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From Rock to Refining: Characteristics of Unconventional Oils and the Main Challenges for Refining

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In the oil and gas industry, oil reservoirs can be classified into two main categories: conventional and unconventional. Unconventional oil reservoirs have specific geological characteristics, such as low permeability and rapid pressure drop, which require stimulation to produce hydrocarbons. They also exhibit a significantly lower oil recovery compared to conventional reservoirs.

The development of the oil and gas industry has been marked by the increasing exploration of unconventional reservoirs, driven by the need to meet global energy demand. As conventional oil resources become progressively scarcer or economically unfeasible, attention turns to sources such as shale and tight oil, and, in the case of Brazil, the pre-salt. These resources present specific technological and operational challenges, derived from the characteristics of geological formations, such as low permeability, high heterogeneity, and the presence of contaminants that directly impact the efficiency of production and refining processes.

Production from unconventional crude reservoirs requires the use of advanced drilling, completion, and stimulation techniques, such as hydraulic fracturing and horizontal drilling, to economically enable hydrocarbon extraction. Furthermore, the refining of these streams imposes additional requirements on the catalytic systems of fluidized catalytic cracking units (FCCU), which demands the development of more robust catalysts and operational strategies capable of mitigating the adverse effects caused by contaminants such as iron, calcium, copper, sodium, potassium, among others, as well as by other inherent feed characteristics (such as higher acidity, oxygen content, and the presence of salts).

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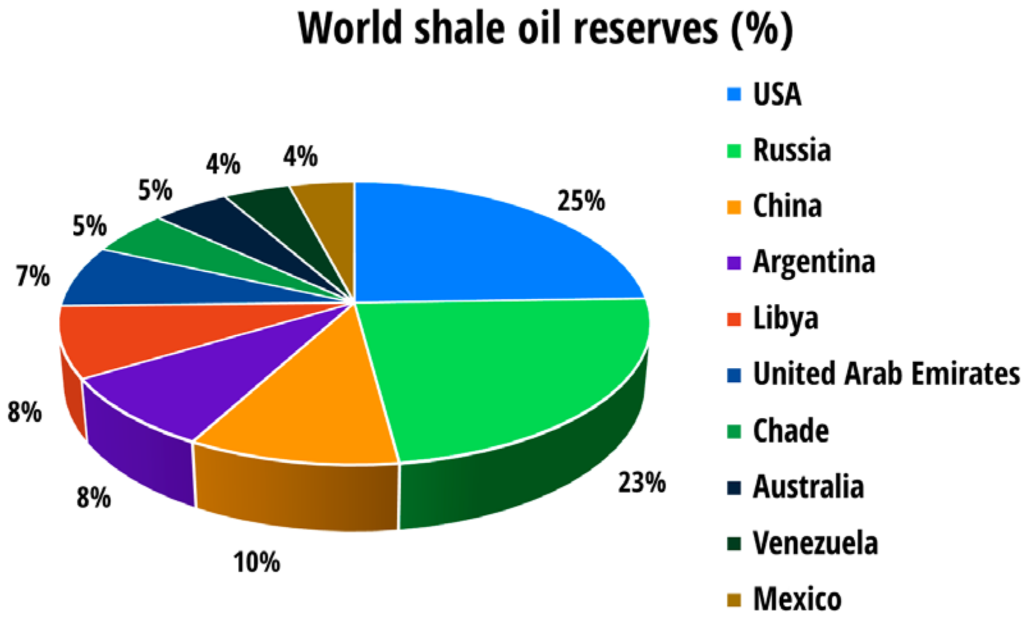
Shale oil

Shale oil is considered the most valuable unconventional oil with the greatest development potential. The production of shale oil in the United States has triggered a revolution in the global energy landscape, rapidly increasing the country's oil output. In China, geological reserves of shale oil are estimated at about 30 billion barrels, representing significant development potential. Another country that stands out for its large shale oil reserves is Argentina, particularly in the region known as Vaca Muerta. In 2013, the U.S. Energy Information Administration (EIA) estimated that the recoverable oil volume in Vaca Muerta would be around 16.2 billion barrels, positioning Argentina as the fourth country with the largest unconventional oil reserves in the world.

Figure 1: Global shale oil reserves.



Source: Adapted from EIA, 2025.

Shale oil is composed of oil preserved in organic-rich shale and exhibits medium to high levels of organic maturity. Shale acts both as a source rock and as a reservoir rock and can therefore be referred to as "generative rock oil". Shale oil exists in adsorbed and free states, and it generally has low density and viscosity. It is primarily stored in pores and nanoscale fractures, distributed along lamellar strata or parallel microfractures. Table 1 presents some characteristics of the main shale oil exploration sites around the world.

Table 1: Properties of some important shale oil exploration points in the world.

Region	Organic Matter*		Thickness	Capacity	Density
	COT (%)	Ro (%)	(m)	(t/d)	(g/cm³)
Jianghan, China	1-10	0,41-0,76	10-50	1000	0,80-1,05
Alberta, Canadá	2,5	>0,7	50-150	20-70	0,82-0,85
Eagle Ford, EUA	3-7	0,7-1,4	20-60	200	0,82-0,87
Vaca Muerta, Argentina	3-5	0,7-1,3	40-150	24,3-81	0,80-0,83

**TOC – total organic carbon (%); Ro – expresses the thermal maturity of organic matter (%)*

Source: Adapted from WANG et al., 2019.

Tight oil

Tight oil is conventional oil found in reservoirs with low permeability (less than 0.1 mD) and low porosity (less than 10%), which require technologically advanced drilling and completion techniques. The extraction process results in liquid hydrocarbons obtained through hydraulic fracturing of shale formations, leaving a heavy fraction, similar to tar, within the shale deposit.

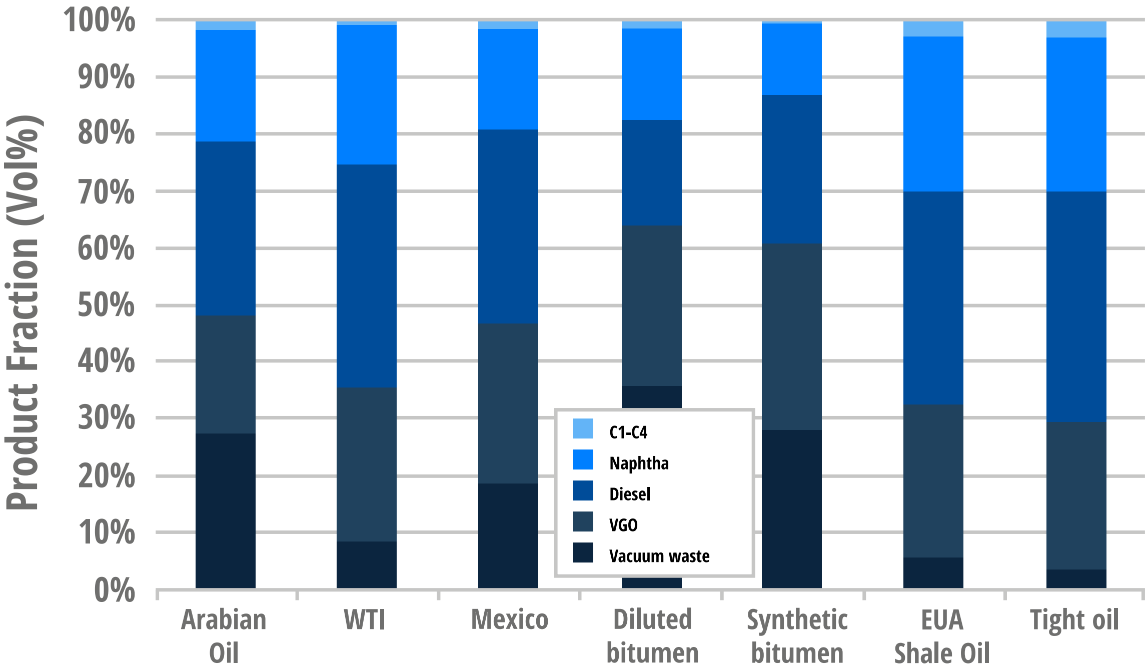
The largest technically recoverable reserves of tight oil are located in Russia (75 billion barrels) and the United States (58 billion barrels), while China, Argentina, Libya, Venezuela, and Mexico also standing out, which together total 30 billion barrels, according to EIA data.

In general, the composition of tight oil is different from traditional oils, exhibiting:

- higher API gravity;
- higher yield of diesel and light fractions;
- higher contamination by Fe, Ca, Na, and Pb;
- lower sulfur content;
- higher paraffinic content.

Due to the difference in product yields compared with traditional crudes, as illustrated in Figure 2, it may be necessary to blend tight oil with other crudes to adjust yields or to adapt processing units, particularly in older refineries.

Figure 2: Comparison between tight oil and other unconventional oils.

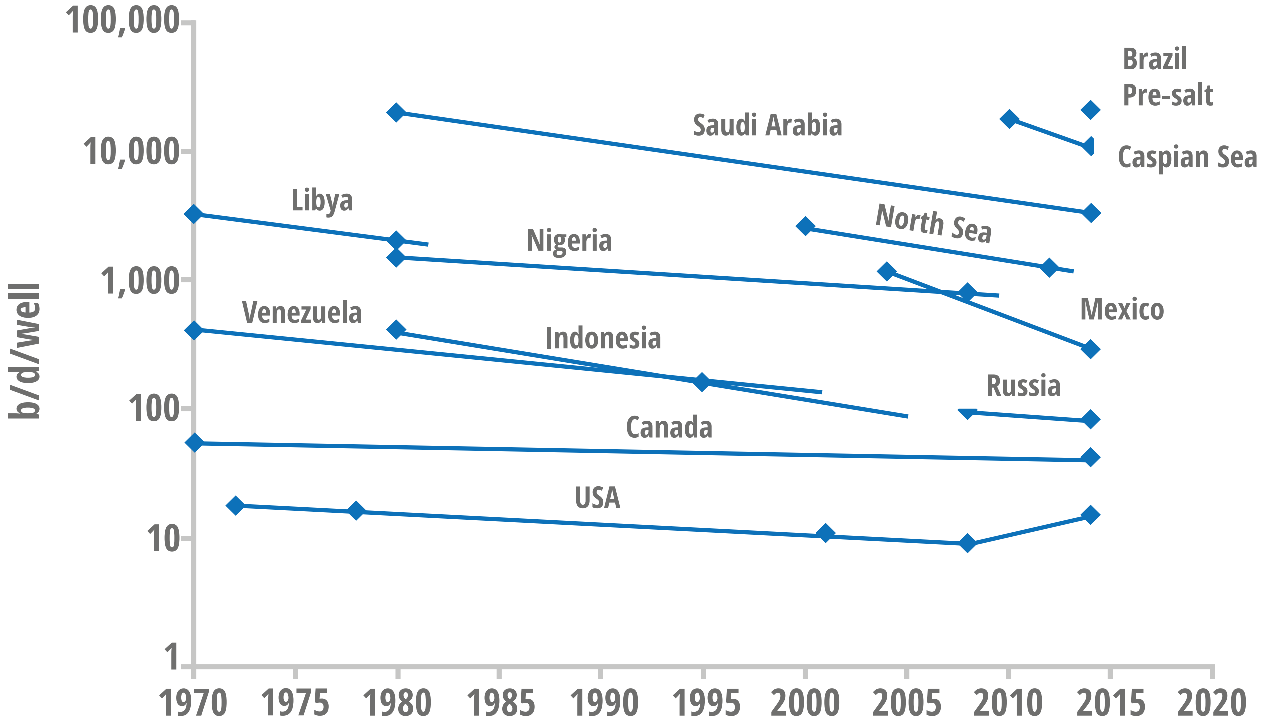


Source: Adapted from LELIVELD and TOSHIMA, 2015.

Pre-salt oil

Pre-salt oil was discovered in Brazil in 2007 and is found in sedimentary rocks located beneath a thick salt layer, up to 2,000 meters, which acts as a barrier preventing oil migration. Daily oil production from the pre-salt fields is remarkably high, having increased from an average of 41,000 barrels per day in 2010 to around 1.9 million barrels per day in 2020, with projections indicating it could reach 5 million barrels per day by 2030. This growth demonstrates the exceptional productivity of pre-salt wells, as shown in Figure 3.

Figure 3: Productivity of oil wells in various regions of the world.



Source: SANDREA and GODDARD, 2016.

According to the National Agency of Petroleum (ANP), pre-salt oil is classified as light crude because it has a higher API gravity compared to other types of oil. In addition, the extracted oil contains lower sulfur content but higher levels of sodium, calcium, and potassium salts. These salts are a source of corrosion for refinery equipment. Table 2 presents a comparison of the characteristics of pre-salt and post-salt crude oils.

Table 2: Comparison between Brazilian pre-salt and post-salt oils.

Oil	°API	%sulfur	%nitrogen	Acidity (mg KOH/ g oil)
Búzios*	28,4	0,40	0,31	0,17
Tupi*	30,7	0,35	0,27	0,17
Sapinhoá*	30,0	0,35	0,30	0,23
Cabiúnas	25,9	0,35	0,31	0,92
Marlim Sul	22,2	0,61	0,40	0,91
Roncador	22,8	0,58	0,36	1,17

** Pre-salt oil wells.*

Source: Adapted from DELGADO and GAUTO, 2021.

Challenges for refining

Each refinery unit is designed according to the expected average quality of the feedstock, with a margin that allows for some operational flexibility within a specified range. Among all units, the distillation unit is the most sensitive to feed quality, while the downstream units are generally affected by the flow rate and the quality of the distillation products.

When processing unconventional crude feeds, paraffin depositions can occur in pipelines, increasing pressure losses in the systems and potentially posing a particularly serious problem for the lines that supply refineries.

Due to specific characteristics such as the presence of suspended solids and the high pour point, processing lighter feeds may require investments in tank and pipeline heating systems, as well as adjustments to pump filters.

Generally, two strategies are employed:

- **Mixing crudes** to adjust product yields and quality according to the refinery's configuration.
- **Modifying process units** to accommodate the new feed and performance profile.

The blending of these oils with conventional crudes, which contain higher levels of heavy hydrocarbons, can exacerbate certain well-known operational issues. In the context of product yield and quality adjustment, blending light crudes with heavier ones is a logical and widely adopted practice.

However, even when there is an intention to initially segregate these lighter crudes, such as in intermediate bases and reception tanks, the storage system's configuration may lead to unintentional mixing due to the presence of slopes in the tanks. This mixture of light and paraffinic crudes with heavier crude oils, whether intentional or not, can result in asphaltene deposition, a phenomenon that indicates crude oil incompatibility. In this context, laboratory analyses performed prior to cargo reception can help predict and mitigate this problem, as well as the use of specialized software.

The main challenges and corresponding solutions for processing lighter crude feeds are described below:

Atmospheric and vacuum distillation	**Challenges:** → Flooding at the top of the atmospheric tower; → Limitations in condenser thermal capacity, pumping systems flow rates, light component fractionation, and naphtha and LPG treatment capacity; → Imbalance in heat recovery systems due to low bottom stream flow rates, leading to increased furnace heat demand; → Greater degradation of diesel range streams into atmospheric residue as a result of higher yields and increased pressure in the flash zone; → Significant increases in the freezing points of aviation kerosene and diesel, requiring higher additive consumption; → Increased corrosion in overhead systems due to the presence of chlorides that are difficult to remove during desalting; → Reduction in brine pH, leading to higher corrosion rates in desalting systems; → Very low feed rates to vacuum towers, which can cause gas oil contamination by carryover and internal coking due to insuficient wetting of trays/beds; → Inability to produce asphalt cement. **Operating solutions:** → Installation of pre-flash towers in distillation units; → Metallurgical upgrades of desalting systems and tower overhead sections; → Expansion of overhead system capacity in atmospheric fractionators and debutanizers (including condenser thermal load, pumps and vessels), furnace thermal capacity, and naphtha and LPG treatment capacity; → Adaptation of the vacuum tower to operate efficiently at lower feed flow rates.

Fluid Catalytic Cracking (FCC)	**Challenges:** → Load reduction due to low availability of diesel and residual streams; → Significant increase in LPG and cracked naphtha yields, which may cause limitations in top condensation systems, water separation, debutanizer, and downstream treatment units; → Risk of coking in the bottom section of the main fractionator due to the low slurry yield; → Changes in the unit's thermal balance resulting from the low coke yield – temperature reduction in the dense phase and increased circulation may limit unit operation; → Reduction in steam generation from catcoolers, CO boilers, and heat recovery boilers; as well as decreased power generation in turbo-expanders and a lower octane number of cracked naphtha; → Catalyst and product contamination by unusual metals such as iron, calcium, magnesium, arsenic, copper, and lead; → Increased formation of salt deposits in the overhead system of the main fractionator. **Operating solutions:** → Reformulation of the catalyst according to unit's objectives, optimizing yield distribution and delta coke; → Slurry recycle; → Processing of atmospheric or vacuum residues – with higher contaminant concentration – requiring increased catalyst replacement and use of more contamination-resistant catalysts; → Improvements in condenser wash systems and in the wet gas compressor discharge gas washing; → Expansion of naphtha and LPG treatment system capacities.
Delayed coking	**Challenges:** → Reduction in feed flow due to low availability of residual streams; → Need to extend the cycle time, as the feed is more refractory to coking; → Operational instabilities in furnaces and feed systems caused by the lower initial boiling point of the feed; → Decrease in coke quality and higher likelihood of shot coke formation; → Increased tendency for the formation of hot spots and liquid pockets, affecting the drum decoking process; → Higher naphtha and LPG yields, which may create bottlenecks in top condensation systems, water separation, debutanizer, and downstream treatment units.

Hydro-treatments of naphtha and diesel	**Challenges:** → Reduction of sulfur content in the feed, which contributes to the longevity of the catalytic system, but may impact heat recovery systems due to lower heat generation in the reactors; → Potential increase in contaminant concentrations such as arsenic and silicon, which can lead to catalyst deactivation; → Increased pressure drop and hydraulic limitations in process systems as a result of higher feed flow rates. **Operating solutions:** → Optimization of the catalytic system to accommodate the new sulfur-to-nitrogen ratio in the products; → Expansion of the unit's volumetric processing capacity.

Final Considerations

Considering the current energy landscape, characterized by the growing exploitation of unconventional oils, refineries in Latin America face complex technological and operational challenges. The variability of the feedstocks, which include high levels of contaminants and shifts in their physicochemical properties, demands a deep understanding of refining processes and the development of adaptive solutions. In this context, the use of advanced catalytic technologies developed by FCC S.A., combined with process adjustments across refining units, is essential to ensure operational stability, optimize product selectivity, and maximize profitability.

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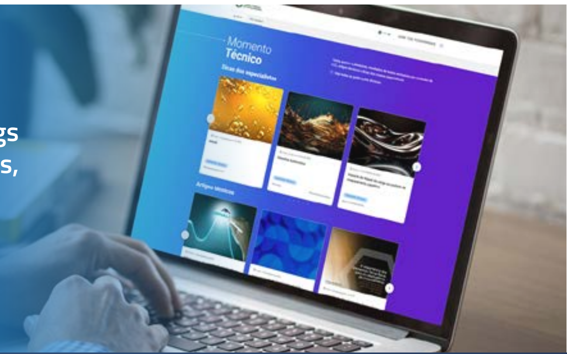

About FCC S.A.

FCC S.A is a leading-edge technology company, with headquarters in Rio de Janeiro, comprising the Petrobras S.A. and Ketjen companies. Being the sole manufacturer of catalytic cracking catalysts and additives for petroleum refining in the South-American market, its consumer customers are the refineries of the Petrobras Systems, as well as the petroleum refineries of South-American countries.

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