoline, which vaporizes and rises to the top of the reactor. There is catalyst dust in the vapor, and it is spun through at least one cyclone to remove the dust from the gasoline vapor; this action is similar to how a bagless vacuum cleaner works. The gasoline (and smaller molecules) leaves the reactor to be separated through another fractionation tower, and the spent catalyst is sent to a regenerator, which burns off any carbon molecules that may have stuck to the catalyst. The catalyst is then returned to the reactor. In theory, it is possible to keep circulating leftover oil through the catalyst until all of its molecules have been cracked, but in practice it causes less carbon buildup in the reactor if a little of the oil is drawn off continuously.

Another method of increasing gasoline yields from oil fields is to collect casinghead gasoline. Casinghead gasoline is extracted from natural gas, not from crude oil. Collecting casinghead gasoline is almost like distillation in reverse; a stream of natural gas that is rich in relatively heavy hydrocarbons is cooled until the heavy fractions, in this case naphtha and gasoline, condense into a

liquid that can be pumped from the condenser and delivered to the refinery. Casinghead gasoline is usually blended with the gasoline the refinery produces.

In a perfect refinery, the only outputs would be marketable products. However, no refinery is perfect, and there are still wastes to consider, many of them toxic. Before the enactment of regulations under the Resource Conservation and Recovery Act in 1980, many of these wastes would be disposed of on the refinery property, because it was a convenient and inexpensive option. Process wastewater could be stored in ponds until the water and volatile organic compounds (VOCs) evaporated. Solid waste sludges, spent catalysts, and spent purification materials might be buried in pits or sent offsite for disposal. Much of a refinery's waste would be discharged directly into the atmosphere through the smokestacks or pressure-release valves in the processing units; these included nitrogen and sulfur oxides, ammonia compounds, VOCs, and combustion by-products such as soot and carbon dioxide.

Refinery wastes are handled much differently now. In fact, more than 70% of all waste material is reclaimed, recycled, or used elsewhere in the refining process. Improvements in leak detection have cut the amount of fugitive emissions into the atmosphere. Spent catalysts are routinely sent for reclamation of the valuable metals in them. Wastes that cannot be reclaimed are carefully disposed of. However, especially in a refinery that operated for decades and closed before modern waste reduction and mitigation processes were developed, there can be a vast amount of legacy contamination that needs to be addressed.

Sampling solid waste sludge at the Western Petrochemical refinery in Chanute. The sludge is the consistency of tar. These technicians have laid plywood over the sludge to provide a place to walk.

A large sludge pit discovered at the Arkansas City Refinery site. This waste is left over from refinery operations that ceased in the late 1920's.

The Standard Asphalt and Rubber Company refinery in Independence closed its doors in 1922. Years later, the property was sold to a developer, and eventually the refinery became a residential neighborhood. Homeowners discovered sludge in their yards, which was removed by KDHE.

Remedial Activities at the Standard Asphalt and Rubber Company site Independence, Kansas

Photo 1

Seepage and mobilization of subsurface sludge associated with former refinery operations.

Photo 2

Sampling and characterization of sludge material.

Photo 3

Stabilization of sludge waste. Impacted soils mixed with cement kiln dust to raise pH and demobilize subsurface waste.

Photo 4

Placement and compaction of clay cap.

Photo 5

Construction of drainage swale.

Photo 6

Subject property following remediation, cap construction, and sodding.

Site Investigation and Evaluation

The remediation process for a large refinery, one that may have operated for more than 70 years, is complex and can last for decades. It is an iterative process of assessment, planning, corrective action, reassessment, and planning for the next stages. To adequately address the complex remedial needs of a refinery, KDHE needs to understand nearly every aspect of the refinery's history, processes, waste disposal practices; as well as addressing stakeholders' needs, concerns, and future plans for the refinery property.

The process begins with assessment and evaluation of the refinery property and the properties adjacent to it. KDHE determines what human or environmental receptors are in the area and likely to be affected by refinery contamination, such as residents, workers, schools or hospitals, and environmentally sensitive areas such as wetlands and waterways. KDHE will contact the landowner and arrange to visit the site to evaluate its current environmental condition, take photographs, and begin developing a site sampling plan. This plan guides the process of collecting samples from soil and groundwater, and possibly collecting water and sediment samples from streams or ponds at the site. These samples are sent to a laboratory for analysis.

Excavating oil-stained soil.

Results from the laboratory are compared to the health standards outlined in KDHE's Risk-based Standards for Kansas (RSK) Manual. KDHE uses this information to assign a priority to the project and determine the nature of future investigation and cleanup.

A responsible party identification search will identify any Potentially Responsible Parties (PRPs) who can be approached to perform cleanup activities under KDHE guidance, either through KDHE's Voluntary Cleanup and Property Redevelopment Program or through another program. The PRP is responsible for paying the cost of cleaning up the site to KDHE standards.

Technicians examine soil cores taken at the Coastal Derby refinery in Wichita. Soil from these cores will be collected and sent to the lab for chemical analysis, helping KDHE determine the extent and depth of the contamination.

ATTACHMENT 1

Region 5 Waste Management Branch "Skinner List"
Constituents of Concern for Wastes from Petroleum Processes

Inorganics

Antimony	Cadmium	Lead	Silver
Arsenic	Chromium	Mercury	Vanadium
Barium	Cobalt	Nickel	Zinc
Beryllium	Cyanide	Selenium	

Volatile Organics

Benzene	1,2-Dichloroethane	Ethylene dibromide (EDB)	1,1,1-Trichloroethane
Carbon disulfide	1,1-Dichloroethane	Methyl ethyl ketone (MEK)	Trichloroethene
Chlorobenzene	1,4-Dioxane	Styrene	Tetrachloroethylene
Chloroform	Ethylbenzene	Toluene	Xylenes (total)

Semivolatile Organics

Acenaphthene	o-Cresol	Diethyl phthalate	Naphthalene
Anthracene	m-Cresol	2,4 Dimethylphenol	4-Nitrophenol
Benzo(a)anthracene	p-Cresol	Dimethyl phthalate	Phenanthrene
Benzo(b)fluroranthene	Dibenz(a,h)anthracene	2,4 Dinitrophenol	Phenol
Benzo(k)fluoranthene	Di-n-butyl phthalate	Fluoranthene	Pyrene
Benzo(a)pyrene	1,2-Dichlorobenzene*	Fluorene	Pyridine
Bis(2-ethylhexyl) phthalate	1,3-Dichlorobenzene*	Indeno(1,2,3-cd)pyrene	Quinoline
Chrysene	1,4-Dichlorobenzene*	Methyl tertiary butyl ether (MTBE)	*- can be tested as a volatile

Low Concentration Polynuclear Aromatic Hydrocarbons (Optional)

Benzo(a)anthracene	Benzo(k)fluoranthene	Dibenz(a,h)anthracene	Indeno(1,2,3-cd)pyrene
Benzo(b)fluoranthene	Benzo(a)pyrene	Chrysene*	

* added to this group to assist the chromatographic resolution of chrysene from Dibenz(a,h)anthracene in sample extracts

Optional Semivolatile Organics

Indene	Benzenethiol**	Dibenz(a,h)acridine	1-Methylnaphthalene*

*Note that 2-Methylnaphthalene is part of Appendix IX and is a CLP TCL organic. 1-Methylnaphthalene is not on these lists.

**Benzenethiol can be detected in certain petroleum refinery wastes. Its measurement must compensate for its instability at neutral and acid pH values during sample preparation and its unstable instrument calibration standards

The U. S. Environmental Protection Agency developed the "Skinner List" to identify contaminants commonly found at former refinery sites.

Remedial Strategies

Each refinery site is a unique challenge, and usually multiple remedial strategies will be used on each one. Once the remedial systems have been put in place and are operating, environmental conditions are constantly monitored to determine overall effectiveness of the cleanup plan and whether pre-established remedial goals are being satisfied. Commonly used remedial options to clean up contamination left at refinery sites include any or all of the following methods.

Source control. Source control can be achieved by either by physically removing the contamination from the site, such as the excavation of contaminated soil or removing a leaking underground storage tank, or by preventing its migration.

Product recovery. In sites where there has been long-term leakage and spillage from storage tanks and refinery process elements, petroleum and product will have infiltrated the groundwater beneath the site, a situation which can be confirmed by installing monitoring wells. If there is enough free product, it may be economical to install wells to pump the product into tanks where it will be transported to another refinery for reprocessing.

A laser-induced fluorescence technology such as this can be used in the field to rapidly determine the concentration of petroleum contaminants in soil. It can be a cost-effective way to determine the severity, extent, and depth of contamination. This information helps KDHE to determine which remedial strategies will be used for cleanup.

This groundwater sampling tube contains a thick layer of oil as free product.

Pump and treat. In this remedial strategy contaminated groundwater is pumped into an above-ground treatment system designed to remove the specific contaminant from the water. Free product found in the groundwater can be removed using an oil/water separator system. Dissolved petroleum contaminants in groundwater can be treated with oxygenation to encourage the growth of petroleum-eating bacteria, or the groundwater can be agitated so that the dissolved compounds evaporate. Other contaminants may be removed through filtration, and the used filters are disposed of properly offsite. Cleaned water can be discharged into a sewage treatment system, directly into the environment through a National Pollution Discharge Elimination System permit, or strategically reintroduced into the aquifer to encourage the flow of more contaminated water to the recovery well system. Pump and treat systems can be expensive to build and operate.

Excavation. Contaminated soil can be managed by digging it out and replacing it with clean fill. The excavated soil will be tested to determine the concentration and nature of contamination, and the appropriate disposal option. Soil contaminated primarily with petroleum products, for example, may be treated by landfarming, while soil contaminated with significant concentrations of metals such as lead may need to be treated as hazardous waste and sent to a permitted landfill. The scope of the excavation can be limited due to structures on the property and cost.

Interceptor trenches. Interceptor trenches are dug perpendicular to the flow of groundwater. Their intent is to provide a collection point for contaminated groundwater, which can then be collected and treated, or to direct uncontaminated groundwater away from a contamination source. Interceptor trenches are routinely installed at site boundaries. If combined with barriers, they can prevent contaminated groundwater from migrating off site where it is harder to collect and treat.

Interceptor trenches are used to control groundwater migration. This trench was dug at the Coastal Derby Refinery site in El Dorado.

A landfarming cell under construction. In this example, a blue plastic liner prevents contaminated soil from mixing with the underlying soil; a layer of sand protects the liner from rips and tears. Contaminated soil is placed on top, and periodically tilled to encourage the breakdown of the contamination. Not all landfarming sites require this level of complexity.

Landfarming. Naturally occurring soil bacteria will break down petroleum products, given the appropriate soil temperatures and oxygen levels. In a soil landfarming solution, contaminated soil is spread on a dedicated field and regularly tilled or turned until testing determines that contamination has been reduced to below action levels. While landfarming is often used for treating soils contaminated with petroleum products, it cannot be used for soils with high levels of metals or other materials that cannot biodegrade. A landfarming permit is required from KDHE, and care must be taken that contamination does not migrate from the landfarming cell into the underlying soil.

Air sparging/Soil vapor extraction. These techniques are sometimes used together to remove dissolved VOCs from soil and groundwater. VOCs are of particular concern when there is a possibility of vapor intrusion, when vapors from the soil enter a building through the foundation where they can become concentrated and are breathed by the building's occupants. An air sparging system injects air, or sometimes steam, into the soil or water table. The soil vapor extraction system applies a vacuum pressure to the soil, sucking the vapors into a collection system where the VOCs are removed.

Enhanced bioremediation. Sometimes the naturally occurring bacteria cannot effectively break down the petroleum because of the lack of a suitable environment. An enhanced bioremediation strategy will inject material, such as nutrients or microbes, into the soil or groundwater being treated in order to encourage biodegradation.

Waste stabilization and burial. The sludges from tank bottoms, still bottoms, and refinery processes can be treated until they are chemically inert. Once these sludges have been solidified, their acid or caustic nature neutralized, and it has been determined that they are not hazardous enough to require disposal in a dedicated facility, they may be buried on-site in a dedicated disposal area. The disposal area is designed to prevent the wastes from becoming exposed to the environment. On-site disposal areas always have an environmental use control applied to them to prevent inappropriate use of the property in the future.

Waste stabilization of pond sediments at the Pester refinery. Once the water was removed and treated, the soft soil from the pond bottom was mixed with portland cement using this special tool to stabilize it and prevent future migration of the waste offsite. Afterwards the pond area was filled to grade with clean soil.

Air stripping equipment installed at the Vickers Petroleum site in Potwin.

Environmental use controls. Also known as deed restrictions, institutional controls, or land use controls, an environmental use control is a legal directive attached to the property deed, instructing the current and future landowner as to the appropriate future use of the property. Common restrictions include a requirement to maintain the engineered cap by preventing and mending damage due to erosion; restrictions on digging or installing water wells; or restrictions on using the property for agriculture, residences, schools, or recreational areas. If any landowner in the future wants to use the property for a restricted use, further remedial

work must be planned and coordinated through KDHE.

Natural attenuation. Over time many contaminants from refineries will slowly and naturally degrade through bacterial action and weathering. In locations where contamination is at very low levels and the risk to human health and the environment has been judged to be low, it is possible to simply monitor the contamination levels over time and let nature take its course. Monitoring is crucial, though, because if contamination levels remain steady or rise more aggressive measures will need to be employed.

Research and development of new technologies. There is a constant effort to create new methods, strategies, and technologies for addressing cleanup of environmentally contaminated sites. KDHE is always seeking new methods that can control costs and more effectively prevent risks to human health and the environment.

The Challenge

Kansas has had some 100 separate historical refinery operations located in 36 communities. These refineries range from simple short-lived oilfield skimming operations to massive factories producing a full array of petroleum products. Identifying, locating, assessing, and remediating all of these is an ongoing challenge that KDHE has been addressing for decades, constantly improving its approach toward investigation and evaluation, working with PRPs, perfecting current remedial strategies, and developing new ones.

When the Verdigris River breached its levee in June 2007, the floodwaters inundated eastern Coffeyville as well as the Coffeyville Resources Refinery. Coffeyville Resources has been coordinating their remediation activities with the Environmental Protection Agency, including buying out and cleaning up more than 300 destroyed homes and businesses.

References

Cross, Roy. 1919. A Handbook of Petroleum, Asphalt and Natural Gas. Kansas City Testing Laboratory (Bulletin No. 15): Kansas City, MO.

A Woman Captain of the Oil Industry. October 3, 1909. *Kansas City Star.*

Kansas Department of Health and Environment, Bureau of Environmental Remediation files.

Kansas Independent Oil and Gas Association. Website at www.kioga.org.

Larson, Henrietta M. and Porter, Kenneth W. 1959. History of Humble Oil and Refining Company. Reprint edition 1976, Arno Press: New York, NY.

Leffler, William L. 2000. Petroleum Refining in Nontechnical Language, 3rd Edition. PennWell Corporation: Tulsa, OK.

Miner, H. Craig. 1987. Discovery! Cycles of Change in the Kansas Oil and Gas Industry 1860-1987. Kansas Independent Oil and Gas Association.

Miner, H. Craig. 1976. The Fire in the Rock: A History of the Oil and Gas Industry in Kansas 1855-1976. Kansas Independent Oil and Gas Association.

Oil and Gas Journal. 1915-1940.

Schruben, Francis W. 1972. Wea Creek to El Dorado: Oil in Kansas 1860-1920. University of Missouri Press: Columbia, MO.

U. S. Census. Website at www.census.gov.

U. S. Environmental Protection Agency. 1995. *Profile of the Petroleum Refining Industry*. Office of Compliance.

U. S. Environmental Protection Agency. 1997. *Skinner List*. Region 5 Waste Management Branch.

U. S. Environmental Protection Agency. 1996. *Study of Selected Petroleum Refining Residuals*. Office of Solid Waste.

Williamson, Harold F. et al. 1963. The American Petroleum Industry: The Age of Energy 1899-1959. Northwestern University Press: Evanston, IL.