The Case for Modular Mini-Refineries

Despite the generally poor returns from petroleum refinery investment, modular mini-refineries, from simple diesel production units to more sophisticated cracking refineries are increasingly becoming a flexible and cost-effective supply option for crude producers in remote regions. This is particularly where there is a need to adapt rapidly to meet local demand. Relatively low capital cost, speed and ease of construction are key advantages of a modular mini-refinery. Two 30,000 bpd\(^1\) units producing high octane unleaded gasoline, LPG, diesel, kerosene and fuel oil can be installed in an 18 month time window, with a budget of 200 million dollars. Modules from 4,000 bpd up to 30,000 bpd primary distillation capacity can added together with debottlenecking to create a refinery of 100,000 bpd or more, should demand dictate. The conditions required to make such an investment workable typically include: a location in close proximity and with access to crude supply; near to sizable markets with logistic advantages—decreases high distribution costs in remote regions; project finance on preferential terms from development credit agencies and almost certainly some government incentives to support regional development.

A Challenging Sector

The petroleum refining sector has undergone significant rationalization in the last three decades. In the 1980s and 1990s surplus refining capacity globally triggered increasing competition among refiners and declining margins. Weak commercial conditions, together with tougher environmental regulations, led to closure of the majority of the less efficient, smaller refineries worldwide. The historically low returns, typically below the cost of capital, also resulted in significant under-investment in the sector and industry concentration with re-investment only into the larger, more efficient complex refineries.

In recent years, despite increasing oil prices and demand growth for refined products, particularly in developing markets, there has been significant volatility and continued the overall declining trend in refinery margins. Short-term improvements have not been sustained and are insufficient to stimulate grass-roots replacement of the aging refinery asset base.

**Historical Refinery Margins**

![Historical Refinery Margins Graph](Image)

\(^1\) Bpd = barrels per day

---

**Source IEA**
Meanwhile, as a consequence of global economic trends, the majority of the new capacity is now coming on-stream in Asia and the Middle East, where demand growth is greatest. There are few viable green-field projects in Europe and North America, where demand is stagnant and the regulatory hurdles are numerous. In spite of this, changes in product slate combined with tighter specifications mean that many refineries in these regions are still required to invest in upgrading of their operations as a cost of staying in business.

At the same time, there are a number of other non-economic drivers for refinery investment. Often this is as a consequence of government intervention, for example - changing environmental legislation or investment incentives to mitigate security of supply issues. In other cases companies appear willing to invest in the refining sector with marginal economics to achieve parallel objectives, such as the Chinese investing in African refineries seeking to get access to upstream resources.

**Adding-up the Numbers**

The overall economics or viability of a refinery depends on the interaction of three key elements: the choice of crude oil used or crude slate; the complexity of the refining equipment or refinery configuration; and the desired type and quality of products produced or product slate.

**Crude Slate:** Crude oil is the primary input into the petroleum refining industry. Even for some oil exporting countries, the transportation costs associated with moving crude oil from the oil fields to the consuming regions and the greater choice of crude qualities make it more economic for distant refineries to use imported crude oil. Similar factors have led to the development of modular mini-refineries in crude producing regions. Modular mini-refineries can be located close to the source of the crude to minimize crude logistics and distribution cost. This approach has been successfully applied in such locations as: Kurdistan, Indonesia, West Africa and West Siberia.

Using more expensive lighter, sweeter crude oil requires less refinery upgrading, but supplies of light, sweet crude oil are decreasing and the differential with heavier and sour crudes is increasing. Using cheaper heavier crude oil means more investment in upgrading processes. Costs and payback
periods for refinery processing units must be weighed against anticipated crude oil costs and the projected differential between light and heavy crude oil prices. The expansion of larger complex refineries is driven by this, due to better operating efficiencies and the ability to process cheaper, heavier crudes. Bigger units can more easily recover the substantial capital cost of secondary conversion capacity, such as a “coker” or hydro-cracker. However, if lighter, sweeter crudes are available a modular mini-refinery, with only primary distillation capacity, under the right conditions can still have significant competitive advantages. Such a unit requires much less capital; it is quicker to implement projects and it is more flexible to respond to demand changes in fast developing regions.

**Refinery Configuration:** Refineries fall into three broad categories. The simplest is a topping plant, which consists only of a crude distillation unit and probably a catalytic reformer to provide gasoline. Yields from such a plant would most closely reflect the natural yields from the crude processed. Typically only condensates or light sweet crude would be processed at this type of facility, unless markets are readily and economically available for heavy fuel oil (HFO is a combination of Residual Fuel and Cat Feed below). Modular mini-refineries generally fall into this category.

![Comparison of Refinery Yields by Crude Type](image)

The next level of refining is called a cracking refinery. This refinery takes the gasoil portion from the crude distillation unit (a stream heavier than diesel fuel, but lighter than HFO) and breaks it down further into gasoline and distillate components using catalysts, high temperature and pressure. A more sophisticated modular mini-refinery can be configured in this way.

The last level of refining is the coking refinery. This refinery processes residual fuel, the heaviest material from the crude unit and thermally cracks it into lighter product in a “coker” or a hydro-cracker. The addition of a fluid catalytic cracking unit (FCCU) or a hydro-cracker significantly increases the yield of higher-valued products like gasoline and diesel oil from a barrel of crude, allowing a refinery to process cheaper, heavier crude while producing an equivalent or greater volume of high-valued products. In special cases it would be possible to acquire and re-install a used hydro-cracker as an add-on to a modular mini-refinery to obtain a full conversion refinery.
Product Slate: Refinery configuration is also influenced by the product demand in each region. Refineries can produce a wide range of products including: propane, butane, petrochemical feedstock, gasolines (naphtha specialties, aviation gasoline and motor gasoline), distillates (jet fuel, diesel, kerosene, and intermediate fuel oil), heavy fuel oil, lubricating oils, waxes, and asphalt. The last three products require a special refinery configuration and are not suitable for a modular mini-refinery.

In the U.S., the demand for gasoline is much larger than distillate demand and, therefore, refiners configure their installations to maximize gasoline production. Gasoline sales account for nearly 50% of demand while distillate sales account for less than 30% of product demand. In several Western European countries, most notably Germany and France, policies exist that encourage the use of diesel engines creating a much stronger distillate component. Gasoline accounts for less than 20% of petroleum product sales in these cases. In developing markets and for common modular mini-refinery applications there is characteristically a high demand for both gasoline and distillates for transport.

Modular Mini-Refinery Configurations

Mini-refineries are typically available in units from 4,000 to 30,000 bpd. The different configurations available for modular mini-refineries, with increasing degree of sophistication are:

1. **Atmospheric – Topping Unit**
   A basic (low capital cost) crude distillation unit for diesel and/or kerosene production, with naphtha and fuel oil as by-products.

2. **With Gasoline Train**
   With a reformer or hydro-treater added (higher capital cost) produces high octane unleaded gasoline and LPG. This configuration can include an isomerization unit to boost total Octane rating of gasoline and produce more premium unleaded gasoline.

3. **Vacuum Distillation – Cracking**
   A second distillation tower can be added to vacuum distil the fuel oil component from the atmospheric tower into a clean heavy diesel (vacuum gas-oil) and heavy residual oil.
4. Hydrocracker Unit – Full Conversion

The hydro-cracker Unit (high capital cost) is a device that converts light and heavy gas oils to more valuable lower boiling point products. The yield across a hydro-cracker may exhibit volumetric gains as high as 20-25% for light end products from fuel oil, making it a substantial contributor to refinery profitability.

A modular mini-refinery provides full flexibility and can be built in a phased manner, such as in the following project schedule:

**Phased Project Example**

A typical configuration of a 30,000 bpd hydro-skimming modular mini-refinery is shown below based upon Angolan crudes, which are light/medium API low sulphur (sweet crudes). In addition to gasoline and distillates, the can produce a Low Sulphur Straight Run (LSSR) fuel oil, which is in high demand and has good prices in export markets. It should also be noted that differing crude inputs can have a significant impact on the yields of gasoline and distillates and consequently the economics of the refinery. The yields of each refined product stream based upon two indigenous Angolan crudes – highly sought after Palanca (a light, good gasoline crude) and the more prevalent Cabinda (a medium, low sulphur crude) are illustrated in the diagram.

**Configuration of a Typical Modular Mini Refinery**
Modular Mini-Refinery Feasibility

While the economics of such a topping unit or “hydro-skimming” mini-refinery are not comparable to a 200,000 bpd complex or “full conversion” refinery with hydro-cracking; the relatively low capital cost and flexibility can make it a cost effective supply option in the right circumstances.

Comparison of +/- of a Modular Mini Refinery with a Conventional Refinery

<table>
<thead>
<tr>
<th>Modular Mini-Refinery (Hydro-skimming)</th>
<th>Conventional Refinery (Hydro-cracking)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Skid Mounted</td>
<td>+ve</td>
</tr>
<tr>
<td>o improves engineering quality</td>
<td>Fabrication on site</td>
</tr>
<tr>
<td>o faster construction</td>
<td>One location for different markets</td>
</tr>
<tr>
<td>• Close to markets</td>
<td>+ve</td>
</tr>
<tr>
<td>• Low capital</td>
<td>High initial capital outlay/long payout</td>
</tr>
<tr>
<td>• Flexible to meet demand (add modules)</td>
<td>+ve</td>
</tr>
<tr>
<td>• More personnel per EDC*</td>
<td>Restricted de-bottlenecking</td>
</tr>
<tr>
<td></td>
<td>Greater volume high value products</td>
</tr>
<tr>
<td></td>
<td>Scale and operating efficiency</td>
</tr>
<tr>
<td></td>
<td>Less personnel per EDC</td>
</tr>
<tr>
<td>*Effective Distillation Capacity</td>
<td></td>
</tr>
</tbody>
</table>

Normally there exist a number of “special conditions” to make a hydro-skimming modular refinery viable:

• Proximity and access to crude
• Proximity to sizeable markets
• An acceptable market for HFO
• Logistic advantages—decreases high distribution costs in remote regions
• Project finance on preferential terms from development credit agencies
• Government incentives to support regional development

These conditions and the refinery economics must be analysed in a feasibility study, which is independently verified as a technical requirement of most development credit agencies. It is essential to have an adequate regulatory framework and evident support from the host government to obtain the project financing.

Building a Modular Mini-Refinery

There are a number of specialist engineering firms that will offer a turnkey service for: design, engineering and procurement; plant fabrication and act as a general contractor for local construction together with supervision of commissioning and start-up. Normally they will arrange local sub-contracts for: civil works and site installation of process plant and utilities.

Modular units are pre-fabricated in workshop conditions and shipped to site for assembly. Quality and speed of construction are key advantages of this approach.
A prime example of this is the construction of the KAR refinery in Ebril, by Ventech Engineers of Pasadena, Texas. The video link shows the assembly on site in just 16 weeks [http://www.youtube.com/watch?v=oZDd2reccZQ](http://www.youtube.com/watch?v=oZDd2reccZQ).

The following is an estimate for a hydro-skimming modular mini-refinery (2 x 30,000 bpd crude distillation units, with reformer hydro-treater). Costs compare very favourably with a 200,000 bpd full conversion refinery estimated to cost between 5 to 7 billion dollars:

<table>
<thead>
<tr>
<th>Item</th>
<th>Value US$ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility Study</td>
<td>0.5</td>
</tr>
<tr>
<td>EPC Equipment &amp; Utilities FOB</td>
<td>120.0</td>
</tr>
<tr>
<td>Ocean Freight</td>
<td>10.0</td>
</tr>
<tr>
<td>Site Preparation and Erection</td>
<td>30.0</td>
</tr>
<tr>
<td>Tank farm</td>
<td>10.0</td>
</tr>
<tr>
<td>Catalyst, Spare Parts &amp; Misc</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>186.5</strong></td>
</tr>
</tbody>
</table>

Including gasoline train.
*On US flagged Vessels.
US Exim requirement.

*Based on a recent project. Please note this may vary significantly depending upon location, water availability, proximity to crude source etc., and excludes logistics infrastructure.*