TITLE: Investing in New Refining Technologies

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ABSTRACT

The oil industry is navigating through a difficult period of falling oil prices and uncertainty in refining margins which is forcing companies to cut investments to a minimum and carefully scrutinize every dollar spent. Within this context of limited cash availability, investments in refining must be selected carefully and executed properly in order to maximize their profitability and minimize payback periods. This article analyzes different factors to take into account in order to make well-informed investment decisions, as well as the key levers which ensure the success of investments by implementing processes and mechanisms which maximize operational efficiency. The latest conversion technologies in particular are analyzed to shed light on the determinant competitive issues refineries need to consider, and the operational capabilities required to achieve a lasting competitive advantage and justify the impact of the initial investment.

Investing in New Refining Technologies

Key Drivers of Successful Investments

There is great uncertainty in the oil industry; low crude prices are putting significant pressure on the market. In this context, refining is perceived as a critical cash flow generator. Companies that committed to an integrated Upstream and Downstream structure and have maintained it throughout the long period of low refining margins (2009-2014) are now receiving significant compensation that may prove critical to their survival.

No matter how favorable the current situation is for refineries, however, the widespread need for optimization and cost-cutting throughout the industry is causing most investment activity to freeze and has made investors increasingly cautious about spending.

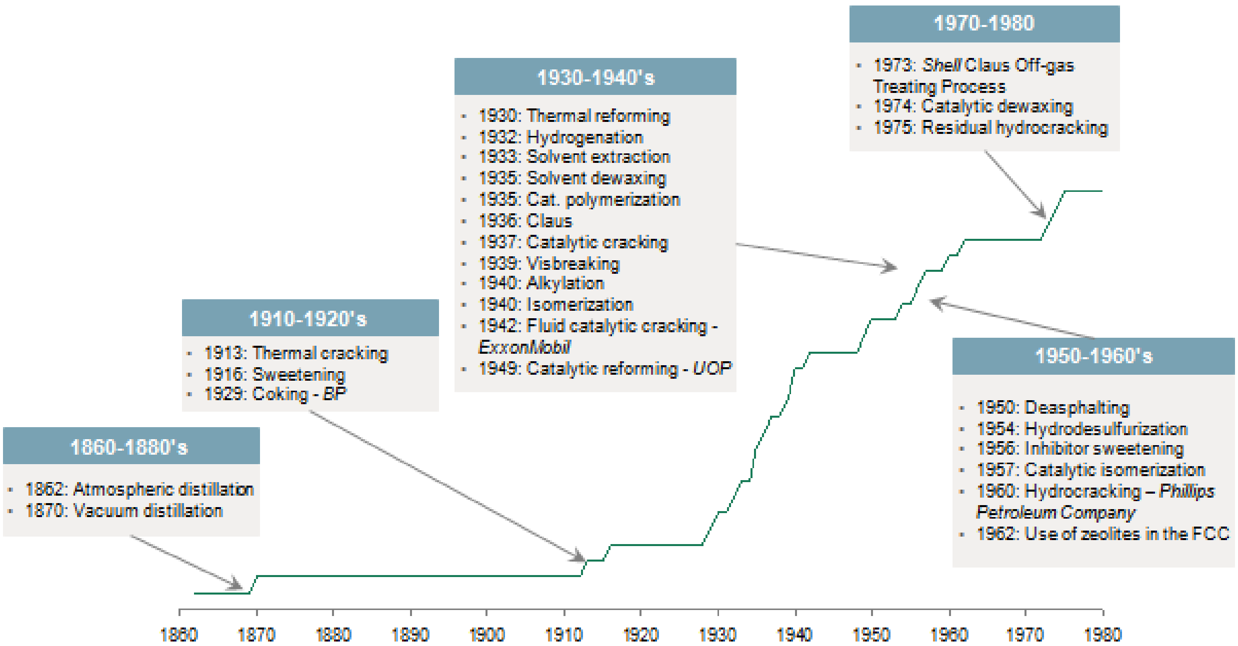
Nowadays, investment decisions must be carefully selected and justified with a premium on returns. In practice, this limits value-generating investments to certain opportunities only available to refineries with specific characteristics that provide them with a competitive edge over their competitors. To be precise, when deciding on refining investments, we need to assess four different aspects in detail:

1. New technology opportunities.
2. Competitive landscape.
3. Operational capabilities.
4. Optimized integrated value chain.

1. New technology opportunities

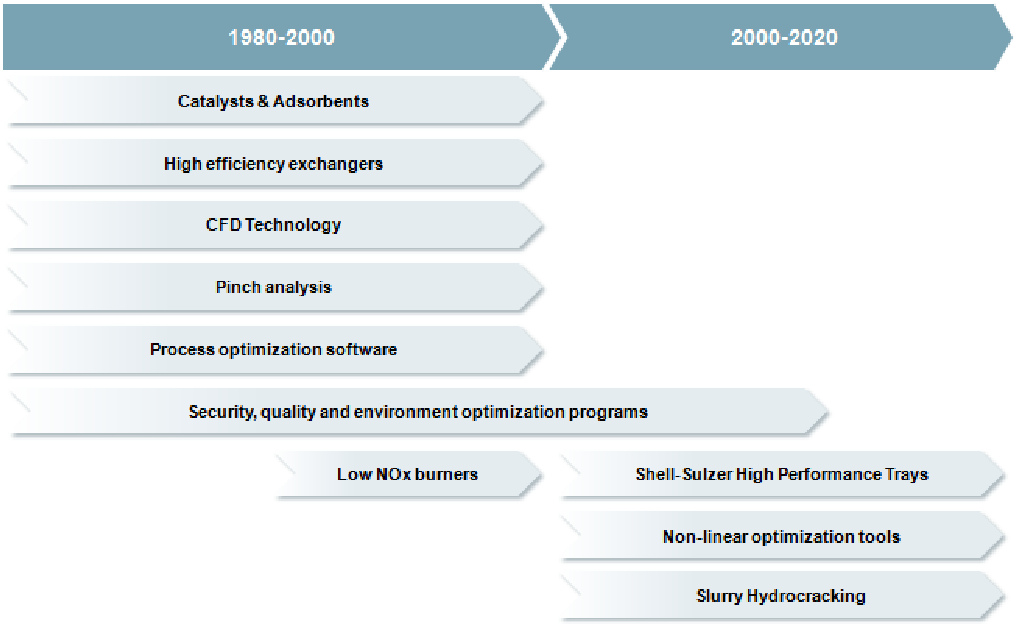
The refining industry has become increasingly complex and efficient since its origins in the 19th century. Technologies developed during the first half of 20th century, such as cracking and coking, have enabled us to process heavier oil components more efficiently.

Key technologies developed in the refining industry, 1860s-1980s



In recent decades, the pace of development in truly innovative technologies has slowed down; however, some new technologies have contributed to increasing efficiency within the refining industry.

Key technologies developed in refining industry since the 1980s



Different factors explain why game-changers aren't expected in the refining industry anytime soon (quotes below).

"... as in other industries with an extensive and expensive fixed capital base, operating [refining] companies have little incentive to promote fundamentally new technologies that might result in the accelerated depreciation or scrapping of a substantial part of their existing capital stock"

– *New Forces at Work in Refining: Industry Views of Critical Business and Operations Trends*

"We are focused on little R and big D. Our horizon tends to be in the two- to five-year time frame. We are very driven by the near term. Once you get beyond five years, the market gets very difficult to predict"

—Technology and Services Executive, *New Forces at Work in Refining: Industry Views of Critical Business and Operations Trends*

In reality, when looking at how much pure refining companies invest in R&D (e.g., Phillips 66, Valero, Tesoro, Enap, Saras, S-oil), which represents around 0-2%of their earnings, the figure is very low when compared to R&D investments for chemical companies (e.g., DOW, BASF, Monsanto, Mitsubishi Chemical, DSM), which is around 5-15%, or even pure Upstream players (e.g., Statoil, ConocoPhillips, Rosneft, Anadarko), which invest 0-4% of their earnings. There are even several refinery players that do not invest anything in R&D (same for upstream players).[1]

[1] Source: IRI. European Economics of Industrial Research and Innovation. Company public data from annual reports

Most efforts are focused on increasing efficiency, optimizing operating margins and capital expenditure, and the opportunities in new units typically stem from increased conversion capacity by processing bottom residues (540+). New technologies in slurry hydrocracking are being developed which present little industrial experience, but they could potentially revolutionize the market if proven successful. The elevated CAPEX requirements and uncertainty regarding the viability and effectiveness of these technologies make investment decisions a matter of the trade-off between the new technologies and proven conversion technologies with potentially inferior financial performance. As of now, the most relevant technologies to consider are:

Slurry hydrocrackers. This technology has generated high expectations due to its impressive conversion rates—above 95%, mainly in the middle distillates range—, its high-quality products and low-to-none sensitivity to metals and CCR, which allows for a wide range of crudes to be processed. If the initial figures are confirmed, slurry hydrocrackers could set a new standard for future investments. That being said, they currently present high risk due to their lack of industrial experience to justify the significant investment required; ~$1Bn for a 25 kbpd unit. Companies like Eni EST, UOP Uniflex and KBR VCC have committed to developing this technology through pilots of varying relevance. There are already 1 EST and 1 KBR industrial units in operation since 2014; furthermore, licensors claim that 5 UOP and 4 KBR units have already been licensed, and a strategic agreement has been signed between Eni and Total to develop the EST technology[2]. If the announced yields and costs are confirmed, at today's prices, the return on investment would be of over 20-30%, which is very attractive for refiners and could potentially alter the market dynamics in the future.

This new technology competes with some technologies already on the market:

Residue FCC units can be high-margin investments if they are propylene-focused, while this is not quite the case when production is focused on gasoline. These units present limitations in the feedstock processed since they require high-quality crude with low CCR or metal residues, and they also require investments in hydrotreating in order to process the production and meet specifications. The quality of the product is inferior to that of slurry HCKs, and the yield is around ~85% (counting coke and gas as not converted).

Cokers continue to be an attractive technology (~65-70% conversion rates) primarily in markets highly concentrated on gasoline production and with high metal and CCR crudes. Nonetheless, these units are the most exposed to the heavy-light differential—the price differential between gasoline/gasoline and fuel oil—due to coke production (~30%wt), and they have suffered from low returns of investments in the recent market environment (2011-2014). Strong hydrotreating is also needed to meet specifications.

Ebullated beds are a proven technology with more than 20 industrial units in operation and conversion rates of around 75-85%. The investment required is approximately 120% of that for coker units, and their ability to use pitch as bitumen or coker feed is a key profitability factor. As with residue FCC units, ebullated beds have limitations in terms of the quality of the feedstock (CCR and metals).

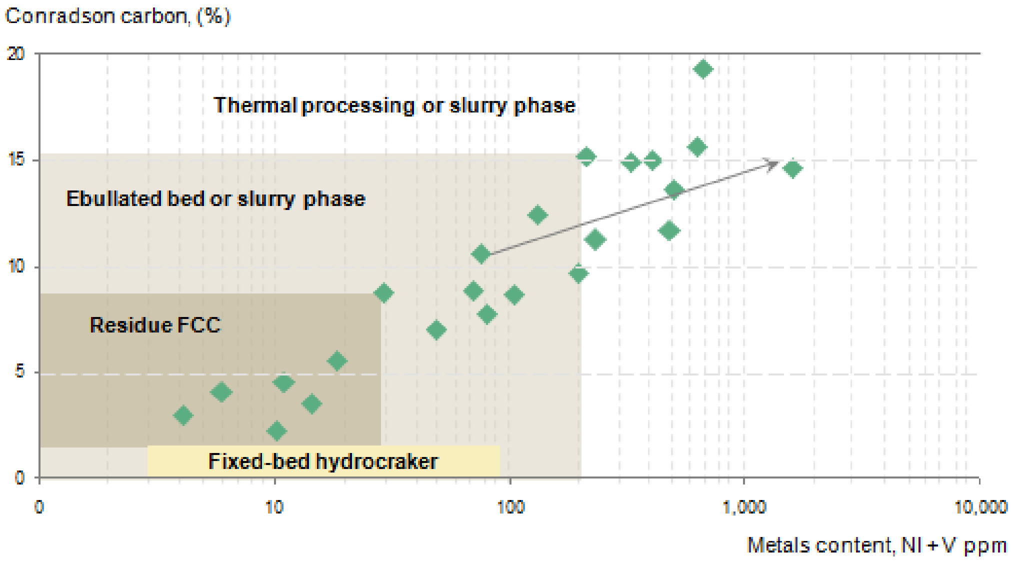
Fix-bed residue hydrotreating is a technology with numerous industrial references (over 60), but its reduced conversion capabilities—in the ~50% range—and limitations in feed quality (mostly metals) compared to the alternatives mentioned seem to limit its potential. Nonetheless, this technology now has a good opportunity to

[2] Source: Collin Chapman, EPC consulting, BBTC (Bottom of the Barrel Technology Conference) in Moscow, April 2015

be used as a desulphurization unit since regulations on sulfur fuel oil are becoming stricter. It can also be used (limited references) to treat residue before it is fed into residue FCC units.

Residue upgrading has been, and will continue to be, a hot topic in the near future for the refining industry. If slurry technologies mature and answers are provided for key questions regarding real investment costs, availability, operating stability, pitch use and industrial yields, they will change the market by offering higher returns than all other technologies. Cokers are an old technology, but still quite profitable in highly gasoline-oriented markets, while residue FCC units are a great option for propylene-oriented refineries that form part of a petrochemical complex.

Options in residue upgrading technologies based on CCR and metal content



Source: Hydrocarbon processing, 2011

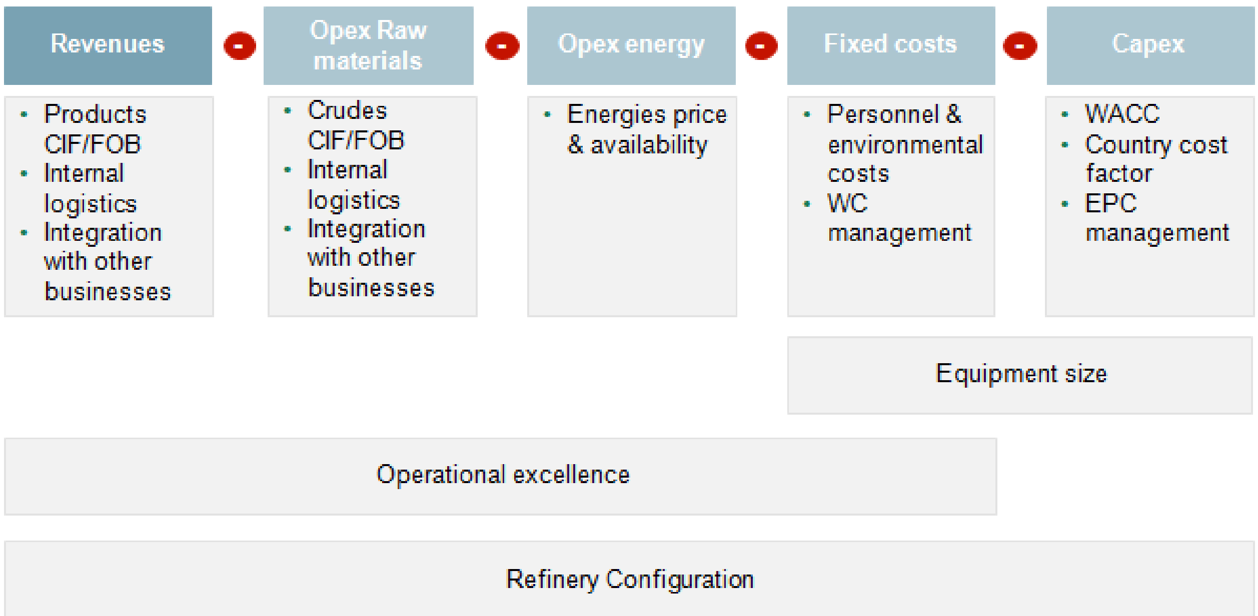
2. Competitive landscape

When deciding on something as important as constructing a new unit in a refinery, economic analyses alone are not enough to make a well-informed decision. The vast capital and other resource requirements needed to carry out a project of this magnitude may very well be better invested in alternatives better-suited to the particular conditions of the refinery, or by taking the very same project elsewhere.

Let us take the example of installing a residue hydrocracker in a European refinery. Preliminary profitability estimates may appear very promising due to high conversion rates and cheap feedstock. However, further economic analysis of the investment may reveal that such a decision should be reconsidered since other geographies present much more favorable conditions for the investment.

Refining investments are particularly delicate due to their complexity, elevated initial investment and typically lengthy payback periods, as well as the numerous factors that can turn an investment into a success or a failure. That being said, some key drivers of success which affect all aspects of refineries can be identified. We will use investments in residue HCKs in Europe vs. Latin America as a guiding example to analyze some of the key economic factors mentioned.

Key drivers of success in refinery investments



External Factors

a) Maximizing revenues

Three key drivers have been identified to maximize the impact of investments on revenues.

First of all, understanding product pricing (CIF or FOB) in the region and in a refinery in particular is fundamental, as product pricing indicates whether a product is scarce or abundant in the region.

In the event of scarcity, products must be imported from other regions and, consequently, the pricing mechanism—in a free market—sets to import parity (CIF: the price of a product will be equal to the price of the product in the marginal exporting region, plus transportation costs from the exporting to importing region). On the other hand, if a product is abundant in a region, it can be exported to other regions and, therefore, the price is set to export parity (FOB: the price of the product will be equal to the price of the product in the marginal importing region, minus transportation costs). In turn, investing in units that consume FOB products (low prices vs. global market) and yield CIF products (high prices vs. global market) would generally be more attractive than the other way around.

Another factor that should be considered, and which is closely related to the previous point, is a region's internal logistics. Higher transportation costs make differences between CIF and FOB products even more significant. For example, differences between CIF and FOB prices in a country with the population mainly concentrated along the coast will be much lower than in a land-locked country with a limited infrastructure.

These two drivers must be analyzed along with national regulations since regulated prices may differ greatly from free market prices. One last driver to maximize revenues is investment and retail business integration. Investments which maximize synergies with retail businesses will be more valuable, as we will analyze later.

As for our example, Latin America is usually CIF in all naphtha and distillates, while Europe is FOB in naphtha, but CIF in diesel. But, again, this depends on the particular country itself.

b) Minimizing raw material costs

Along with the product pricing mechanisms mentioned, equally important are pricing mechanisms for crudes (CIF / FOB). Investments which facilitate the consumption of FOB crudes will be more attractive than those which require that imported crudes be consumed. For example, in a refinery located in a region which exports heavy crudes, imports light crudes, and with problems evacuating fuel oil, it would likely be optimal to invest in residue upgrading units which allow for more heavy crudes to be consumed, thereby reducing the need for light crudes. As in the case of products, internal logistics can maximize or minimize the impact of this driver.

In our example, the price of vacuum residue—the main input for residue HCKs—is set as FOB in Europe due to the ample availability of fuel oil which ends up being exported to other markets; mainly North America. This could translate into cheaper feedstock; however, residue is even more widely available throughout Latin America due to its lower refining conversion levels, which causes fuel prices to trade at a discount over Europe.

Another relevant factor to consider is existing synergies with a company's upstream division, if any exist. Investments which facilitate integration with upstream businesses will typically be more attractive. An example would be an investment that enables the consumption of crudes produced by Upstream and with difficulties to be evacuated.

c) Minimizing energy costs

Energy costs can turn a theoretically successful investment into a failure, which is why the addition of energy consumption, as well as the price and availability of energy, must be analyzed in depth. A unit consuming large quantities of gas will be more competitive in a region with an abundance of gas and low prices than in a region with scarcity and elevated prices.

The primary operating cost of residue HCKs stems from hydrogen consumption, and the cost of hydrogen is linked to the price of gas used in its production. European gas prices are relatively high when compared to global averages since the region imports large amounts of gas.

d) Minimizing fixed costs and CAPEX

The limited availability of cash has become one of the industry's primary limitations. As with any investment, the initial capital expenditure is particularly important, and recurring fixed costs in personnel, maintenance and environment-related costs must be understood and analyzed. An investment's impact on working capital is also a key driver of the success of investments in refining. As an industry which requires vast amounts of working capital to achieve a small margin, investments which reduce working capital requirements—such as enabling consumption of cheaper crudes—will be very attractive. These factors are affected by two main elements: the cost of capital and country costs.

The cost of capital (WACC) accounts for the country and debt risk. It seems reasonable not to require the same returns for an investment in the European free market as one in a developing country with elevated risk of regulatory changes. On the other hand, investments with higher risks will require lower capital costs and higher cash flows to account for the extra discount applied to the returns on riskier investments.

In this case, the low interest rates and reduced associated risk in Western Europe imply reduced requirements for returns on investments in Europe.

Other drivers to be considered are country costs and EPC management (engineering, procurement and construction). Cost differences between countries (workforce efficiency and costs, technological development in the country, etc.) may often tip the scale in favor of a particular location. For instance, building a state-of-the-art unit along the U.S. Gulf Coast with an experienced workforce and near a strong technology industry would clearly be different than building the same unit in a developing country where importing technology may prove difficult—and potentially twice as expensive.

Europe presents a premium on costs over South American countries in several areas: labor, basic materials, utilities, etc. This not only translates into more extensive initial capital needs in the construction phase, but also higher operational costs.

Furthermore, expertise in EPC management is key to preventing elevated construction costs. It would be highly risky for a company with limited experience in EPC management to invest in a recently developed technology.

Internal Factors

a) Size

The size of new units is central to determining the profitability of investments, as scale is an important factor in boosting the returns on units. With economies of scale, unit costs can be reduced both in terms of the initial capital expenditure and operations. In the case of size and scale, the factor is unaffected by the geographic location. In refinery units, the two-third rule applies quite well (e.g., for double the size, the cost is 60% greater).

b) Operational excellence

Operational excellence is also of great importance in specific refineries as well, as it accounts for a company's efficiency in managing an investment and operating the refinery. Most of the drivers mentioned can be managed more efficiently given a refinery has highly efficient daily operations, as this makes it easier to minimize added costs stemming from new investments (e.g. maintenance and energy costs).

Furthermore, refineries that have optimized integration with other businesses will be able to maximize their investment-based revenues.

We will cover these aspects in the following sections.

c) Refinery configuration

Finally, it is essential that the marginal configuration of refineries be analyzed in depth so as to understand which investments are most profitable.

A refinery's configuration can indicate inadequacies and problems, as well as help make an investment successful. For example, if a refinery's FCC is not operating at maximum load and the refinery is a net exporter of fuel oil, investing in residue upgrading would be probably more attractive than investing in a new hydrocracker, despite the currently elevated diesel prices.

European Residues HCK investment decision: Key determining factors

Source of advantage	European player	
Feedstock: Vacuum Residue Cost	FOB +	✗
Products: Diesel/Jet/Naphtha cost	CIF– /FOB	✓
Operating cost: H2 cost	CIF +	✗
Cost of capital	Low	✓
Country cost	High	✗
Size	Refinery specific	?
Operational excellence	Refinery specific	?

In summary, to make such a significant investment in a region like Europe, a refinery would need to satisfy specific internal conditions and have a competitive edge over the average player; otherwise, the project could potentially be better invested elsewhere.

The conditions mentioned include being large enough to take advantage of economies of scale and, more importantly, a track record of operational excellence to guarantee returns—even in potentially negative future scenarios.

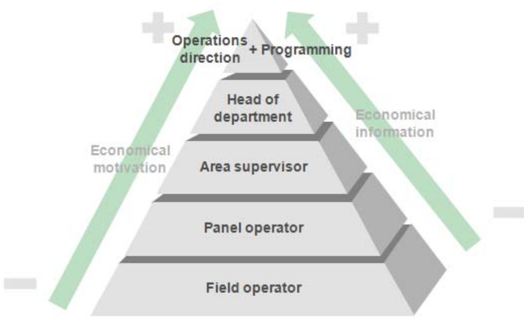
3. Operational capabilities

As mentioned, in the near-term the refining industry will experience important reductions in investments and challenges in generating cash flows, and, as such, net cash margins will be a key factor in competitiveness. Companies with excellent operational capabilities—including a strong focus on margins, shared targets, aligned departments, are flexible and which respond quickly to market opportunities—will provide superior value. This can be achieved by optimizing three different layers: processes & culture, tools, and skills & know-how.

Processes and culture

All operational processes need to be aligned and include a culture of joint optimization of margins in order to excel in operations. In order to do so, companies must:

- Have a clear understanding of economic drivers throughout the value chain. Some key questions regarding refinery operations include: Does the trader understand the economic impact of his decisions throughout the value chain? Does the scheduling team understand the impact of a distress crude cargo? Do the operators understand the cost of a changing the quality in a diesel blending stream? Are there clear and shared criteria for risk at all levels? (e.g., to decide when edging is required, or how to test a new opportunity in crude).

  Most refineries have a programming and planning department focused on maximizing the value of the crude barrels processed. However, the more operationally-focused roles become in a refinery, the more this economic culture tends to be lost throughout the organization. Imbuing an entire organization with an economics-focused culture is the first step towards optimizing margins across the value chain.
- Empowerment at all levels of the organization. This means having the adequate mechanisms to delegate decision-making powers throughout an organization and enable a flexible structure which minimizes processing times to take action and capture opportunities. Centralized decision-making

centers in refineries need to shift towards a model with accountability mechanisms for technicians and operators, and which provides them with the right information needed to take decisions.

- Strong cooperation between areas to maximize total profits. As we will detail in the section on integrated margins, more than ever before, refineries must ensure that the general interest of the company is prioritized above local KPIs. In order to guarantee this, workforces require a shared, common economic language.

Significant opportunities are often identified when technical and cultural factors are combined. Let's take a visbreaker unit, for instance. These units heat distillation residue and make 10-20% light products. The harder these units are run—at higher temperatures—the more light products are produced. The main potential issue is fuel oil instability in getting an off-grade tank, which implies the additional cost of reprocessing and mixing. Many refiners do not run at optimal point their visbreakers. To avoid tank off-grades, they miss out on $10-20k/day (profits from conversion) while saving 1-3 off-grades per year at $0.3-1.0M/year, which is not the optimal point ($10k/day is $3.6M/year).

Illustrative metaphor:
Running visbreaker units is like a businessman saving time and cutting it close to his flights. If he never misses a flight—if the unit isn't run hard enough—, he probably just isn't cutting it close enough, meaning efficiency could be improved.

Interviewer: "When you are going to catch a flight, do you arrive with extra time or try to cut it as close as possible?"
Passenger: "Well, I usually just barely make it in time to minimize waiting around."
Interviewer: "You surely miss a flight every so often since you usually barely make it in time, right?"
Passenger: "Actually, no, I never miss any of my flights."
Interviewer: "Then you don't really cut it that close, do you?"

Tools

Optimizing margins is one of the most complex processes in the refining industry, as it involves highly sophisticated models and numeric analyses that are carried out continuously in refining companies' planning and programming departments. Linear programming (LP) is a powerful tool to reach a complete understanding of economics throughout the value chain. Nowadays, major improvements have been made to these tools, and top LP tools have evolved in different forms: multi-asset and multi-period models, non-linear and recursion for optimum blending modeling, linked with simulation tools for key non-linear units, linked with scheduling, planning and trading tools, etc.

However, it is an interesting contradiction that the sophisticated tools used by today's operators to run refining units—e.g., DMCs, RTOs, etc.—systematically attempt to optimize the economics of operations, but the workers managing the systems are usually unaware of the financial consequences of their decisions. All these tools need to be accessible at all levels of a refinery, and have the proper associated KPIs, in order to be able to track and optimize margin contributions at all levels; otherwise, some margins will be systematically left on the table.

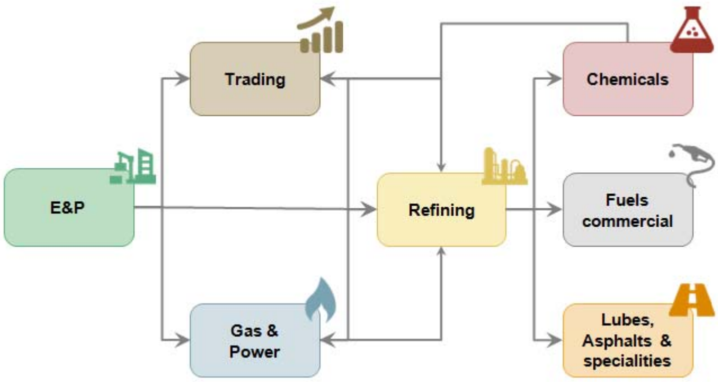
Skills and know-how

Even with adequate organization and the best technology running a refinery, operational excellence is impossible to achieve without a motivated, knowledgeable workforce clearly focused on maximizing its results. Every modern refinery should at least have:

- An established strategy to attract local talent through cooperation with institutions and in-company rotations; and incentives and recognition processes to retain top talent.
- A process and supporting platform in place to identify margin improvement initiatives at all levels, track them and generate feedback. Ideas from the largest collective at refineries—the shift workers—is oftentimes neglected, despite the fact that this group works closest to the units and can offer relevant ideas for improvements.
- Mechanisms to share know-how throughout the refinery and across divisions to stay up to date on best practices in refining operations.
- A training system that consistently detects and fills gaps in workforce development.

4. Optimized integrated value chain

Margin integration with other businesses is also a key element in order for downstream companies to extract value from their refinery assets and technologies.



There are several interfaces that are key to maximizing value. Adding businesses to refining—e.g., trading or chemicals—can create synergies in both businesses and make them more competitive than on their own. For example, for a company with a naphtha steam cracker with a capacity of 1Mt/year and a refinery of 200kbd, synergies could reach ~$100/t for ethylene or, if you count them on the refinery site, of ~$1.4/bl.

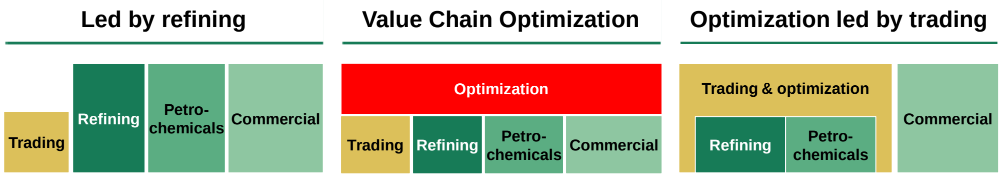
Achieving all the synergies may seem trivial, but there are significant opportunities even in many top-performing companies. The difference between mid- and top-performing players in margin integration is of around $0.2 to $0.6/bl.

As follows, several enablers allow for margins to be captured across the entire value chain:

- Organization and processes.
- Incentives.
- Culture.

Organization and processes

Below are different structures to maximize the value chain. The first and most common approach is when refining business units (BUs) lead in capturing the integrated margins.



Led by refining

- Businesses act in autonomously maximizing its own internal objectives
- Coordination basically established though transfer pricing
- Refining as a Business Unit

Value Chain Optimization

- Focus in optimization of integrated margin
- Optimization is the key source for decision making regarding programming and coordination
- Trading focused in accessing the market (crudes and products)
- Refineries focused in optimizing its operations

Optimization led by trading

- Strengthen trading as a source of value creation
- Trading leads decision making regarding programming and coordination
- Optimization becomes a middle office function within trading
- Refineries focused in optimizing its operations

Incentives

Incentives are a key enabler to align all BUs and BU departments to work on common goals. There are two main kinds of incentives:

<u>1. Individual incentives</u>
Rewarding BUs based on their individual P&Ls. For instance, a chemicals BU is rewarded according to how much it contributes to the business. There is no reward for collaborating to help make money for other BUs. These incentives are the most commonplace incentives in the refining industry, as they foster accountability and dissuade against 'free rider' behaviors. If a chemicals BU's P&L is €10M and refining BU's is €200M, and chemicals is compensated according to the total figure of €210M, there is little incentive to increase their own P&L, as it is just 5%.

2. Collective incentives

Collective incentives are established by adding together the P&Ls of different BUs—e.g., €210M in the example above. These incentives avoid using transfer prices, foster overall profit maximization and collaboration; however, they have the risk of 'free riding'.

3. Hybrid incentives

Hybrid incentives are quite new to the industry. They reward BUs according to their P&L, but at the same time reward certain departments within BUs for collective P&Ls. For instance, the FCC department of a plant that produces, among other products, propylene for a chemicals BU and gasoline for a refinery BU, may be rewarded according to how much it contributes to each BU. These incentives are difficult to design, but are central to fostering accountability and collaboration between BUs.

Culture

Last but not least is fostering a culture of collaboration. Companies can use several techniques to do so:

- Rotating personnel through BUs.
- Sitting certain departments together.
- Forbidding mention of transfer prices, or only allowing mention of them during one month per year.
- Introducing words or sentences to emphasize the idea—e.g., general interest, enterprise first—that are 'drilled' into the employees.