Working with Tight Oil

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Crude oil derived from shale plays is less expensive and more readily available than traditional crudes, but it poses unique challenges to refiners.

Tight oil, sometimes referred to as light tight oil, is a crude oil from shales or other low-permeability geologic formations. Permeability is a measure of a material's ability to allow fluid, such as oil or gas, to move through it. Obtaining tight oil from shales requires hydraulic fracturing, often using the same horizontal well technology that is employed in the production of shale gas.

Tight oil is found throughout the world, as shown in Figure 1 and Table 1 *(1)*. However, the U.S., Canada, China, and Argentina are currently the only four countries in the world that are producing commercial volumes of either natural gas from shale formations (shale gas) or crude oil from tight formations (tight oil). The U.S. is by far the leading producer of both shale gas and tight oil; Canada is the only other country to produce both shale gas and tight oil.

Most refineries process many different crudes. For example, coastal refineries often process 50 or more different crudes over the course of a year. Each crude requires slightly different processing conditions in the major process units. Typically, a refinery is designed to process crude oil of a particular composition and produce products with specified properties, with some flexibility based on the capabilities of equipment such as pumps, heat exchangers, and the particular catalysts within the reactors. Refiners try to match the crude oil composition to their refinery's configuration, usually by blending two or more crude oils, if a single crude oil with the required composition is not available or economical.

American Petroleum Institute (API) gravity is a specific gravity scale developed by the oil industry to classify crude oils and other petroleum liquids based on their relative densities. It is expressed in degrees (°API), and is an inverse measure of the relative density of a petroleum product and the density of water. The lower the API gravity, the denser the oil. Light crude oil has an API gravity higher than 31°API, medium crude between 22°API and 31°API, and heavy crude an API gravity below 22°API. Sweet crudes contain less than 0.5% sulfur (sour crudes contain more than that). Tight oils are typically light and sweet. U.S. crude oil production is significantly lighter than in the past (Figure 2); especially noticeable is the increase in tight oils with a typical API gravity of 40–45°API.

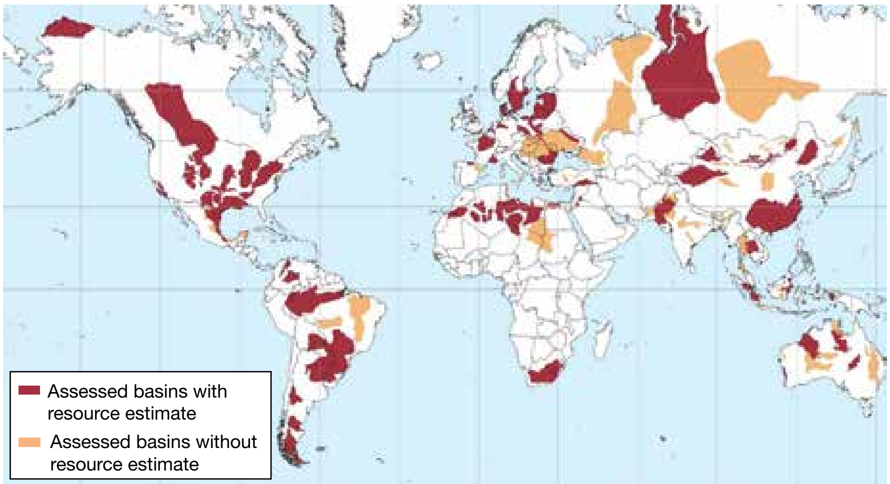
Refineries in the U.S. Gulf Coast area have made major investments to enable them to process heavier sour crude oils from sources such as Venezuela and Canada. These changes were made before the technological advancements that triggered the recent shale boom. Because tight oil is light and sweet, there is now a mismatch between tight oil's properties and the properties that these upgraded refineries require.

Challenges of tight oil

Tight oil is currently more readily available for refiners in North America. However, tight oils present numerous challenges, which is why these crudes typically cost less than crude oils such as Brent (global crude oil benchmark) or West Texas Intermediate (U.S. crude oil benchmark).

Tight oils typically pose unique challenges because they:

- are difficult to transport due to a lack of pipeline infrastructure
- contain entrained hydrogen sulfide (H_2S)
- require the addition of amine-based H_2S scavengers in the pipeline, truck, or railcar prior to transport
- are contaminated with paraffin waxes that cause fouling in piping, tank walls, and crude preheat exchangers
- contain large amounts of filterable solids
- can have a wide range of API gravity
- require crude blending to balance the atmospheric



◀ **Figure 1.** Tight oil is found throughout the world, as shown in this map of basins with shale oil and shale gas formations. The red areas represent basins with shale formations for which the U.S. Energy Information Administration (EIA) estimated recoverable oil and natural gas resources; the tan areas represent basins that were reviewed, but for which the EIA did not provide shale resource estimates, mainly due to the lack of data necessary to conduct the assessment. Source: *(1).*

▼ **Figure 2.** U.S. crude oil production is trending toward lighter crudes. Source: *(2).*

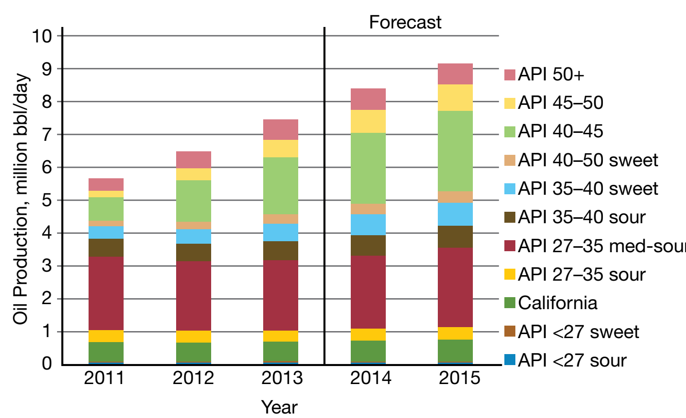


Table 1. These ten countries have more than three-quarters of the world's recoverable shale oil reserves. Source: *(1).*

Rank	Country	Shale Oil Proven Reserves, billion bbl
1	Russia	75
2	United States	58
3	China	32
4	Argentina	27
5	Libya	26
6	Australia	18
7	Venezuela	13
8	Mexico	13
9	Pakistan	9
10	Canada	9
Total Global Recoverable Shale Oil Reserves = 345 billion bbl		

crude fractionator cut-point yields for best downstream utilization

• may be incompatible with other types of crudes used for blending

• require energy balancing across the crude preheat exchangers

• may experience cold flow property deficiencies that require modifications to catalysts.

In addition, the U.S. has banned the export of crude oil, including tight oil. This exacerbates the mismatch between the abundant tight oil available to U.S. refineries and the equipment designed to process medium to heavy crude oils.

Transportation difficulties

In 2014, 64% of U.S. tight oil production came from two basins (Figure 3): the Eagle Ford in South Texas (1.21 million bbl/day, or 36% of total U.S. tight oil production), and the Bakken Shale in North Dakota and Montana (0.94 million bbl/day, or 28% of total U.S. tight oil production) *(3)*. The U.S. produced 91% of all North American tight oil, with the remaining 9% coming from Canada. Both the Eagle Ford and Bakken basins have limited traditional pipeline infrastructure to transport the tight oil to refineries throughout the country. As a result, rail transport (for Bakken) and truck transport (for Eagle Ford) are the norm for shipping tight oil to refineries.

The tight oil production boom happened quickly, and the oil industry was not accustomed to transporting crude oil by rail. A few derailments prompted a re-evaluation of safety protocols, and jacketed railcars will be mandatory by 2017 *(4)*. Many cars will need to be retrofitted with thermal protection systems, thick steel plates at the ends of tanks, and outer steel jackets. In addition, the cars' bottom outlet valve will need to be reconfigured to prevent it from breaking off and releasing oil in the event of a derailment.

Proper testing, classification, and handling are important when shipping any material subject to U.S. Dept. of Transportation Pipeline and Hazardous Material Safety Administration (PHMSA) regulations, and crude oil is no exception. The API recently published ANSI/API Recommended

Practice 3000, "Classifying and Loading of Crude Oil into Rail Tank Cars" (www.api.org/rail). These guidelines are the product of extensive work and cooperation among the oil and natural gas industry, the freight rail industry, and PHMSA to ensure crude shipments are packaged appropriately and emergency responders have the necessary information to deal with any incidents that occur.

Tight oil contaminants

Although tight oil is considered sweet (*i.e.,* low sulfur content in the crude oil itself), hydrogen sulfide gas comes out of the ground with the crude oil. H_2S is flammable and poisonous, and therefore must be monitored at the drilling site and during loading, transport, and offloading of the tight oil. Amine-based H_2S scavengers are added to the crude oil prior to transport to refineries. However, mixing in the railcar due to movement, along with a change in temperature that raises the oil's vapor pressure, can cause the release of entrained H_2S during offloading — creating a safety hazard. For example, crude from the Bakken shale play in North Dakota that is loaded on railcars in winter and then transported to a warmer climate becomes hazardous due to the higher vapor pressure.

Paraffin wax fouling. Paraffin waxes contaminate tight oils and remain on the walls of railcars, crude oil tank walls, and piping. They are also known to foul the preheat sections of crude heat exchangers (before they are removed in the crude desalter). Paraffin waxes that stick to piping and vessel walls can trap amines against the walls, which can create localized corrosion.

The severe fouling in heat exchangers upstream of the desalter was initially a surprise to many refiners — fouling is typically worse in the hotter exchangers that are downstream of the desalter. Refiners now monitor the crude preheat exchangers more closely, and are working with both automation and chemical companies to counter this fouling and corrosion potential.

In a refinery processing tight crude oil, each heat exchanger bundle upstream of the crude desalter should be equipped with online temperature monitoring at the inlet and outlet of both the tubeside and shellside to detect any changes in the rate of heat transfer as they occur. Typically, the flow is measured on both the hot and cold side of the heat exchanger, but where the flow is split between parallel exchangers, individual flow measurements should be added to calculate the heat transferred in each heat exchanger; fouling in heat exchangers is not equally distributed.

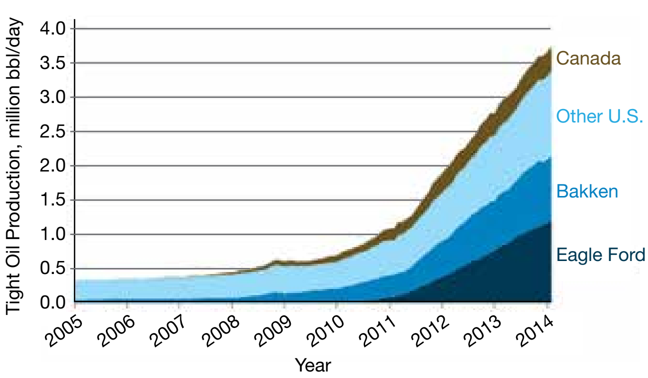
Filterable solid fouling. Filterable solids also contribute to fouling in the crude preheat exchangers. A tight crude can contain over seven times more filterable solids than a traditional crude. Refiners have reported filterable solids in excess of 200 lb per thousand barrels of tight oil. For a refinery that processes 100,000 bbl/day, this translates to more than 10 ton of solids per day entering the refinery with the crude.

To mitigate filter plugging, the filters at the entrance of the refinery require automated monitoring because they need to capture large volumes of solids. In addition, wetting agents are added to the desalter to help capture excess solids in the water, rather than allowing the undesired solids to travel further downstream into the process.

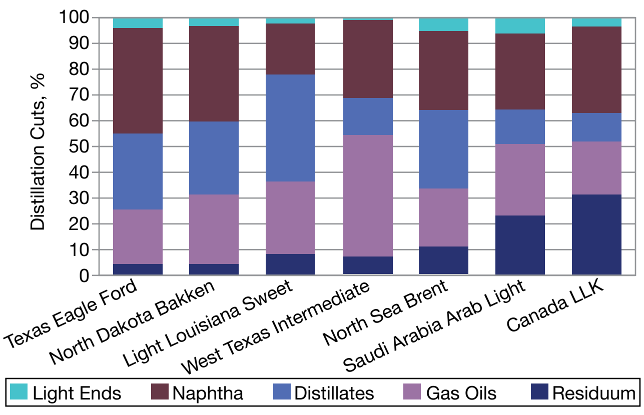
Composition variability

Tight oil tends to have a higher API gravity than traditional crude oils, as well as much different properties. For example, Eagle Ford tight oil can have twice as much naphtha as Light Louisiana Sweet, a typical light U.S. crude (Figure 4). Also, Eagle Ford tight oil has an average API gravity in the range of 40–45°API, whereas Light Louisiana Sweet has an API gravity around 35°API. Figure 4 *(5)* compares the distillation cut-points of Eagle Ford and Bakken tight oils with those of other crudes.

To best utilize existing downstream units, tight oils must be blended with heavier crudes, because a more-consistent



▲ **Figure 3.** In 2014, the Eagle Ford and Bakken shale basins accounted for nearly two-thirds of all North American tight oil production. Source: *(3).*



▲ **Figure 4.** Distillation cut-points for light tight oils and other crude oils. Source: *(5, 6).*

feed to the crude unit facilitates optimized operation. If tight oil feeds are not blended with heavier crudes, the lighter oil can create a bottleneck in the crude overhead and naphtha processing units, and limit production in bottom-of-the-barrel processing units such as the delayed coker.

Crude incompatibility. Some refiners blend two or more crudes to achieve the right balance of feedstock qualities. This may cause problems if the crude oils being mixed are incompatible.

When crudes are incompatible, increased asphaltene precipitation accelerates fouling in the heat exchanger train downstream of the crude desalter. Accelerated fouling increases the amount of energy that must be supplied by the crude fired heater, which limits throughput when the fired heater reaches its maximum duty. It may also necessitate an earlier shutdown for cleaning. This sequence of events increases operating costs and negatively impacts the profitability of the refinery. Manual monitoring of heat exchanger fouling often fails to detect crude blends that are incompatible, so the same incompatible crudes might be blended in the future.

Asphaltenes do not dissolve in crude oil, but exist as a colloidal suspension. They are soluble in aromatic compounds, such as xylene, but precipitate in the presence of light paraffinic compounds, such as pentane. Mixing stable crude blends with asphaltic and paraffinic oils creates the potential for precipitating the unstable asphaltenes. The high naphtha content of tight oils also creates favorable conditions for asphaltenes to more readily precipitate.

It should be noted that the ratio of crudes in a blend may have an impact on crude incompatibilities. For example, 20% tight oil in an 80–20 blend might not cause accelerated fouling, whereas a 70–30 blend may be unstable and cause more rapid fouling.

Energy imbalances. Some refiners that tried to run with a high percentage of light tight oil found that the preheat exchangers did not have sufficient heat-transfer capability, which created an energy imbalance across the preheat train and fired heater. The heavy sidecut streams from the atmospheric crude unit fractionator provide a large amount of heat to the preheat exchangers. When the flowrates of these sidecut streams are low (due to the lack of heavy components in tight oil), there is an energy imbalance in the preheat exchangers.

With very little gas oil and residuum (*i.e.,* the heaviest materials in a crude oil, also referred to as the bottom-of-the-barrel components) in tight oil, the amount of heat available in the crude preheat exchangers upstream of the crude fired heater is insufficient, which increases the crude fired heater's fuel consumption. Some refiners experienced fired heater limitations and reduced throughput, as well.

Energy imbalances are one of the main reasons crude blending is more common with tight oils than other crudes.

Problems with catalysts. Refiners processing tight oils initially saw deficiencies in product qualities (*e.g.,* cold flow properties such as cloud point, pour point, and cold filter plugging point) because of the high paraffin content in these feedstocks. Additional processing, such as catalytic dewaxing or product blending of other valuable streams, may be required to meet fuel property specifications. In addition, tight oil contains higher levels of calcium and iron, which can poison catalysts. Catalyst manufacturers have responded by changing the functionality of catalysts to compensate for changes in feedstock properties and desired product qualities.

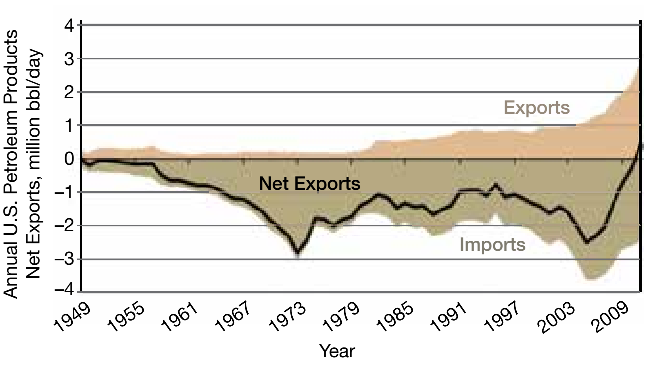
Export issues

It has been illegal to export raw crude oil from the U.S. since the Energy Policy and Conservation Act (EPCA) of 1975 directed the president to ban crude oil exports except in select circumstances. However, there is no ban on exporting oil once it has been refined into gasoline or diesel fuel. In fact, U.S. refineries are now shipping record amounts of gasoline and diesel abroad. In 2011, the U.S. exported more petroleum products, on an annual basis, than it imported for the first time since 1949 (Figure 5), but American refiners still imported large, although declining, amounts of crude oil *(8)*. The increase in foreign purchases of distillate fuel contributed the most to the U.S. becoming a net exporter of petroleum products.

Crude oil prices

New tight oil production might not be economically viable when prices for traditional crude oil are as low as they are now — around \$50/bbl for benchmark crude oils when this article was written. It is estimated that crude oil pricing needs to be above \$50/bbl for new tight oil exploration and production to be profitable.

In addition, the depletion rate of hydraulically fractured (fracked) tight oil wells is high. For instance, production for a fracked well in the Bakken field declines 45% per year,



▲ **Figure 5.** In 2011, the U.S. exported more petroleum products than it imported for the first time since 1949. Source: *(7)*.

versus 5% per year for conventional wells. Producers need to keep drilling in order to stay in production with a steady flow of oil.

Closing thoughts

For now, tight oil production is a great economic advantage for U.S. energy independence. The boom has created many domestic jobs and has increased self sufficiency, which will provide security should a global crisis occur.

However, tight oil poses many challenges in transportation and refining. Refiners must learn to process this challenging crude supply and make the required modifications to their processing configuration to best utilize the lighter crude oil. CEP

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